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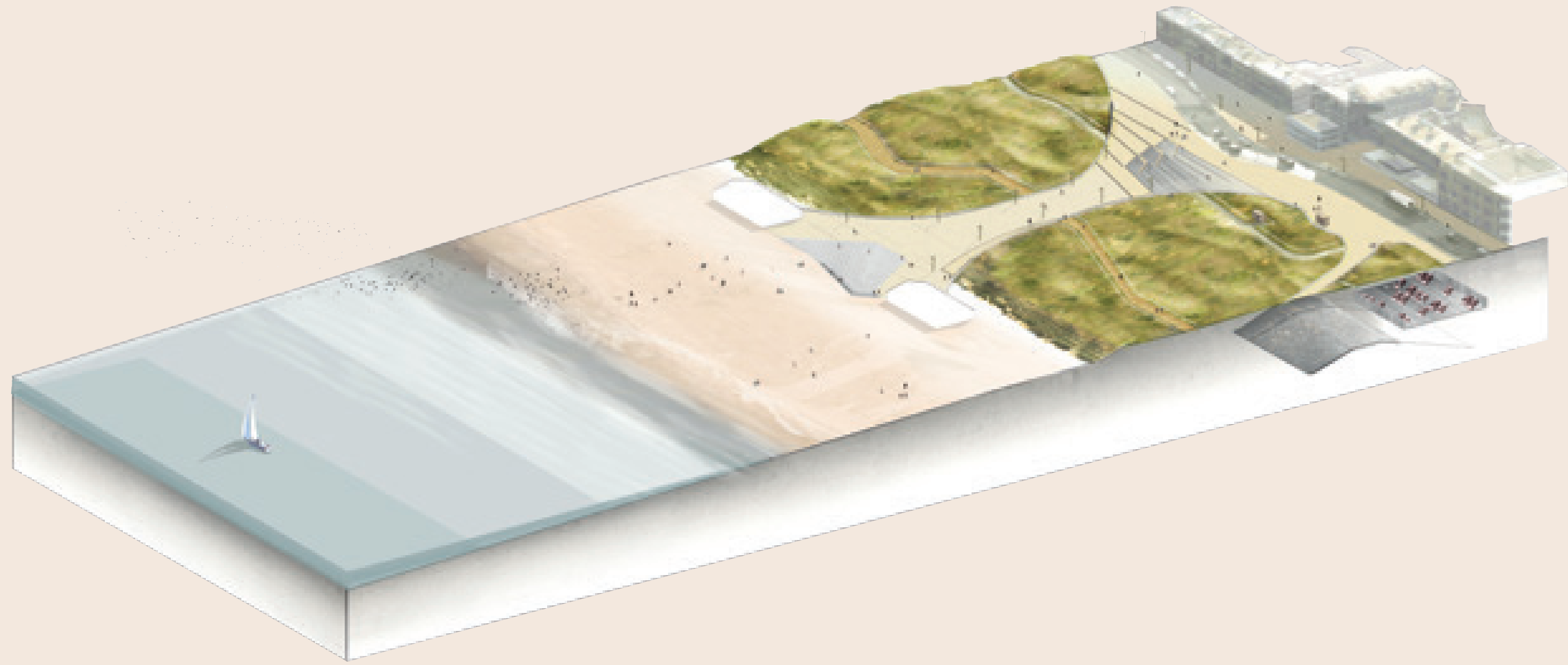

Multifunctional flood defenses protect areas against flooding, but serve other functions as well. Although these types of defenses can be seen almost everywhere, they pose special technical and governance challenges.

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.

STW connecting innovators

TU Delft

WAGENINGEN UNIVERSITY & RESEARCH

UNIVERSITY OF TWENTE.

ISBN 978 94 6186 808 4
NUR 950

Kothuis, Kok
INTEGRAL DESIGN OF MULTIFUNCTIONAL FLOOD DEFENSES
MULTIDISCIPLINARY APPROACHES & EXAMPLES

INTEGRAL DESIGN OF MULTIFUNCTIONAL FLOOD DEFENSES

MULTIDISCIPLINARY APPROACHES & EXAMPLES

EDITED BY
Baukje Kothuis
Matthijs Kok

Prof.dr.ir. Matthijs Kok is Professor of Flood Risk at the Faculty of Civil Engineering and Geosciences at TU Delft; he was Program leader of the 'Integral and Sustainable Design of Multifunctional Flood Defenses' research program, funded by the Dutch Science and Technology Foundation STW. Presently, he is Program leader of the STW-Perspectief research program 'All RISK', which will study the implementation of new risk standards in the Dutch national flood protection program (2017-2022).

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The MFFD program is a collaborative multidisciplinary
STW Perspectief research project

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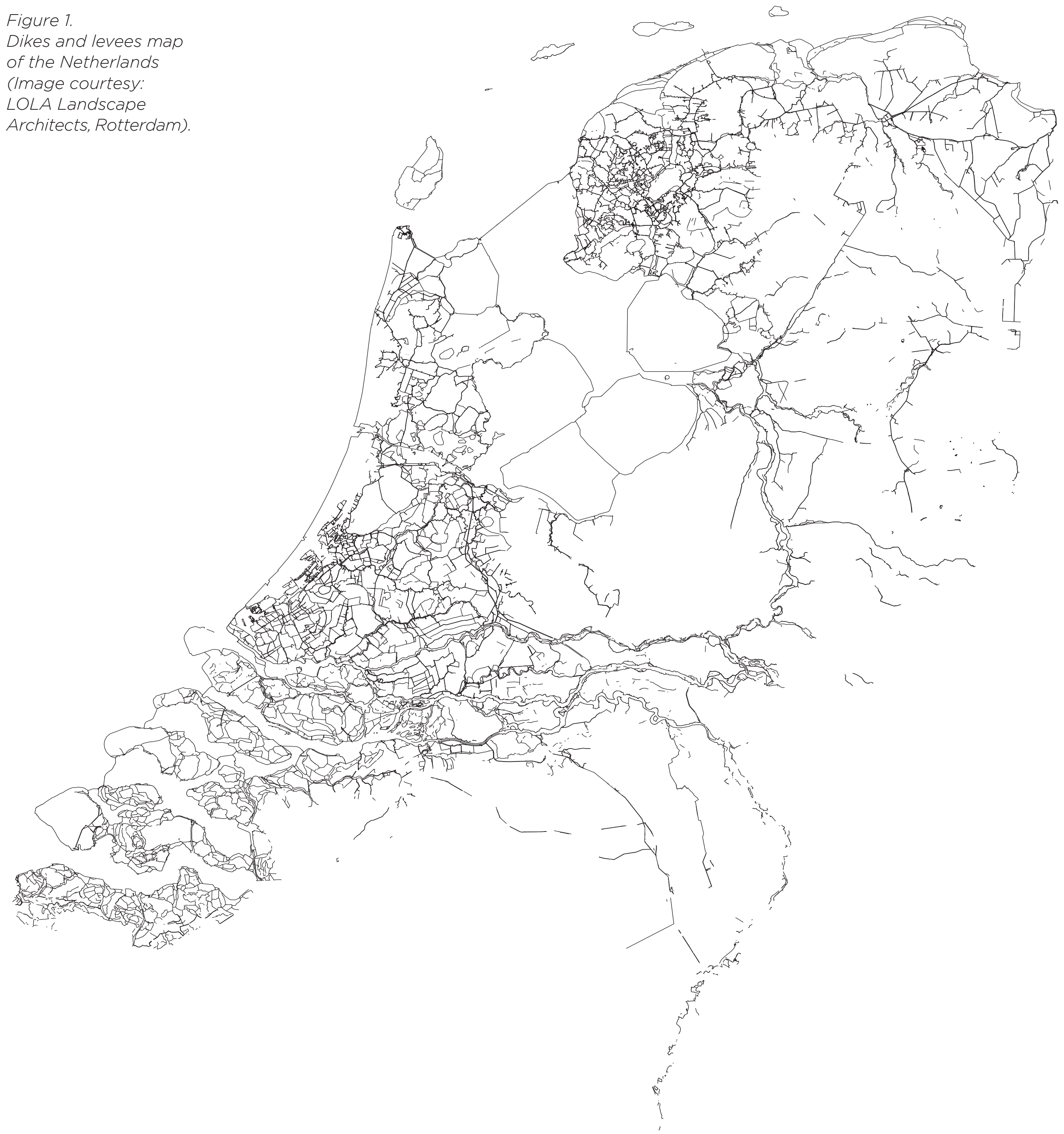
Figure 1.
Dikes and levees map
of the Netherlands
(Image courtesy:
LOLA Landscape
Architects, Rotterdam).



Hetty Klavers

MULTIFUNCTIONAL FLOOD DEFENSES: NO FAD, BUT NECESSITY

PREFACE

Ir. Hetty Klavers is the 'dijkgraaf' at Water Authority Zuiderzeeland. Before, she held various management positions at Rijkswaterstaat including Program director of the Delta Program IJsselmeer region. As a member of the Union of Dutch Water Authorities she is responsible for the portfolio 'flood risk management'.

Figure 2. Hetty Klavers (Photo Courtesy: Lars van den Brink)

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 timeson a larger, more serious scale, with integrated parking garages and boulevards, 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 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*.

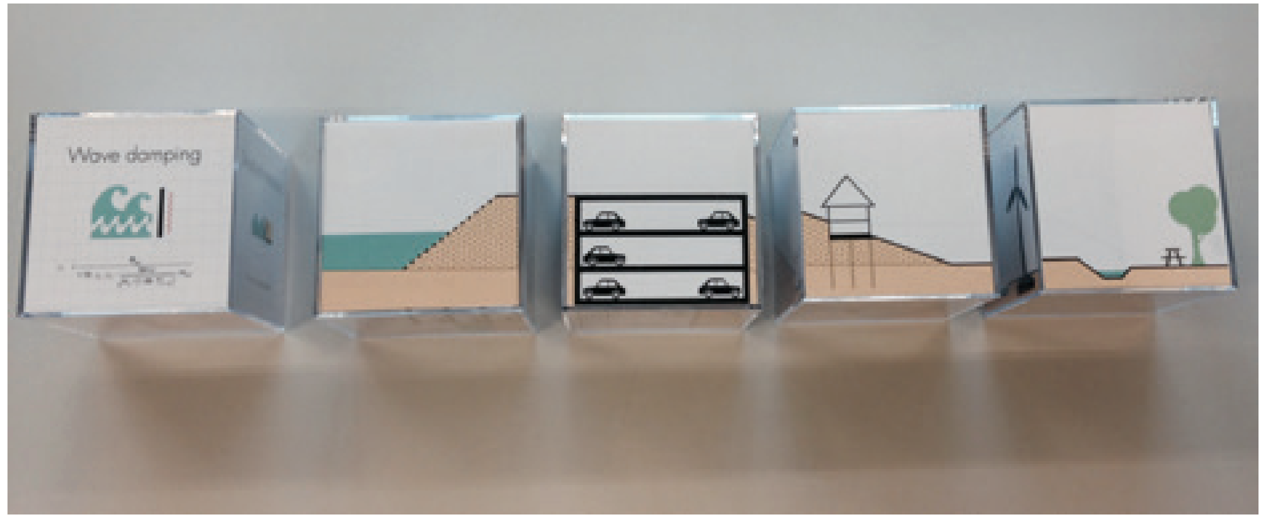


Figure 1. Dice-game to creatively explore options for multi-functionality; co-developed by Mark Voorendt, 2014.

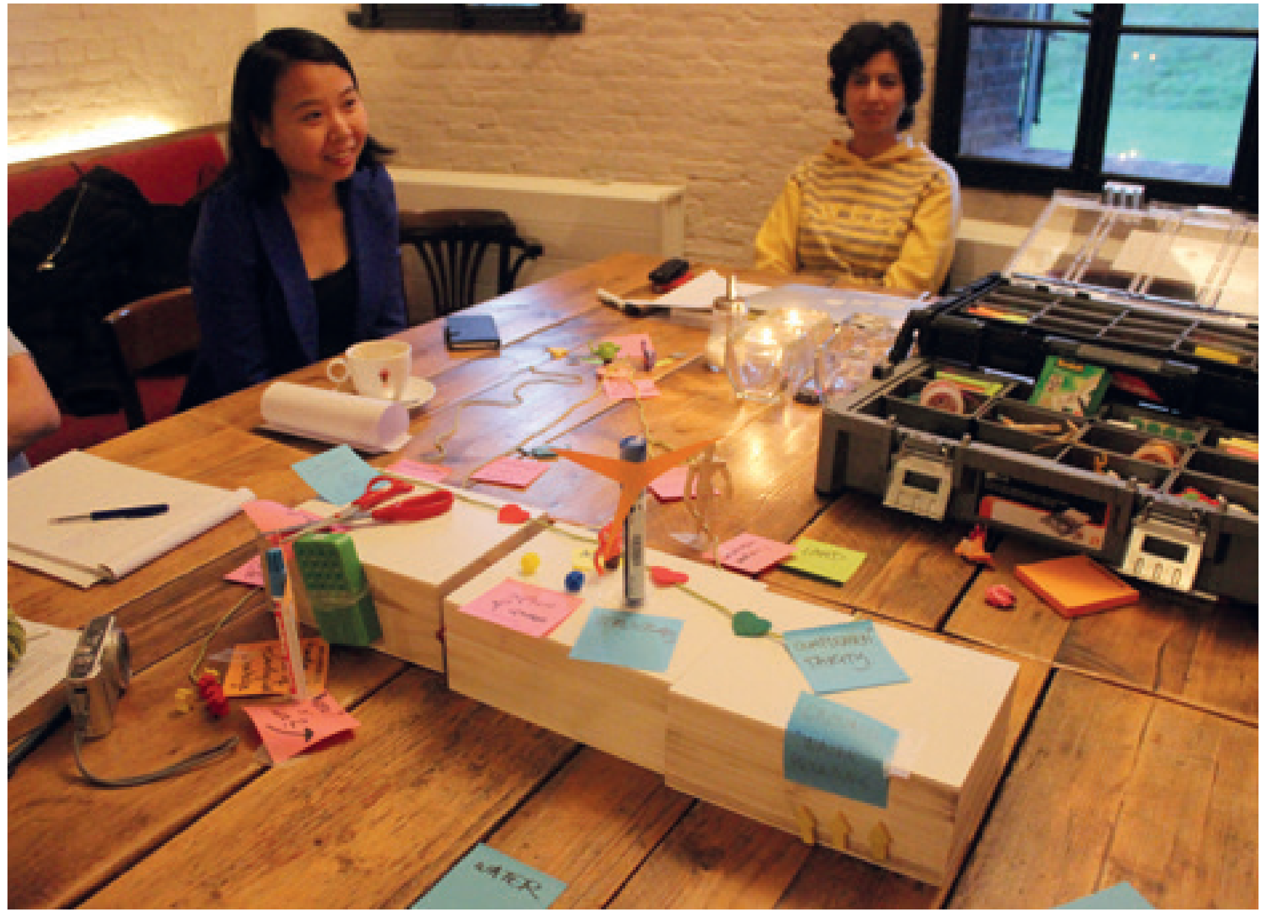


Figure 2. Knowledge integration activity at MFFD Reflection Day November 2014; co-designing a multifunctional flood defense in an urban area using the design integration toolbox developed by Julieta Matos-Castaño

Erwin Meijboom, Ruben Sharpe

IMPLEMENTATION OF KNOWLEDGE

STW - DUTCH TECHNOLOGY FOUNDATION

Drs.ir. Erwin Meijboom was Program Officer of the STW Multifunctional Flood Defences Research Program from 2015–2017 and is owner of Elias Consulting, a consultancy, research and training bureau for sustainability and water management.

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 Organization for Scientific Research (NWO).

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, conceivably, 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 must be done in the context of future uncertainties, such as those associated with climate change. Moreover, this needs to be translated into a design that integrates the different functionalities, ideally 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.

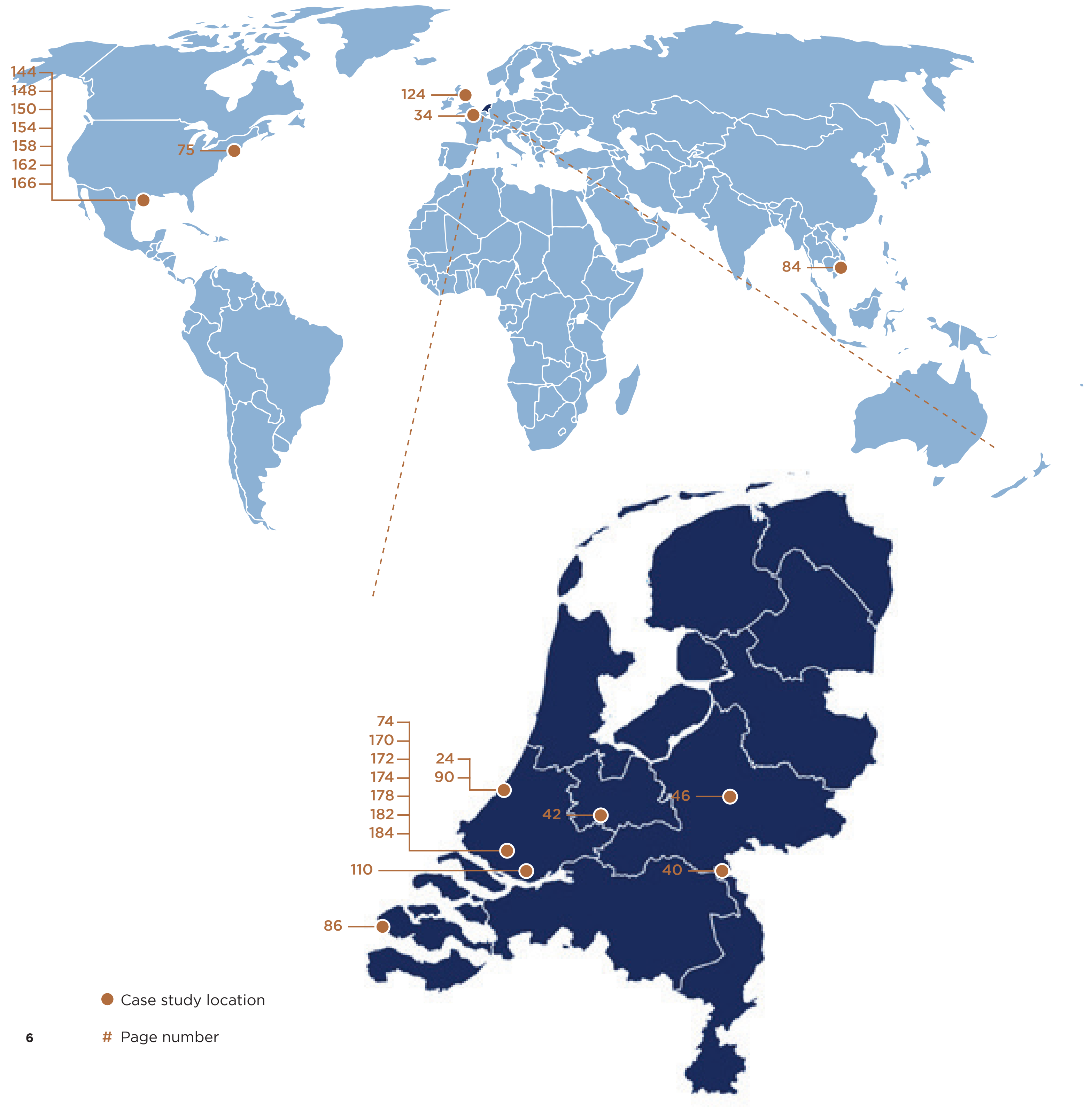
For STW (the current NWO domain TTW - *Toegepaste en Technische Wetenschappen* - Applied and Engineering Sciences), the MFFD program was one of their first integrative and multidisciplinary programs. At present, these kinds of programs have a well-established position within the range of TTW instruments. In the water sector alone, the MFFD program has been followed by successful programs such as Nature-Coast, RiverCare, WaterNexus 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 marked a milestone in the way that multidisciplinary projects 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.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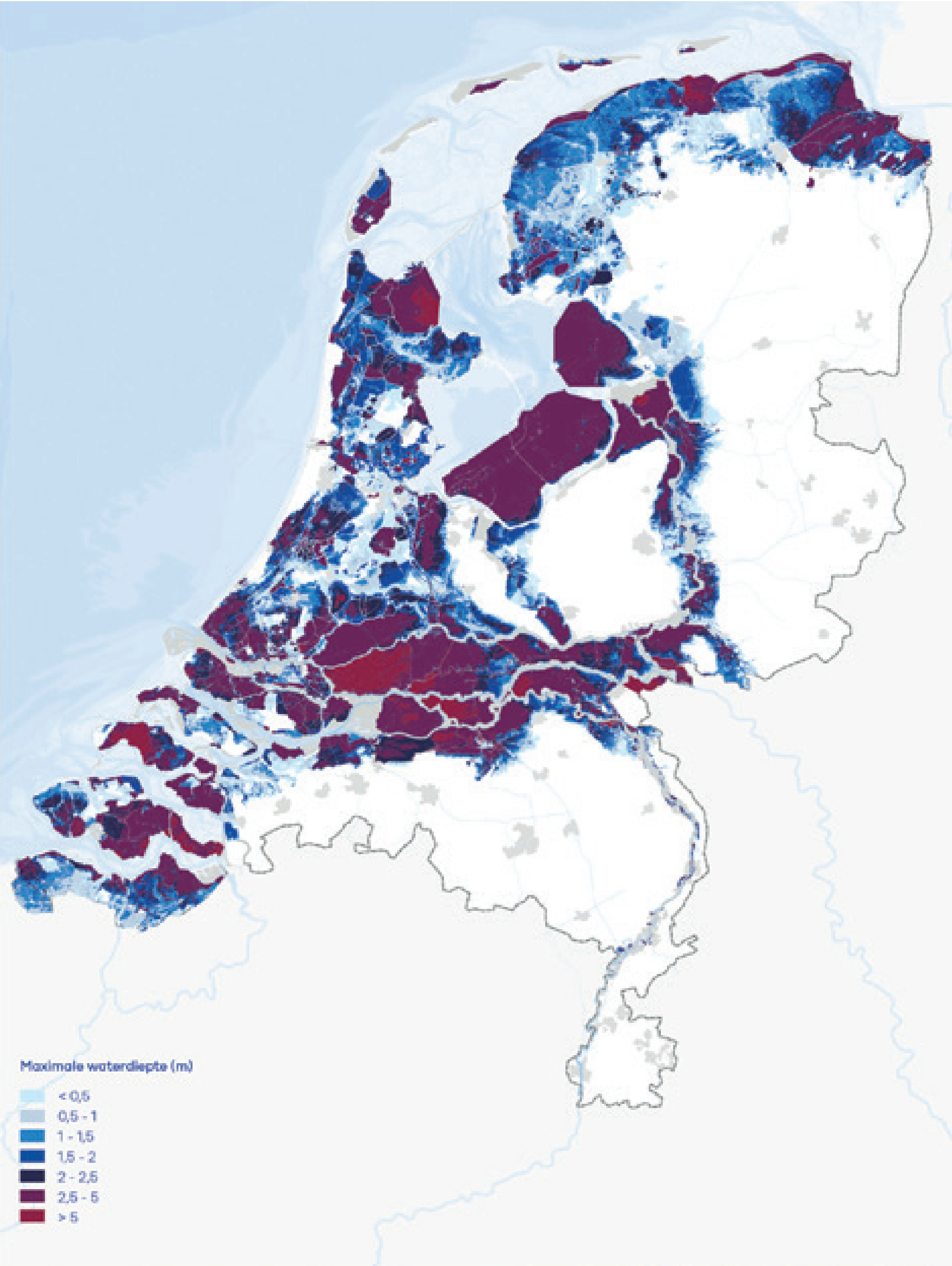


*Figure 1.
Sixty percent of the Netherlands is liable to flooding from the sea, lakes and major rivers, to water depths exceeding five metres in some places.*

Legend: Maximum water depth in meter. (Image courtesy: ENW, Fundamentals of Flood Protection, Utrecht, December 2016).

Matthijs Kok

SOCIETAL NEED FOR MULTIFUNCTIONAL FLOOD DEFENSES

INTRODUCTION

Prof.dr.ir. Matthijs Kok is Professor of Flood Risk at the Faculty of Civil Engineering and Geosciences at TU Delft; he was Program leader of the 'Integral and Sustainable Design of Multifunctional Flood Defenses' research program, funded by the Dutch Science and Technology Foundation STW. Presently, he is Program leader of the STW-Perspectief 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: structures 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 or increasing water levels.

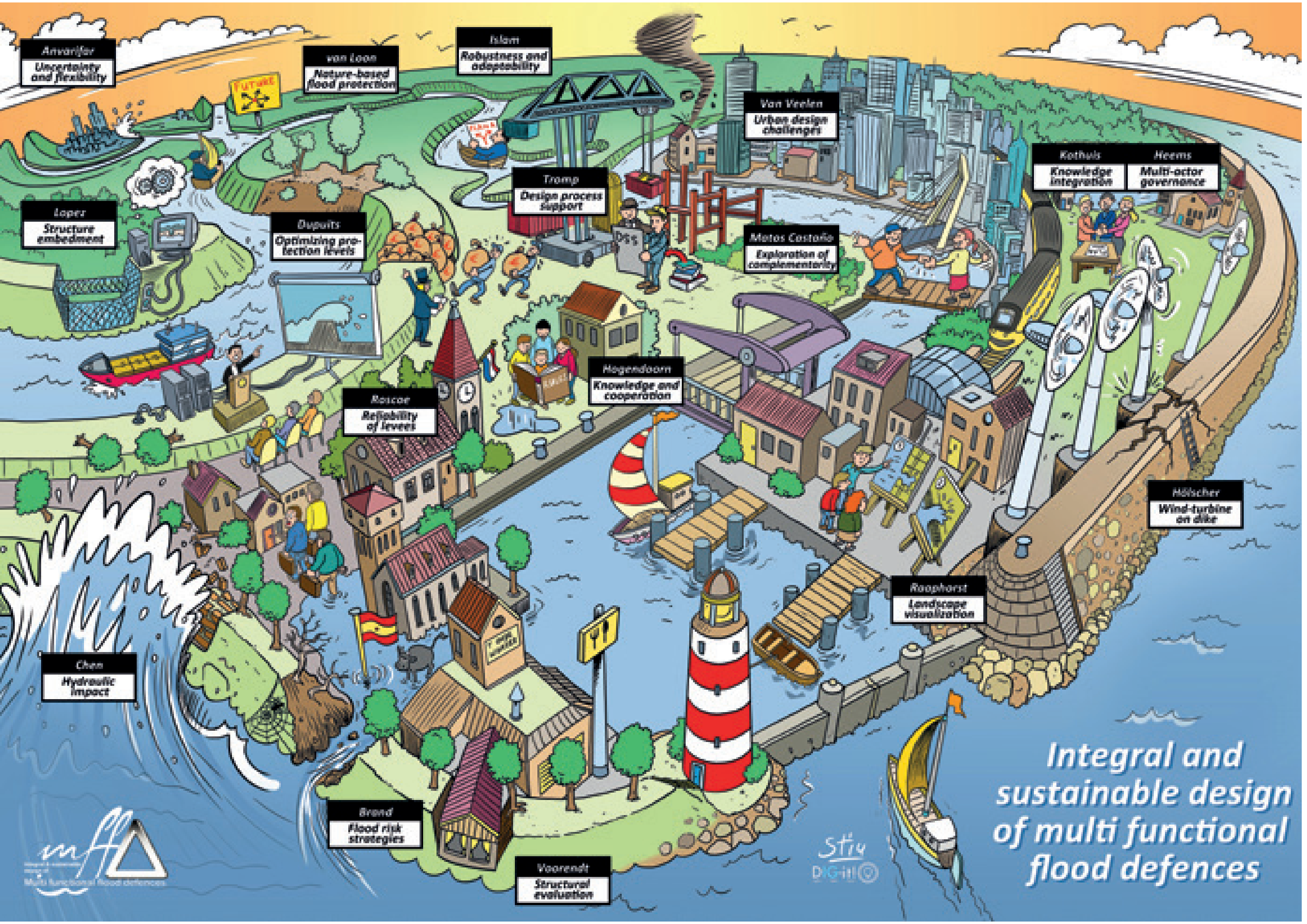
A multifunctional flood defense is a flood defense that also serves other purposes. This could include a variety of functions, for example pasture for grazing cattle or sheep, a walking path, a bicycle path or road on the top of the defense, a parking garage or tunnel inside the flood defense itself, pipelines near the toe or windmills on the top of the defense. Of course, multifunctional flood defenses are nothing new: they can be seen in every city with flood defenses, as well as in rural areas, where many flood defenses serve agricultural or transport functions.

On a worldwide scale, the importance of flood defenses in the toolkit to reduce the risk of flooding seems to be increasing. More attention needs to be paid to integrating these structures into the environment, and this explains why the research program 'Integral design of Multifunctional Flood Defenses' (MFFD) was started. The program aims to gain a deeper understanding of multifunctional flood defenses in order to provide a foundation for their design, assessment, 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 basis of the project. For example, if a parking garage is combined with a flood defense, than 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 redevelopment) 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 integrate 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.



The program faced a number of scientific challenges:

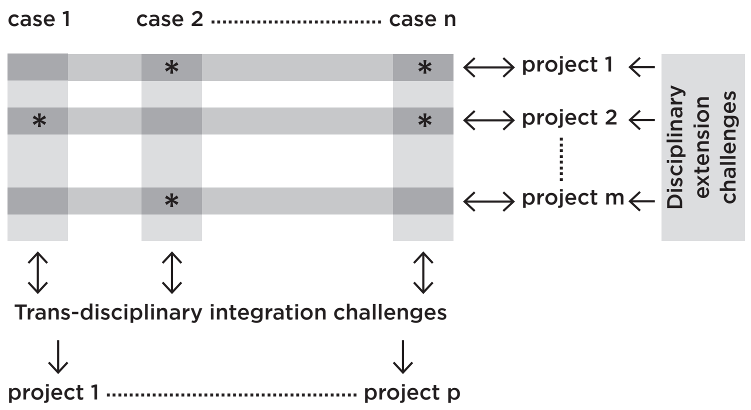
- Evaluating the reliability and risk of multifunctional flood defenses requires new methodologies, since the risk to a multifunctional defense is not simply the sum of the risk to the individual functions. Current approaches neglect extra functions when assessing future failure probability. For example, 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) extends knowledge to adjacent research fields.

The expertise of three universities, with seven different research groups within these universities, were 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, geo-information, 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, TOTAL-SHOT in colaboration 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.



Program	**STW Program ‘Integral and sustainable design of multifunctional flood defenses’ (MFFD’s)** Program Leader: Prof.dr.ir. Matthijs Kok							
Research Lines	**1. Disciplinary extension challenges**						**2. Trans-disciplinary integration challenges**	
Work Packages	1.1 Risk Assessment of multifunctional flood defenses			1.2 Urban and Rural MFFD design		1.3 Governance & Finance	2.1 Integrated Design	
Projects	1.1.1 Hydraulic impact of overtopping waves on a MFFD	1.1.2 Structural assessment of MFFD’s	1.1.3 Safety and reliability assessment of MFFD’s	1.2.1 Urban design challenges and oppor-tunities of MFFD’s	1.2.2 Contribution of MFFD’s to landscape values and spatial quality	1.3.1 Governance and finance of MFFD	2.1.1 Design Support for MFFD	2.1.2 Adaptivity and robustness
University & Research group	TU Delft Civil Engineering & Geosciences	TU Delft Civil Engineering & Geosciences	TU Delft Civil Engineering & Geosciences	TU Delft Civil Architecture & the Built Enviroment	Wageningen UR Water & Climate Centre	University of Twente Engineering Technology	TU Delft Technology, Policy & Management	UNESCO IHE & TU Delft Technology, Policy & Management
Project Leader	Prof.dr. Wim Uijttewaal	Prof.dr.ir. Matthijs Kok	Prof.dr.ir. Matthijs Kok	Prof.dr.ir. Han Meyer	Prof.dr. Rik Leemans	Prof.dr.ir Timo Hartmann	Dr. Pieter Bots	Prof.dr. Chris Zevenbergen
PhD(s) Supervisor(s) Postdoc(s)	PhD: Xuexue Chen (TUD) Supervisors: Wim Uijttewaal & Bas Jonkman	PhD: Mark Voorendt (TUD) Supervisor: Han Vrijling Postdoc: Dr.ir. Paul Hölscher (TUD)	PhD: Kathryn Roscoe (TUD) Supervisors: Han Vrijling & Ton Vrouwen-velder PhD: Juan Pablo Aguilar-López (UT) Supervisors: Suzanne Hulscher & Ralph Schiel-en & Jord Warmink PhD: Guy Dupuits (TUD) Supervisors: Matthijs Kok & Timo Schweckendiek (Former PhD: Wouter ter Horst)	PhD: Peter van Veelen (TUD) Supervisor: Han Meyer Postdoc: Dr. Nikki Brand (TUD)	PhD: Kevin Raaphorst (WUR) Supervisors: Adri van den Brink, Wim van der Knaap & Ingrid Duch-hart (Former PhD: Chris van der Zwet) Postdoc: Dr. Jantsje van Loon (WUR) (Former PhD: Aike van der Nat)	PhD:Julieta Matos Casta-ño (UT) Supervisors: Geert Dewulf & Timo Hart-mann PhD: Daniel Hogendoorn (TUD) Supervisors: Ernst ten Heuvelhof & Bertien Broekhans	PhD: Ellen Tromp (TUD) Supervisors: Wil Thissen, Bartel van de Walle & Pieter Bots Postdoc: Dr. Baukje Kothuis (TUD) Postdoc: Dr. Trudes Heems (TUD)	PhD: Flora Anvarifar (TUD) Supervisors: Chris Zeven-bergen & Wil Thissen Postdoc: Dr. Tushith Islam (TUD)

Baukje Kothuis

A FIVE-YEAR RESEARCH PROGRAM IN ONE BOOK

READING GUIDE

Dr. Baukje Kothuis was a Postdoc in the STW-MFFD 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 NWO Program ‘Integral & sustainable design of ports in Africa’ and for TU Delft and Texas-based universities as an independent consultant and co-PI in the NSF-PIRE 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 impossible. The true record of our efforts can be found in multitude of papers, reports, journal articles, posters, presentations and, ultimately, twelve dissertations across multiple disciplines. However, to create an overview for various interested parties, to hint at where to start looking for in-depth disciplinary knowledge and, not unimportant, to communicate the efforts and outcomes of integral design, is what we hope to provide for with this book.

In the Table on page 14, the set-up of the STW Perspectief Multifunctional Flood Defenses research program (MFFD) 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:

- Hydraulic impact of overtopping waves on a multifunctional flood defenses;
- Structural assessment of multifunctional flood defenses;
- Safety and reliability assessment of multifunctional flood defenses;
- Urban design challenges and opportunities of multifunctional flood defenses;
- Contributions of multifunctional flood defenses to landscape values and spatial quality;
- Governance and finance of multifunctional flood defenses;
- Design support for multifunctional flood defenses; and
- Adaptive capacity and robustness of 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 derived 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 & planning;
- 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. In an interview they explain if and how the collaboration 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 considering multifunctional 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 make use of 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 will be an inspiration for anyone who is involved in one way or another in the integral design of multifunctional flood defenses.

ONE | RISK ASSESSMENT

Figure 1.
Wind turbines at dike near Borkum-kade, Eemshaven, Groningen (Photo courtesy Gerben Spaargaren).

Perspective of an end user: Gerben Spaargaren, Witteveen+Bos

INTEGRATING FUNCTIONS FOR MULTIFUNCTIONAL USE

INTERVIEW

Ir. 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. Witteveen+Bos was a user of the knowledge produced in the STW-Multifunctional Flood Defenses program project 'Risk Assessment of multifunctional flood defenses'. Gerben collaborated with Mark Voorendt on structural evaluation of multifunctional flood defenses (see pages 20-25) and Paul Hˆlscher 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 lot of this 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 governments, 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 foundation layer could also function as flood-barrier structures."

What specific kind of knowledge is needed for integral 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 Voorendt's work is very close to this line of thought, because it looks at the multifunctional use of an area. A good example is his analysis of the Roof Park in Rotterdam. The water authority wanted the dike to be independent of the building for reasons of safety, and also so that they could inspect it. So ultimately, two walls were built where one slightly thicker wall as part of both the building and the flood defense might have been enough, according to one of the designs. But to make multifunctional use of such kind of wall, stakeholders need to identify 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 as close as possible to the dike or even on or in it, and find the arguments for doing that?' "

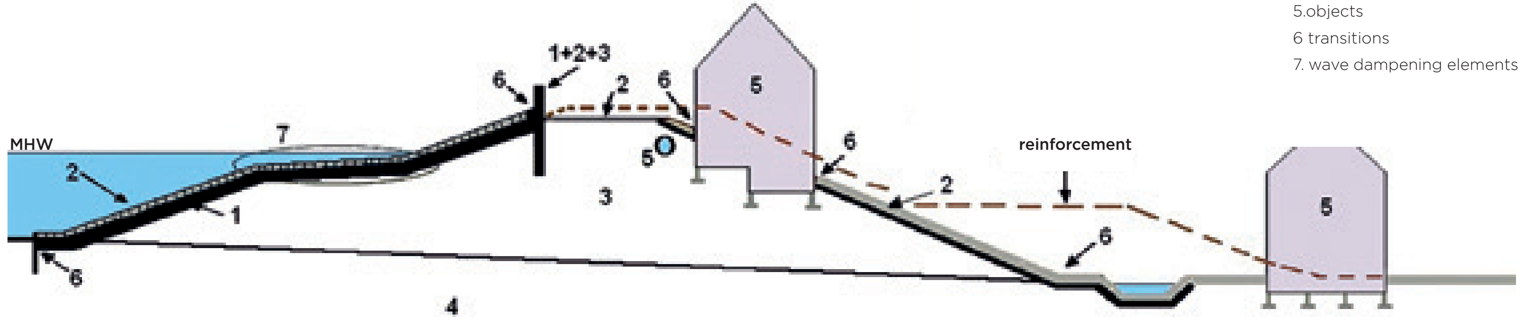
"Paul Hölscher investigated the effect of vibrations of wind turbines. And there are more issues, especially now that wind turbines are getting bigger. For example, what happens if a turbine falls over and hits the flood defense? Or the turbine house, or one of the blades? Some say it completely shatters 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 separated 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. We just started a new project looking into 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 on or near a dike obviously has more effects. And Mark's methodology helps investigate what those effects could be."

Figure 1 (below). Hypothetical flood defense with all element types present.

Figure 2 (below below). Structure built into dike. at Schoonhoven.

Legend
1 water retaining element
2. erosion-proof element
3 supporting element
4 subsoil
5.objects
6 transitions
7. wave dampening elements



Mark Voorendt

STRUCTURAL EVALUATION OF MULTIFUNCTIONAL FLOOD DEFENSES

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 defences.'

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

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.

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. Huis in 't Veld (1986) and Venmans (1992) also distinguished elements, but to develop this method, this was done more systematically. Seven types of elements were identified:
1. Water-retaining elements
2. Erosion-proof elements
3. Supporting elements
4. The subsoil
5. Objects
6. Transitions
7. Wave-damping elements

The way structural elements can be identified is demonstrated with the help of the hypothetical dike in Figure 1. This example contains all structural element types.

Figure 3. MFFD houses in Dordrecht, Netherlands (Photo courtesy Mark Voorendt).

Figure 4. MFFD quay in Hamburg, Germany. (Photo courtesy Mark Voorendt)

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 an 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, supporting 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 supporting element.

The subsoil bears 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 mastic that prevents scour. 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 where 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 coffer 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 sluice was analyzed as an example of a hydraulic structure, and a reservoir dam was taken as an example of an atypical form. This provided 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. That means that flood defenses consist of two or more of these element types (a water-retaining element and the subsoil are always present).

The structural elements of flood defenses identified in this model are indeed generic and the method of identifying them is practical. Identifying the function(s) of structural elements gives insight into the consequences of different degrees of integration and different ways of combining the functions. By relating these elements to failure mechanisms, a reliability analysis can be performed. This enables the over-all failure probability of multifunctional flood defenses to be calculated. This approach enhances the possibilities of expanding urban activities near flood defenses, while at the same time improving the flood protection level.

Figure 1 (below). Cross-section of the dike-in-dune alternative (Kustwerk Katwijk, 2012).

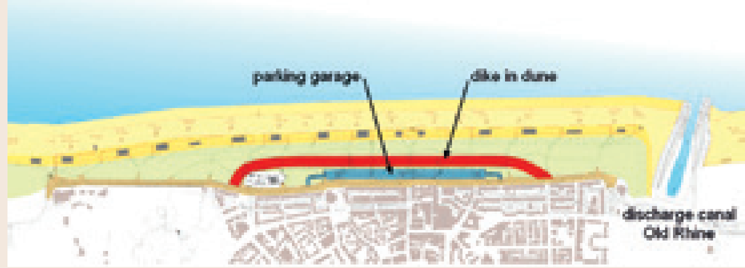
Figure 2 (mid below). Katwijk: overview of the area wih location of the dike-in-dune and parking garage. (Kustwerk Katwijk, 2012).

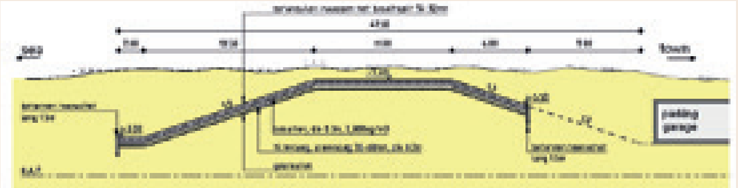
Figure 3 (bottom below). Design of dike in dune and materials used.

Figure 4 (top right). Artist impression of wall-in dune design alternative (DP6 architectuurstudio, Delft).

Figure 5 (mid right). Dike under construction (Photo Courtesy Mark Voorendt, 2014).

Figure 6 (bottom right). Entrance to the parking garage (Photo Courtesy Mark Voorendt, 2014).





Mark Voorendt

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 insufficiently protected against storm surges from sea (Figure 2). About 3000 inhabitants were in fact 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 2001 report from the *Steering Committee Coastal Vision 2050* (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 boulevard, and the dune area was re-shaped and widened. The dike-in-dune has been designed by engineering bureau Arcadis and the parking garage by engineering bureau Royal HaskoningDHV.

The dike-in-dune is constructed along the part of the boulevard that was too low to retain critical water levels that could occur during a 1 in 10,000 year flood, which is the flood safety standard for this area (figure 2). This is a stretch of about 900 m, where the boulevard is lower than NAP + 10.00 m. The total erosion volume of the dune and beach in a cross-shore direction is the major factor when calculating flood protection offered by the dune. It is not really important whether this volume is present in the height or in the width, so for aesthetic 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 dune, a 'hard structure' was needed to prevent further erosion. The total width of the dunes over the dike, 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 as low as NAP + 7.50 m, but for aesthetic reasons the dike is now covered with sand, which brings the top of the dunes to about NAP + 8.00 m.

At locations where the original dunes were already higher than 7.50 to 8.00 m, the existing dune top was maintained. The crest of the dike is 5.00 m wide, and the dike will only be exposed to wave attack when the sand on and in front of it has eroded. In that case, the remaining sand in front of the dike will be sufficient to reduce wave overtopping. In addition, the dike can be relatively easily adapted in future, as needed (Arcadis, 2013).

The parking garage is located between the dike-in-dune and the boulevard. Although it is covered with the same sand as the dike and therefore gives the impression that it is integrated into the dune, it is not actually part of the flood defense. The development of the parking garage, therefore, does not fall under the Dutch Water Act and therefore it is not a multifunctional flood defense regarded from a structural point of view.

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 15 to 20 m deep (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 of it. Dune erosion - when 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 would be completely eroded after 15 hours. Waves would than directly hit and overtop the wall.

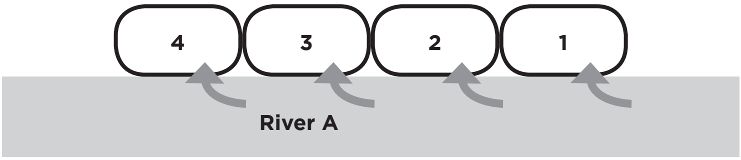
The parking garage was designed at the land side of the flood wall. The flood wall had a double function: in addition to retaining water, it would provide stability to the garage structure. The flood wall was sufficiently strong and stable on its own, so that even if the parking garage were to collapse, 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.

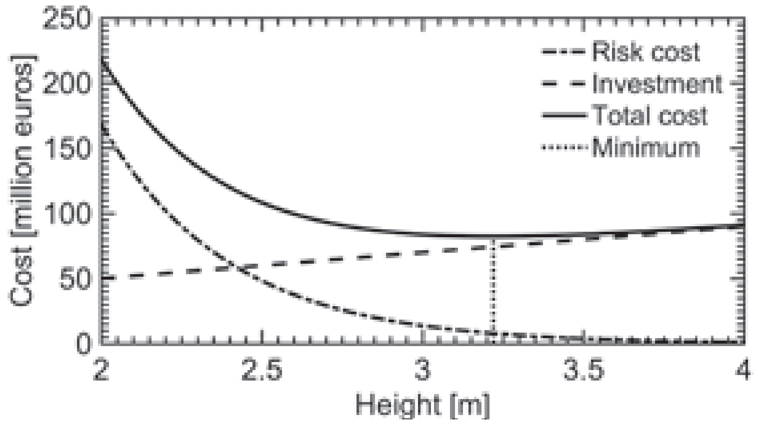
Figure 1 (top left). Top view of a river with four dike rings. The arrows indicate possible breaches.

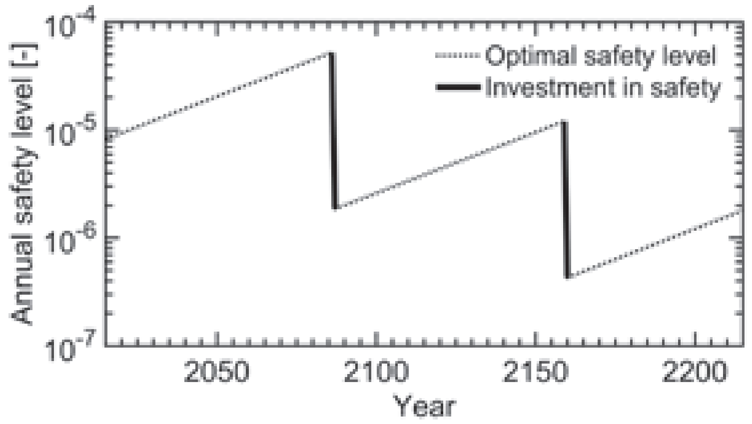
Figure 2 (top right). Example of an economic cost-benefit analysis for a flood defense.

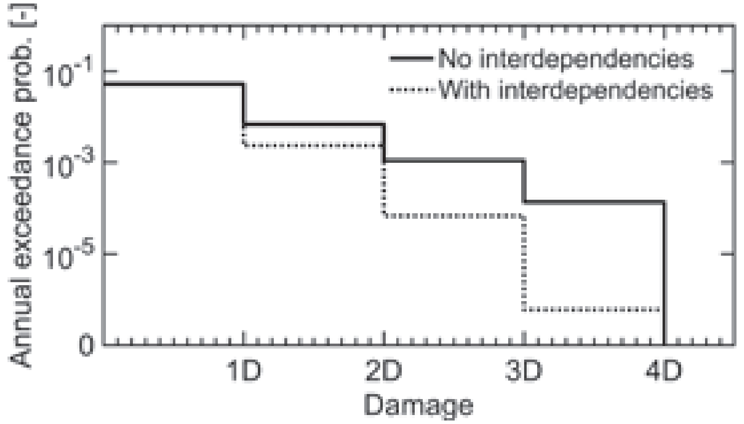
Figure 3 (Bottom left). Example of a changing economically optimal safety level over time due to for example economic growth. The 'investment in safety' lines indicate the optimal moments (and how much) to invest.

Figure 4 (bottom right). Flood damage curve with and without interdependencies for the flood defenses of figure 1. If a flood defense breaches, a constant damage D will occur. Therefore, the horizontal axis shows the damage in terms of D.









Guy Dupuits

ECONOMICALLY EFFICIENT FLOOD PROTECTION LEVELS

EFFECTS OF SYSTEM INTERDEPENCIES

Ir. Guy Dupuits is a PhD candidate in the STW-MFFD program at department of Hydraulic Engineering, faculty of Civil Engineering & Geosciences, Delft University of Technology. He is part of the project 'Safety and reliability assessment of multifunctional flood defenses'. Guy is expected to graduate in 2017.

(Tentative) dissertation title:
'Economic optimization of flood defense systems with multiple lines of defense.'

PhD Supervisors:
Prof.dr.ir. Matthijs Kok, TU Delft
Dr.ir. Timo Schweckendiek, TU Delft

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 where, 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 also needs to be taken into account in the cost-benefit analysis.

interdependencies for flood defenses
When dealing with flood defenses, the relevant interdependencies are those that have an impact on the hydraulic loads. For example, consider a river with a number of dike rings, as shown in Figure 1. If dike ring 1 has a breach during a flood event, a certain amount of water would be diverted from the main river into the lower-lying land protected by the dike ring. Even though this will probably lead to damage behind dike ring 1, less water will reach dike rings 2 to 4. In other words, a breach upstream at dike ring 1 will reduce the 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.

Flood defenses, interdependencies and risk
In the previous example a positive interdependency effect will occur in the case of a breach. However, a breach can also have a negative effect, for example if extra water enters another river due to the breach. This extra water increases the flood risk for areas alongside that other river. The consequences of interdependencies can therefore be either positive or negative.

In my research, the consequence of interdependencies has been expressed in terms of changes in the hydraulic loads. In order to quantify this, the 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 a flood defense, the interdependencies need to be incorporated in probability

distributions of hydraulic loads. A straightforward method of moving from deterministic hydrodynamic simulations to probability distributions of hydraulic loads is by using a Monte Carlo simulation, for example as implemented by De Bruijn et al. (2014). If we take the example in Figure 1, with a constant damage estimate for each flood defense, a flood damage curve with and without interdependencies looks like the graph in Figure 4. This indicates that the interdependencies in Figure 1 decrease the probability of multiple breaches during the same extreme discharge event.

Impact of including interdependencies on a cost-benefit analysis

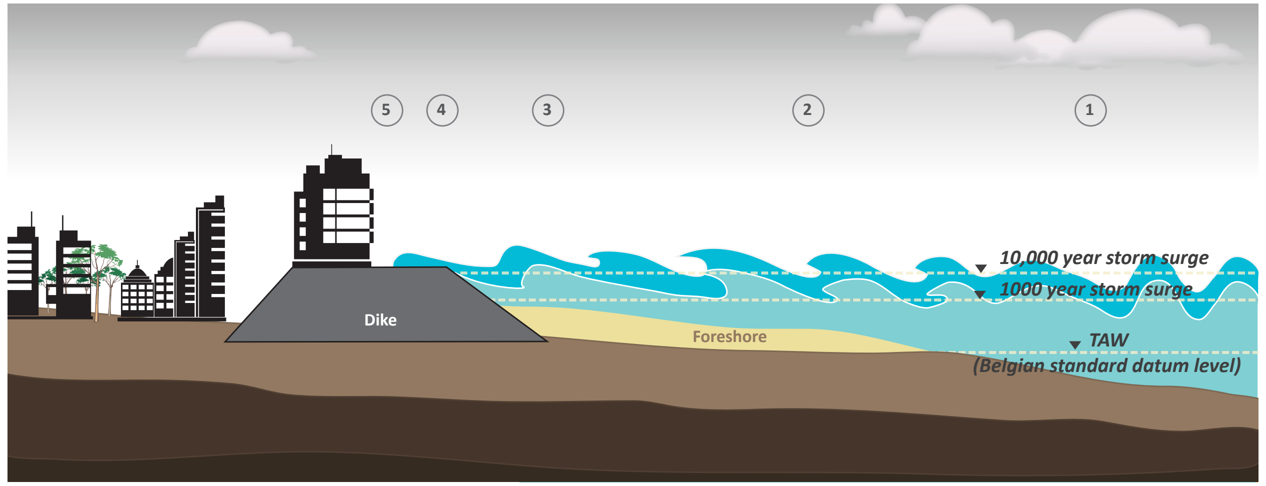
As previously described, an economic cost-benefit analysis balances risk costs and investment costs. Therefore, a change in flood risk can lead to different economically optimal investments. With interdependencies, the total number of relevant system configurations can become large. For example, suppose 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 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.

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.

Figure 5. Example of multiple lines of defense - Houtribdijk in Lake IJssel, The Netherlands (Photo courtesy Jesse Allen, NASA images)

Figure 1 (right). Full process of overtopping waves and their impact on a building on the crest of a multifunctional flood defense.

Figure 2 (below). Typical configuration of a Belgian coastal town, in this case Wenduine along the North Sea coast (photo courtesy Koen Trouw).



Xuexue Chen

PREDICTING WAVE IMPACT ON STRUCTURES ON TOP OF A LEVEE

Dr.ir. 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
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Dr.ir. Bas Hofland, TU Delft

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 defenses (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.
3. A turbulence bore runs up on the seaward slope of the dike and overtops the crest of the dike.
4. Part of the overtopping waves continues across the dike crest, and the other part flows back into the sea.
5. 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 multi-functional 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:

- The support or foundation can fail, making the structure lose stability
- 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:

- The failure of windows and doors;
- 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).

Figure 3. Image of flume in Antwerp: wave breaking on the foreshore (photo courtesy Xuexue Chen).

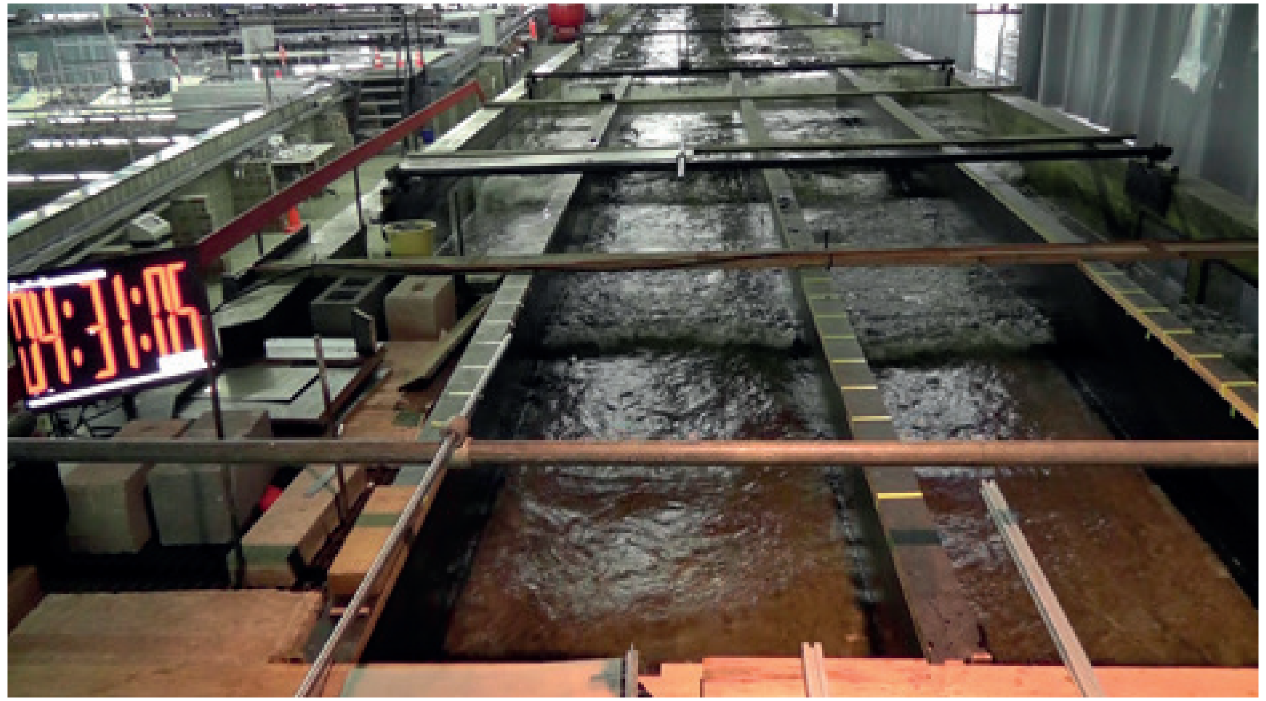


Figure 4. Image of flume in Antwerp (photo courtesy Xuexue Chen).

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 dike 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.

Figure 5. Wave flume in Flanders Hydraulic Research (Antwerp, Belgium). (a) is a top view of the flume, below are the respective sections: (b) 'Outer section', (c) Section A, and (d) Section B.

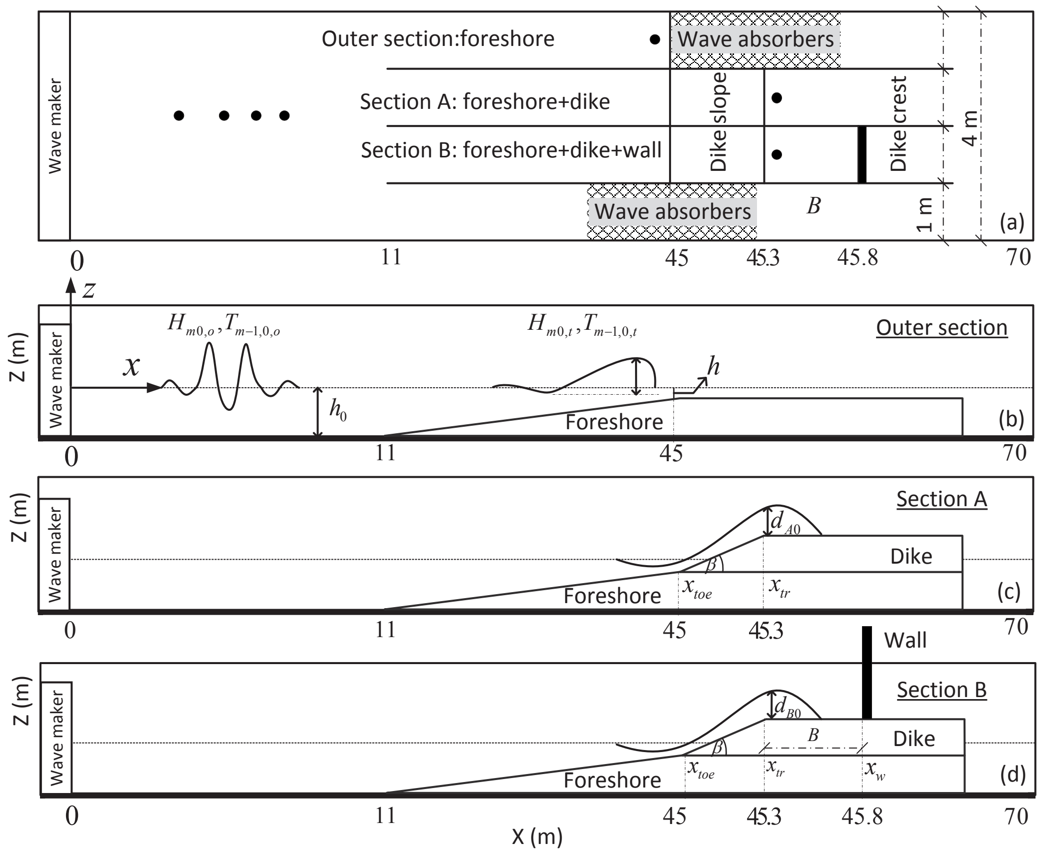


Figure 1 (left). Villa on coastal dike in Wenduine, Belgium (Photo courtesy Koen Trouw).

Figure 2 (bottom right). Raised first floor for flood protection (Photo courtesy Koen Trouw).

Figure 3 (top right). Basement with flood protective window shutters (Photo courtesy Koen Trouw).

Xuexue Chen

CASE STUDY: WENDUINE, BELGIUM

VULNERABILITY OF BUILDINGS ON A COASTAL DIKE

On coastal dikes in Belgium, many residential buildings are found. Most of the old 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 (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 year conditions 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).

Figure 4. Belgian coast (Image courtesy Jesse Allen, Earth Observatory, NASA).

Figure 1. Piping and wave overtopping erosion based failure mechanisms may contribute o 48 percent of the total failure probability of a dike.

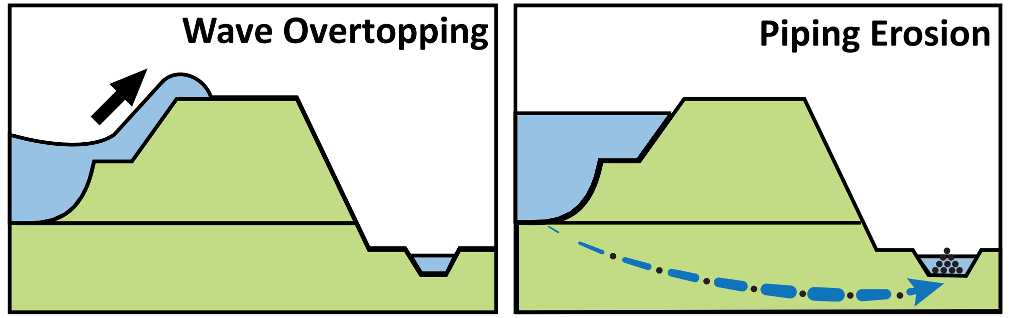
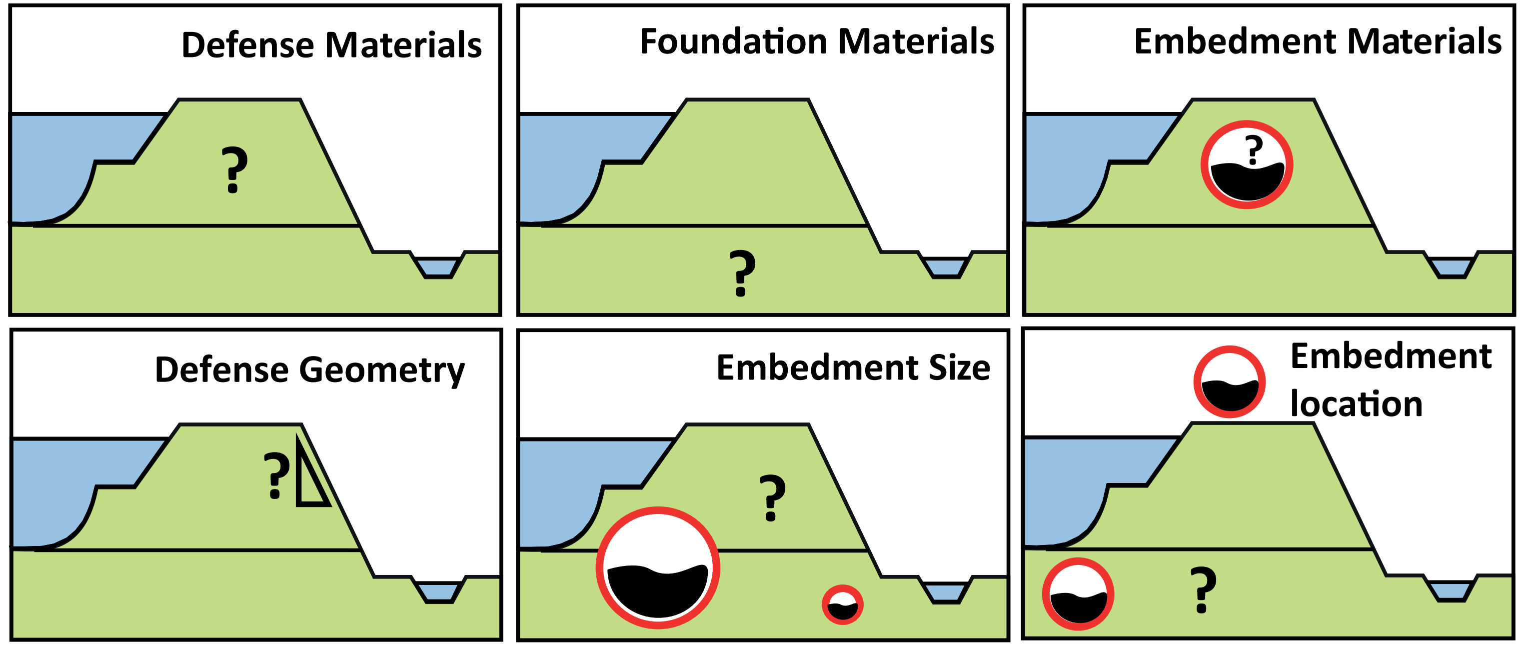


Figure 2. MFFD design choices: Material choices (top row below) and dimension choices (bottom row below).



Juan Pablo Aguilar-López

EMBEDDED STRUCTURES IN FLOOD DEFENSES

EFFECTS ON SAFETY AND FAILURES

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Dissertation title:
'Probabilistic safety assessment of multi-functional flood defences.'

PhD Supervisors:
Prof.dr. Suzanne Hulscher, University of Twente
Dr. Jord Warmink, University of Twente
Dr. Ralph Schielen, University of Twente

Flood defenses are exposed to deterioration processes that compromise their stability. These processes are called 'failure mechanisms' and they are mostly triggered and/or exacerbated by the hydraulic loads generated during extreme high water events, which are becoming more frequent due to climate change. Concepts such as the 'Delta dike' or the 'Unbreachable dike' have been developed in the Netherlands to deal with these failure mechanisms.

These approaches resulted in the design of massive flood defenses that can withstand extreme water events thanks to their larger dimensions and highly resistant materials. However, these characteristics should be optimized to make them cost effective. A good way to achieve this goal is to use the initial space allocated exclusively for flood defense in combination with additional functions. These extra functions may also help to reduce their required size to cope with the failure mechanisms, but in order to do this, we need to quantify the additional resistance provided by the embedded structures.

Multifunctional flood defenses (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 embedments 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 a risk-based policy, where systems are evaluated based on the probability of flooding and the resultant consequences of an specific event. The probability of flooding is determined by the reliability of the flood defenses for different evironmetnal loads. MFFDs will definitely be exposed to the same failure mechanisms as conventional flood defenses 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 defenses.

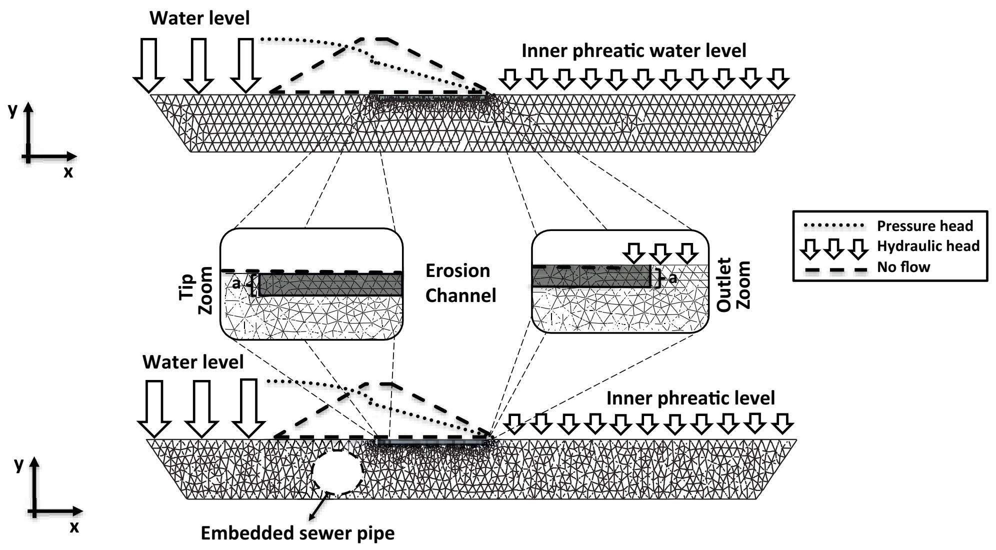
Extensive research performed around the world and particularly in the Netherlands, has shown that from all the possible failure mechanisms, two of them may account for as much as 48% of the total estimated failure probability. These failure mechanism are the Backward piping erosion and the wave overtopping (Figure 1).

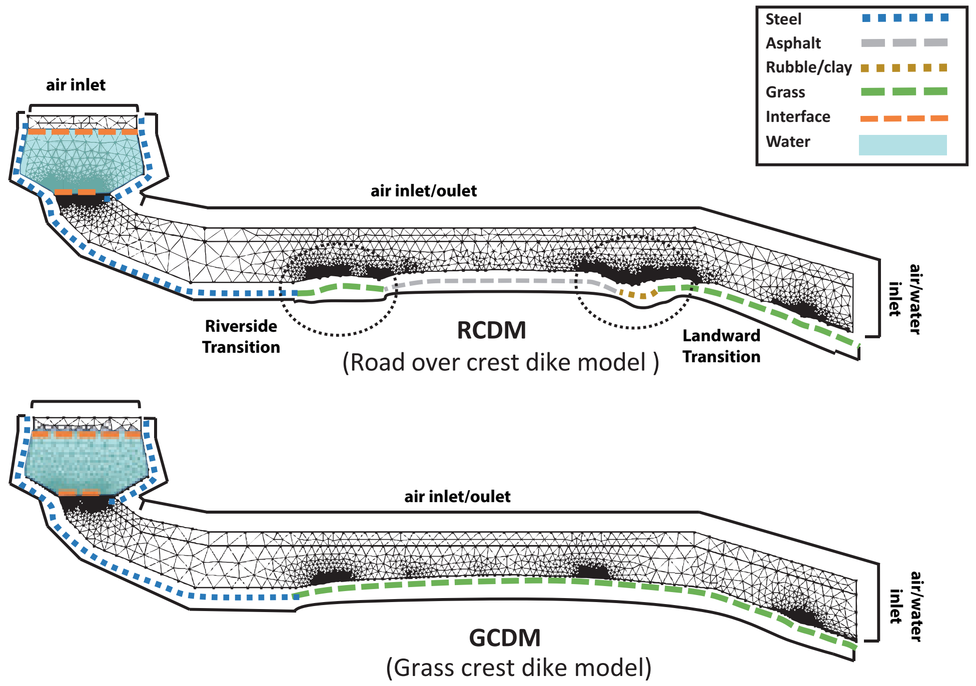
- *Backward erosion (piping):* Collapse of the granular foundation due to cavity formation (also known as pipes) derived from fine sediment transport towards the landward side.
- *Wave overtopping:* Landward slope erosion of the grass cover on the landward side caused by overtopped waves.

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.

Figure 3 (below). Piping erosion FEM model boundary conditions of the IJKDIJK experiment.

Figure 4 (below below). Wave over-topping FEM model boundary conditions of Millingen WOS experiment.





Though all the failure mechanisms will eventually result in a dike breach, each is directly linked to a certain part of the dike. For the case of piping erosion, the foundation is eroded; whereas for wave overtopping the outer grass cover is eroded (Figure 1). Hence the location and size of the embedded structure(s) is the design choice (Figure 2) which may directly influence a particular failure mechanism. The defense geometry will also have an influence but the ideal way to quantify the effects of the embedment is by benchmarking. This means that and initial monofunctional flood defense is compared with one identical in terms of materials and geometry but including the additional embedments.

In order to perform such benchmarking, detailed finite element models (FEMs) were used to simulate both MFFDs with high level of detail. These models allow to simulate the physical processes, while including extreme flood events and the main characteristics of the structures in the analysis as external triggering conditions. FEMs allow us to find the approximate solution of boundary value problems for the partial differential equations which describe the governing physics of each failure mechanism. In our case, each of the two failure mechanism can be described by a different physical process: Groundwater Darcy flow for backward piping erosion; and Navier-Stokes fluid flows flow for wave overtopping.

Structural embedment cases

When possible, the result of any model should be compared with the reality which in our case is represented by the measured values of two large scale experiments performed in the Netherlands; the IJkdijk piping erosion experiment and the Wave overtopping simulator experiment (page 40-41). Extensive amount of data was collected during these two real scale filed experiments which allowed to validate both later FEM models.

The first experiment consisted simulating a controlled failure of an artificial dike built with realistic dimensions, which was tested with a lateral water load. The artificial dike was monitored in terms of preassures, displacements and inner temperature in order to understand better the physical processes that governed the piping erosion failure mechanism. The second experiment consisted in placing the wave overtopping simulator (WOS) on the crest of a dike which had a road on top. Later, random water volumes which followed a predefined statistical distribution where released during representative storm durations in orde to test the dike erosion resistnce during wave overtopping extreme events. Volumes, valocities and scouring depths where measured in order to understand the process and validate the actual modeling approaches. Based on the measured data of the two experiments, two FEM models (Figures 3 and 4) where calibrated and validated for different loading conditions tested in the field.

Once the models are accepted as sufficiently representative of reality, the failure probabilistic analysis is conducted by representing the hydraulic loads and the characteristics of the structures as statistical distribution which allow to represent their associated uncertainty. Such distributions are represented in the models as random variables. This means that each variable used in the model follows a probabilistic distribution which can be later sampled during different model runs. One sampling at the time of all involved variables are then used as the model input for one single run of the model. After running a large number of combinations of samples, a probabilistic distribution of the output is obtained. Based on a predefined safety criterion for each failure mechanism (e.g., values of pressure, deformation or scouring depth), these distributions are used to estimate the probability that these values will be exceeded.

Materials effects: random variable correlation

The different climate and material scenarios are represented by the chosen input variables and their statistical distributions and therefore their correct selection and representation will also determine the MFFD estimated reliability. Such selection also include their joint occurrence, In other words, it is not only important to select the statistical distribution that will better represent each material characteristic but also the correlation between variables. Correlation determines the degree of joint occurrence between two or more variables. For example, during a extreme storm, high wind speeds will definitely influence the occurrence high wave heights. If both characteristics are used and represented as statistical distributions in one single model, their joint occurrence should also be included during the random sampling of both variables. This joint occurrence may be represented by joint correlation models known as 'copulas'. These copulas not only allow to represent two or more probabilistically correlated variables but also allow to give more importance for large or small values during the sampling process. This is important for MFFDs as the correct representation of correlation will have a significant effect in the estimated reliability of the flood defense for each particular failure mechanism.

Surrogate modeling for faster computing

The FEM models are very powerful, but their computational burden is also high. This means that it may not always be possible to conduct sufficient model runs to calculate the failure probabilities. In those cases, surrogate modeling becomes a powerful tool for probabilistic assessment based on FEM models. Surrogate models or 'emulators' are computationally inexpensive models that are trained and validated based on the original input and output values obtained from more complex models such as the FEMs. In other words, fewer FEM model runs are used to built a surrogate which runs faster and 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 commonly used for building the surrogates as they are capable of representing highly nonlinear process while reducing the computational time by an order of magnitude. These models allow the original probabilistic distributions of the input to be changed and represent different uncertainty scenarios. Surrogate models were used to test the effect of different water events and different material uncertainties on the two different structural embedment cases.

Main results

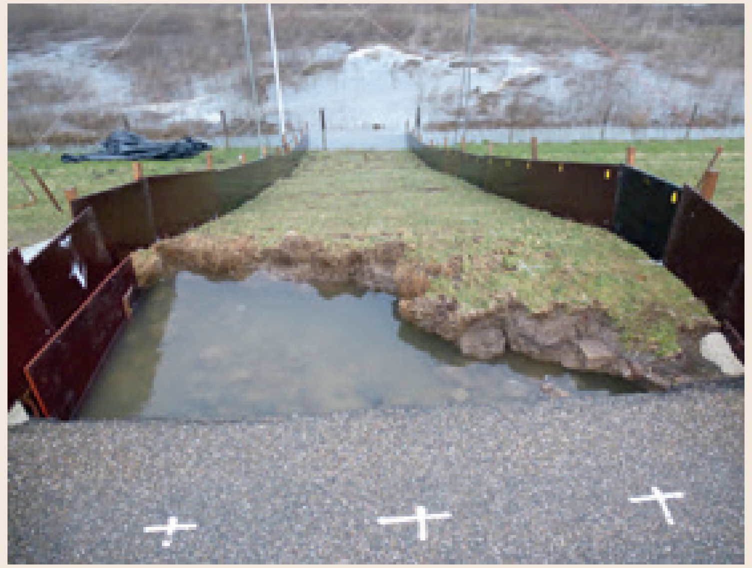
Overall, the results indicate that having embedded structures under, inside, and on top of flood defenses has significant effects on the safety of these flood defenses. It is expected that these effects become more in the case of more extreme flood events. Large MFFDs are intended to withstand such events, but other smaller MFFDs as the ones found in the actual Dutch landscape, may only withstand such events if the embedded structures are correctly positioned and dimensioned. These smaller MFFDs are often found in the flood defense systems as a consequence of the urban development requiremets and not conceived as integral solutions. While their safety is always assessed by experts in order to ensure that they don't compromise the overall system reliability, is not common to include the embedment effects in the actual probabilistic models. Note that, these effects are not only harmful by catalyzing failure mechanisms, but also beneficial by increase the flood defense resistance or dissipating the energy of the hydraulic loads.

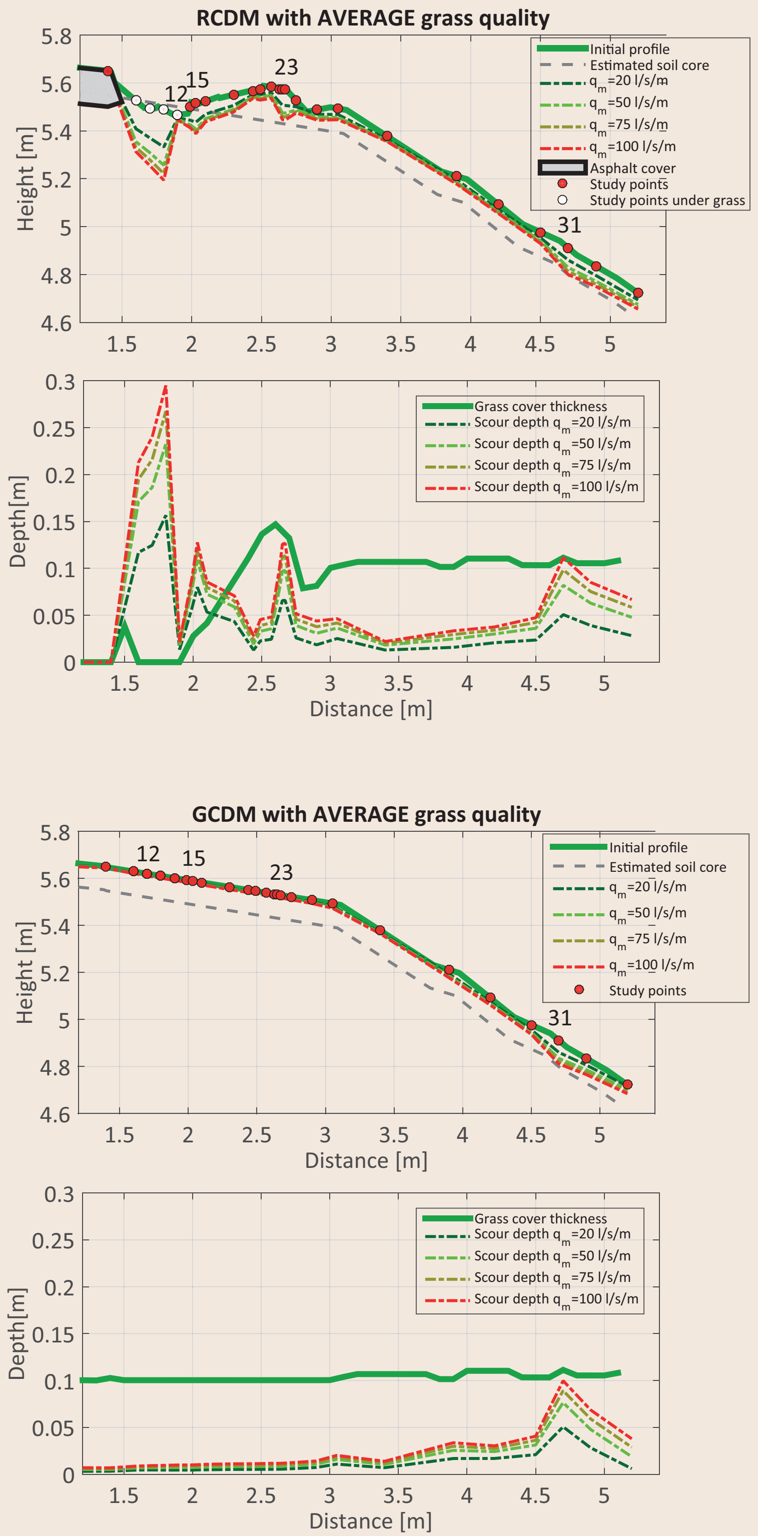
Our approach showed that surrogate modeling was able to capture the additional embedment effects in the probabilistic results, as long as they where incuded in the original complex model. In addition, the correct inclusion of correlation between variables which are used as inputs for the original and surrogate models also have an important influence in the estimated failure probabilities and consequently in the required MFFD dimensions which also determine the size and location of future embedments. Surrogate modeling techniques in combination with correlation modeling are expected to have an enormous potential for the MFFD probabilistic design. We recommend further studying the possibility to develop a generalization of the method so that in the future one robust surrogate model can be used for different locations.

Figures 1 and 2 (below). Final scoured grass cover of a dike with a road after 100 L/s/m test in Millingen (Images by Infram bv).

Figure 3 (right four images). Model results of average scoured profiles after different overtopping storms.

Top two graphs: Road over crest dike model (RCDM). Two graphs below: Grass crest dike model (GCDM).





Juan Pablo Aguilar-López

CASE STUDY: MILLINGEN AAN DE RIJN

CASE LOCATION

In the area of Nijmegen, Rijkswaterstaat tested a stretch of dike near the village of Millingen along the river Rhine. In cooperation with the local Water Authority Rivierenland and knowledge institute Deltares, the strength of the grass cover of this dike was researched and tested for wave overflow that could occur in circumstances of concurrent 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 empties at once with thousands 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.waterschaprivierenland.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 dike conditions (with road and without). The main conclusion from these simulations is that the actual existent 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.

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

Juan Pablo Aguilar-López

CASE STUDY: LEKDIJK (VIANEN, UTRECHT)

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 the a plausible scenario of future climate change. Therefore it was decided that this section needed to be strengthened so that it could 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 an hypotethical MFFD designed for the encountered conditions in this location.

(Source: www.waterschaprivierenland.nl)

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 assesment will directly affect the MFFD geometrical choice, which determines the potential available space and the estimated MFFD reliability.This was concluded from a case study in a location along the Lek River in Utrecht Province (The Netherlands), where a large number of samples containing these parameters was available.

A hypothetical MFFD design wich 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 where 200 meters with correlation and 230 meters without correlation as shown in Figure 2 below.

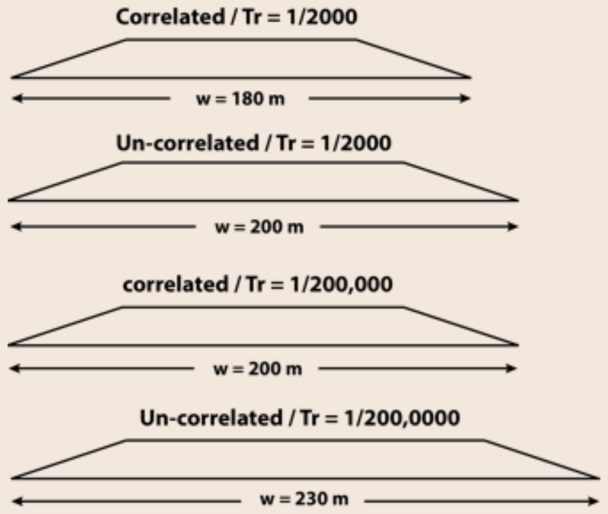


Figure 1 (page 42). River Lek at Vianen (Image courtesy Rijkswaterstaat beeldbank).

Figure 2 (left). Required widths (w) based on correlation and failure chance (Tr).

Figure 1.
Failure of dike in North Holland, polder Beschoot (Photo courtesy Beeldbank Rijkswaterstaat beeldbank, Hein Versteeg).

Kathryn Roscoe

LEVEE SYSTEM RELIABILITY AND PERFORMANCE OBSERVATIONS

Dr.ir. Kathryn Roscoe is a researcher at Deltares. In the STW-MFFD program she worked at the faculty of Civil Engineering & Geosciences, TU Delft University of Technology as a PhD candidate in the project 'Structural assessment of multifunctional flood defenses'. Kathryn graduated in 2016.

Dissertation title:
'Bayesian networks for levee system reliability: Reliability updating and model verification.'

PhD Supervisors:
Prof.drs.ir. Han Vrijling, TU Delft
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Flood risk analysis is necessary to make smart, informed decisions about which risk reduction measures deserve priority. When levee systems play a key role in flood protection, these decisions often translate to which levee improvements should be carried out first. In flood risk analysis, the probability that a levee system fails is a critical component, but one that is wrought with uncertainty. Much research has focused on how to calculate the probability of system failure. However, for levees, what is typically seen in practice is an over-simplification of the system to make calculating the system failure probability easier.

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
1. 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 network. The BN selected for use in this dissertation works with Monte-Carlo (MC) sampling, and correlates variables in the network using the Gaussian copula. In this sense, it can be considered a more explicit, less approximating method than the algorithms in Hydra-Ring.

The BN was used to test the MO algorithm, and MC directional sampling and exact solutions were used to test the EP algorithm. While both methods produce some error relative to more exact MC methods, the error is not substantial, even after incorporating a survival observation. The BN was applied to two case studies in the Netherlands, to calculate system failure probabilities due to the piping failure mechanism. In these cases survival observations were used to improve the system reliability estimate.

These applications show that not all survival observations have equal impact on the levee system reliability estimate. It was investigated under which conditions survival observations are useful. A BN was also developed specifically for the estimation of the model uncertainty in a geotechnical failure model. This uncertainty can dominate the failure probability estimate, and it is therefore important to estimate it as sharply as possible. The research shows that using a BN, high quality hindcasts (geotechnical model output for historic input data) can be used together with observed failure (or survival) to substantially improve the model uncertainty estimate, even with limited data.

The developed BN serves as a useful augmentation to the levee system reliability methods currently in use. A system reliability calculation with the BN is not prohibitively slow, but it can be substantially slower than the approximate algorithms within Hydra-Ring. Therefore, it should not be seen as a replacement for Hydra-Ring, but rather a yardstick which can be used to verify Hydra-Ring algorithms when results are questionable, or when survival observations are expected to be useful

This text is adapted from text in Bayesian networks for levee system reliability: Reliability updating and model verification' by Kathryn Roscoe (2017).

Figure 1. Levee system considered in the case study; three levee segments, 13a, 13b, and 14, which protect agricultural land and the western part of Zutphen from the IJssel River.

Kathryn Roscoe

CASE STUDY: ZUTPHEN

ESTIMATES OF LEVEE SYSTEM RELIABILITY

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 (tables see next page), 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. Arcs 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 system 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 are 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.

Table 1. **Variables used in piping analysis**

Variable	Description	Constant over segment
D_0	Thickness of aquifer	No
D	Thickness of blanket layer	No
L	Distance, waterside levee toe to landside water	No
θ	Bedding angle of sand	No
d_{70}	70th-percentile of sand grain diameter	No
η	Drag coefficient	Yes
γ_{wc}	Volumetric weight of blanket layer	No
γ_k	Volumetric weight of sand	No
m_u	Error in critical pressure difference, for uplift	Yes
m_h	Damping factor	No
m_s	Error in piping model	Yes
h_{ls}	Water level on landside of levee	Yes

Table 2. **For an observed 1/400 year water level: Prior and posterior segment fallure prohabilities for Segments 13a, 13b, and 14 computed with the BN and tehe MO method, and the system failure probabillity computed by BN, and a combination of the MO and EP methods. The ratio of prior to posterior failure probability is als given.**

Return period of observed water level: 400 years

Segment	BN Prior	BN post.	BN ratio	MO/EP prior	MO/EP post.	MO/EP ratiow
13a	6.8E-5	4.4E-5	1.6	9.0E-5	4.7E-5	1.9
13b	1.4E-3	1.2E-4	11.8	1.6E-3	1.4E-4	11.3
14	5.7E-4	1.5E-4	3.7	8.4E-4	1.8E-4	4.8
System	**1.9E-3**	**2.8E-4**	**7.0**	**2.5E-3**	**3.3E-4**	**7.5**

Table 3. **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 probabillity 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

Segment	BN Prior	BN post.	BN ratio	MO/EP prior	MO/EP post.	MO/EP ratio
13a	6.8E-5	6.6E-5	1.0	9.0E-5	6.9E5	1.3
13b	1.4E-3	5.2E-4	2.7	1.6E-3	6.1E-4	2.6
14	5.7E-4	4.6E-4	1.2	8.4E-4	5.3E-4	1.6
System	**1.9E-3**	**9.7E-4**	**2.0**	**2.5E-3**	**1.2E-4**	**2.1**

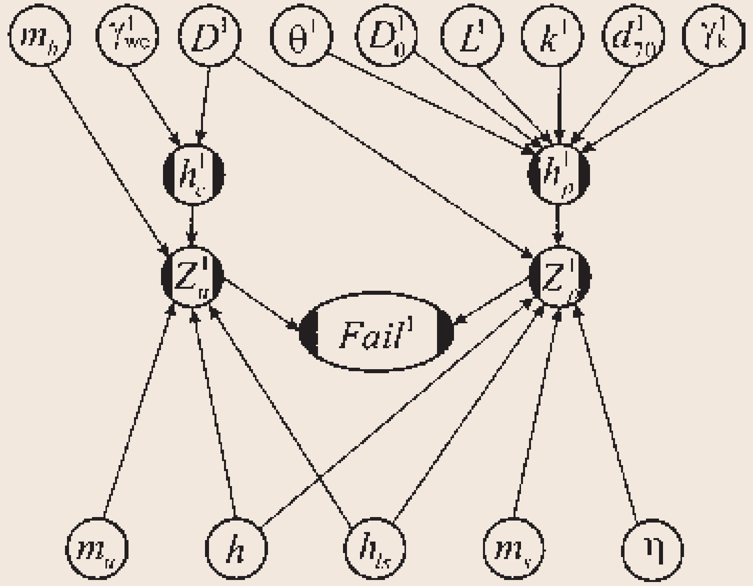


Figure 3. Bayesian network to calculate failure probability of a single cross section, due to the piping mechanism. The superscript indicates these variables are for the first cross section in the segment.

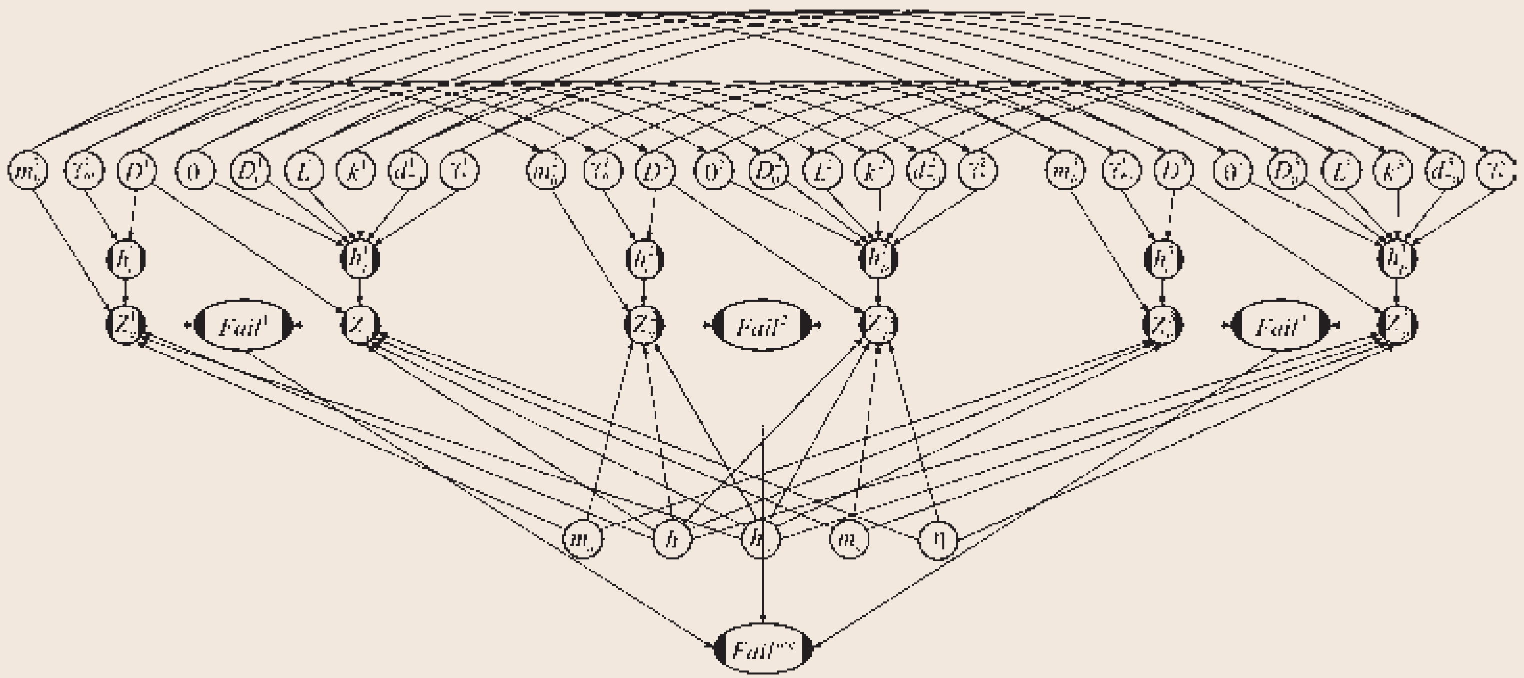


Figure 4. Bayesian network to calculate failure probability due to the piping mechanism for a levee segment represented by three cross sections. Spatially variable input random variables are shown repeated for each cross section (variable superscripts indicate cross section). Variables which are constant over the segment are shown near the bottom of the network (once for the whole segment).

Paul Hölscher

WIND TURBINES AND DIKE SAFETY

INFLUENCE OF TIME DEPENDANT LOADS AND FOCUS ON LONG TERM BEHAVIOR

Dr. ir. Paul Hölscher is a researcher at Deltares. For the STW-MFFD program he worked as a Postdoc at the faculty of Civil Engineering & Geosciences, TU Delft University of Technology in the project 'Structural assessment of multifunctional flood defenses'.

Figure 1. Wind turbines along Eastern Scheldt dike, Sint Annaland (Image courtesy Rijkswaterstaat, beeldbank, Joop van Houdt).

Dikes are attractive locations to construct wind turbines. Wind turbines can accentuate the dike as a linear element in the landscape. Dikes are often windy spots, that are accessible for construction and maintenance using the existing work road along the dike. With the construction of wind turbines on a dike, the district water board contributes to a more sustainable world.

The authorities hesitate to permit wind turbines on their dikes. A wind turbine on a dike is an additional risk for the water safety of the dike, since an accident with a wind turbine during a storm may damage the dike.

But an intact, well-functioning generate always vibrations in the soil. No structure in a dike generates many vibrations, a wind turbine generates an large number of vibrations. Knowing that resonance and fatigue are two important aspects in wind turbine design, the authorities quite reasonably ask designers to evaluate the additional risk wind turbine pose for dike safety due to their vibrations.. Do these vibrations reduce the structural integrity of a dike? If so, which additional risk reduction measures can and should be taken?

General evaluation of a dike
In the Netherlands the safety of the dikes is evaluated using comprehensive methods based on long experience and thorough study. However, vibrations are not included in these methods. How can we introduce the vibrations generated by wind turbines into these methods?

Behavior of a wind turbine
The vibrations in the foundation of a wind turbine have two sources: the wind makes the blades rotate and it also excites the natural frequencies of the structure, mainly the tower-nacelle system. At low wind speeds (those below cut out, with the rotor turning) 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 (page 52) 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 rotat-

Figure 2.
Calculated static and dynamic parts of the loading on a stiff wind turbine foundation for different wind speeds (top: static part; bottom: dynamic part).

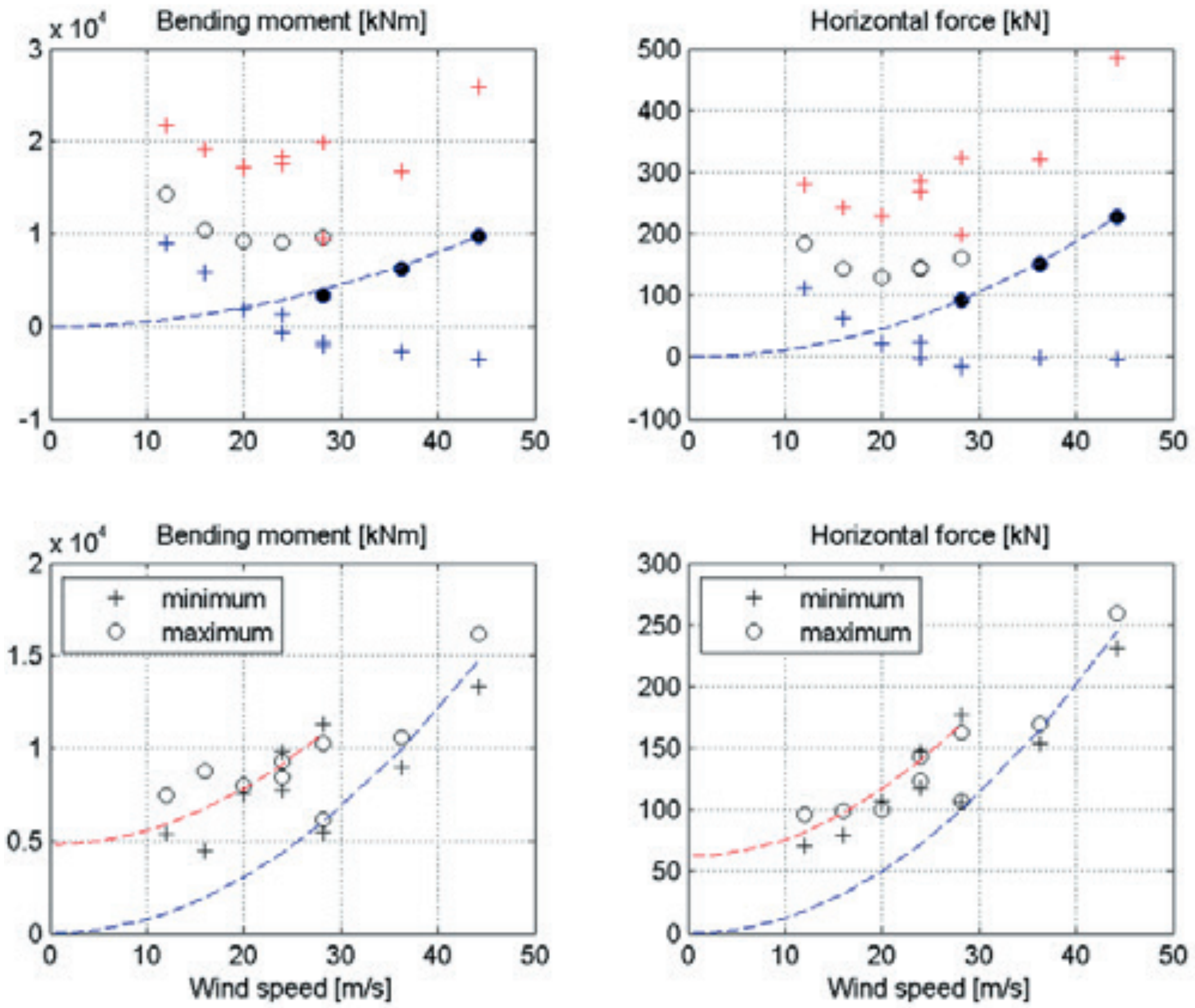
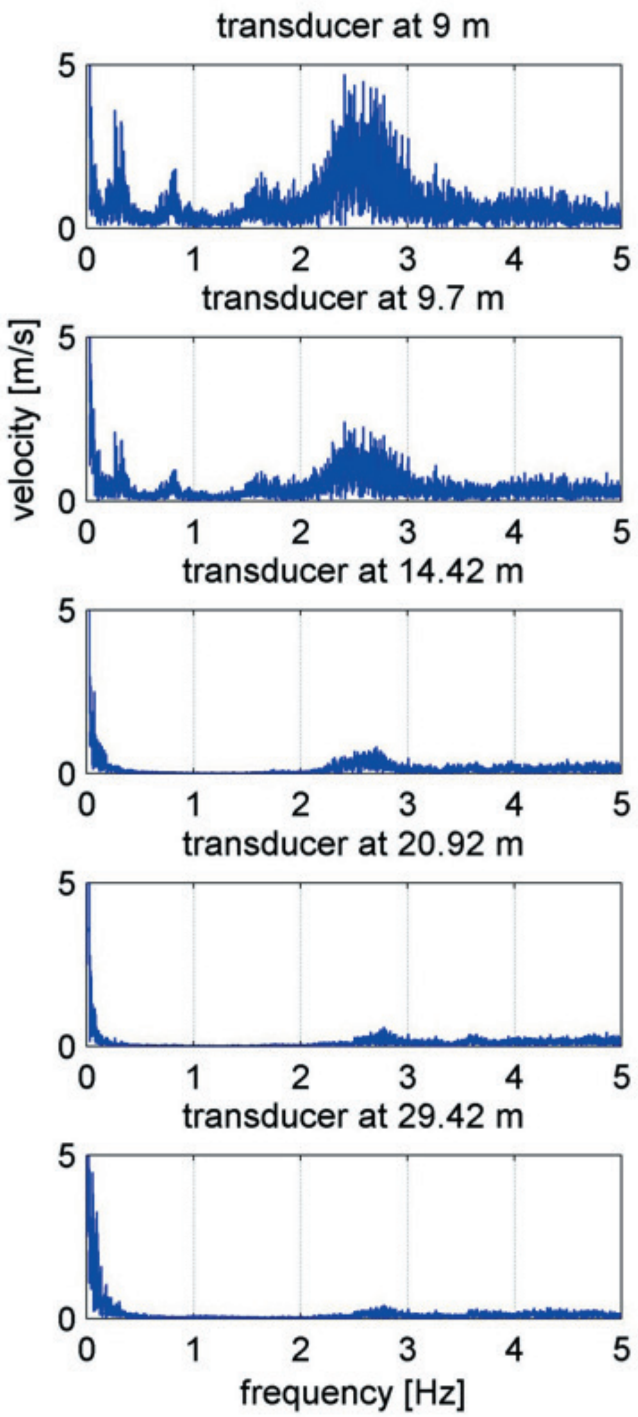


Figure 3.
Measured velocity in frequency domain at various distances from the wind turbine

In the figures for small distances (9 m and 9.7 m from the wind turbine), high thin peaks are observed at the frequencies 0.3 Hz, 0.4 Hz and 0.8 Hz.

Such a peak means that the soil vibrates with that frequencies. These peaks are not observed in the points further away from the wind turbine.

The thick peak at 2.5 Hz decreases much slower with distance. This is the vibration from the resonance of the foundation. Due to its higher frequency, it has a much wider spreading around the foundation.



ing. The measured peak acceleration was approximately 0.02 m/s². 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/s² 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.

Suzanne Hulscher

MULTIFUNCTIONAL FLOOD DEFENSES: DEALING WITH FUTURE CHANGE AND UNCERTAINTY

REFLECTION

Prof.dr. Suzanne Hulscher is full professor of Marine and Fluvial Systems, section Water Engineering and Management, Department of Civil Engineering, Faculty of Engineering Technology, University of Twente. In the STW-Multifunctional Flood Defenses research program she was promotor in the project 'Safety and reliability assessment of MFFD's'.

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. Second, requirements for the functionality of dike may change in the future: e.g. a different safely 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. We can also expect more and more intense rainfall, directly leading to changes in river discharge. These changes will affect storm and discharge loads, 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 average sea level is expected to keep rising in a nonlinear way, which has a direct effect on the coastal dike height (making it lower with respect to the main sea level) and an indirect effect on river dikes as river levels will adapt to the sea level change. On a longer timescale, from 5 to 50 years, higher sea levels will lead to changes in bed level of the river and seabed, with increased erosion affecting safety (unless countermeasures are taken).

Indirect changes are related to adaptations in water systems elsewhere. For example, the outflow 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 tidal pattern. Coastal locations will face significant changes in tidal range, which might be lower or higher. Large-scale land reclamation 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 North Holland and Friesland. However, as it turned out, car transport grew much faster than foreseen. 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.

Figure 1. Afsluitdijk (Closure Dike). (Photo courtesy Rijkswaterstaat beeldbank, Joop van Houdt).

Han Vrijling

MULTIFUNCTIONAL FLOOD DEFENSES: TECHNICAL DESIGN PROBLEM OR POLICY CHALLENGE?

REFLECTION

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

Over the ages delta areas have greatly benefitted 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 deltas 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 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 systems - first built in London in the 19th century - which facilitated city transport unbelievably. These underground technologies were the first to show the way to the 'multiple use' of space, which is necessary to keep cities pleasant to live in and economically successful.

History has also shown that flood protection is economically beneficial, not withstanding its cost. The slow recovery of New Orleans after Hurricane Katrina provides empirical evidence to support this theoretical analysis (Dupuits, 2017).

Ever higher and safer flood defenses have to be built in ever denser cityscapes or in ever scarcer nature reserves. This dilemma has to be solved by the 'multiple use' of space. This means that flood defense functions have to be integrated with functions like living, parking, recreation, transport, or amenities.

From a strictly hydraulic engineering standpoint, integrating multiple functions in a flood defense is less difficult than designing a storm surge barrier in an open estuary, because of the smaller scale, the less exposed situation and the better-known subsoil. However, if the intention is to apply multifunctional flood defenses more widely, it might be wise to clarify and standardize the design approach. A comprehensive effort to categorize the elements that are required in a proper flood defense has been made by Voorendt (2017). His overview helps to check if the function 'flood defense' is safely implemented in the multifunctional structure, and provides a basis for the probabilistic evaluation of the probability of flooding as required by law. A similar multifunctional approach can be applied to dikes situated behind environmentally valuable salt marshes (Van Loon-Steensma, 2014), although in this case the attention is shifted from the dike itself to the wave-reducing properties of the marsh.

As shown above, introducing multifunctionality seems rather simple when judged through the lens of a single scientific discipline like risk optimization, hydraulic engineering, traffic engineering, or nature conservancy. However, in real cases the difficulties mount because 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 interest groups. Moreover, each interest group 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, analyze and attempt to solve this real life problem, the specific structure of this research program was chosen (Figure 1). Horizontally, the mono-disciplinary studies are sketched, but vertically the real case studies show that all requirements have to be met for the project to come to life. It is typically the task of the civil engineer to combine all aspects simultaneously to create a solution in a single design. And although this design is usually technically quite feasible, in practice various interests seem to create problems, leading to the

Figure 1 (below). Structure of the MFFD Research Program.

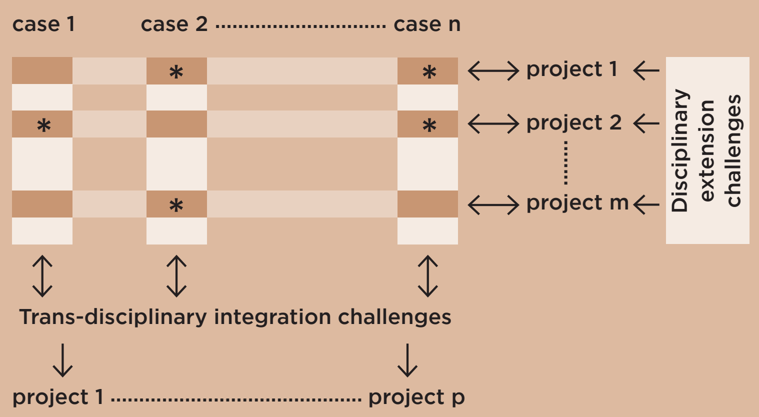


Figure 2 (below). Parking garage in dune Katwijk (Courtesy RWS beeldbank, Maarten van Rijn).

Figures 3 & 4. (below below). Urban flood defense construction along Rhine river, Dusseldorf, Germany; including car traffic tunnel and multi-functional promenade (Image courtesy Google Earth).

choice of less efficient solutions. The case study in Katwijk (see Figure 2, and Voorendt page 24-25 and Anvarifar page 90-93) shows one aspect of the problem. From a technical point of view, the two functions 'flood defense' 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 requirements 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 reasons that this seemingly simple problem was not solved could not be identified.

Another example of a less efficient solution is the design of the Dakpark (Roof Park), an attractive shopping mall that looks like a dike (see Program Case pp. 166-183). 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.

Less efficient solutions seem to be chosen due to the specific planning paths 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 can thus lead to the abandonment of the optimal multifunctional project. This problem needs attention, and all the concerned parties need to communicate openly in order to provide society with the solutions it needs to attain the highest level of welfare.

TWO | **DESIGN & PLANNING**

Figure 1. High water in the historic port area of Dordrecht (photo courtesy Dordrecht beeld-bank).

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

LOOKING FOR ADAPTIVE CAPACITY IN DORDRECHT

INTERVIEW

Ir. Berry Gersonius is an expert on flood safety and stormwater for the City of Dordrecht. He is also a member of the MIRT 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 and opportunities of MFFD's'. Berry was part of the user committees of Flora Anvarifar, who researched flexibility, and of Peter van Veelen, who developed a tool for adaptive flood risk management.

How would 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 overflow. 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 could 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 up 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 houses is built directly against the dike, just below the crest. In the past, the dike was strengthened with a technical intervention that is truly integrated: foundation and design of a number of houses are part of the dike."

What specific kind of knowledge is needed for integral design of a multifunctional flood defense?
"For the Voorstraat we still need knowledge to incorporate the reliability of the stop log system into the statitury 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 a protocol: how do you execute the closure in practice? And you need to know howthis protocol positively influences the closure reliability. Is other words: How to 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 Anvarifar. 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 multifunctionality, but especially at the Noordendijk where the functions are fully integrated. It's a very attractive architectural design 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 a 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 Veelen's adaptation strategy research was relevant, and he 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 2100, we'll have to decide whether individual solutions are sufficient to be able to live in this area. Or would it be it better to opt for other solutions, such as replacing 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? So that we can reassure 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 his adaptation model is a useful tool to do so."

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).

Mark Voorendt

A METHOD FOR INTEGRATED AND SUSTAINABLE DESIGN

FIVE DESIGN STAGES

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 defences.'

PhD Supervisor:
Prof.drs.ir. 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 their 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 fulfils 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 enables 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.

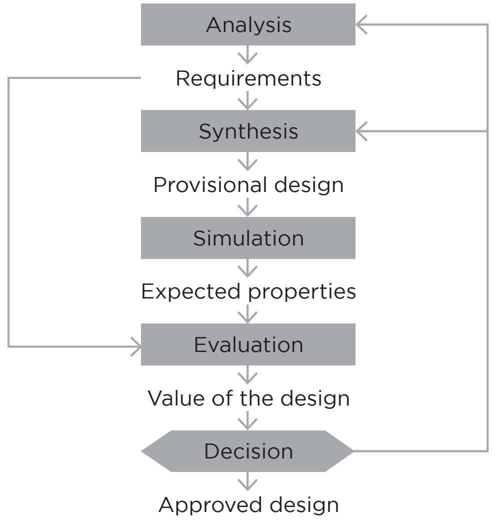


Figure 3. The Roozenburg and Eekels model of the design cycle (Roozenburg and Eekels, 1995)

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

Figure 4.
MFFD Kampen, touristic walkway integrated in flood defense structure (photo courtesy Mark Voorendt)

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 fulfil 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).

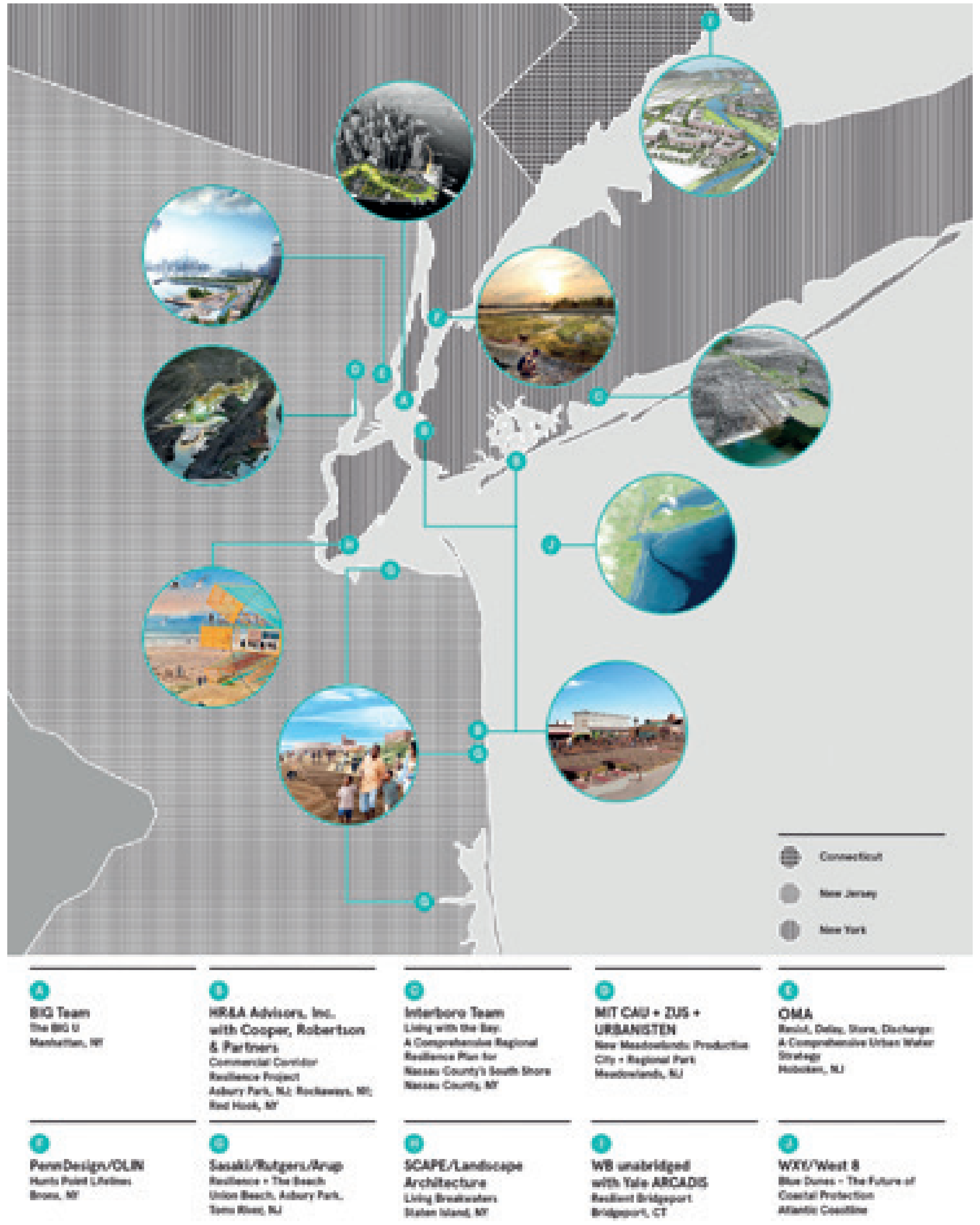
5. Decision
The alternative with the highest value-cost ratio could possibly be enhanced by adding strong elements from other alternatives, and possibly by adding values. The optimal variant can now be proposed to the client. If the client approves, the 'winning' alternative can be detailed in another 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 monodisciplinary 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 design 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.

Figure 1. Overview of the 10 Rebuild by Design competition finalists (Rebuild by Design (2015: 64)).



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. This new 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-sector, cross-professional collaboration, and iterative design development. Rebuild by Design gathered the talent of the world to work with the local talent of the Sandy-affected region. From 148 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

MATERIALIZING THOUGHT

THE ROLE OF VISUAL REPRESENTATIONS IN PARTICIPATORY MFFD DESIGN PROCESSES

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

PhD Supervisors:
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Research through designing
A landscape architect conducts research through designing (Lenzholzer, Duchhart, & 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 innovation: 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, 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 jagged 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.

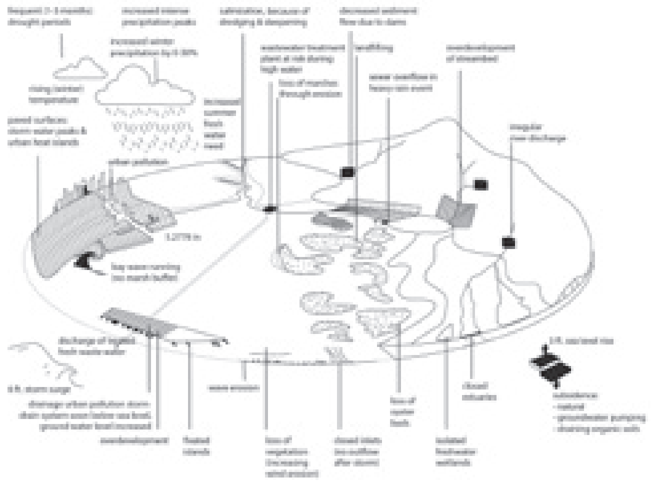
To facilitate such processes, landscape architects apply a range of visual tools, techniques and styles. Information is gathered, shared, documented and analyzed; ideas are formed, experimented with, criticized, praised, developed further or taken apart completely - all by means of visual representation. Such a range of communicative functions requires a range of visual representation techniques (Raaphorst, Duchhart, van der Knaap, Roeleveld, & 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 representation 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 content, 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 be sensitive to stakeholders' backgrounds, both their personal and professional frames, and understand how visual techniques function, and which are appropriate in a given context.

Figure 2 (right). 'Readability', what do you see: a specific depiction of the study area, or a re-designed flood defence landscape? (Rebuild by Design, 2015, p. 120) (© MIT-CAU + ZUS + URBANISTEN)

Figure 3 (below left). 'Interactivity', scale model in a presentation hall invites discussion. (Rebuild by Design 2015, p. 115) (© MIT-CAU + ZUS + URBANISTEN)

Figure 4 (below right). 'Validity', Schematic drawing with captures that explains the design challenges from a landscape system perspective. (Rebuild by Design, 2015, p. 99) (© Interboro team)



In this research project we have developed a framework that can guide a way to take into account stakeholder configurations and the role of visual techniques in participatory processes (Raaphorst 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 world
2. Readability: the visual qualities of the representation
3. Validity: the ideas embedded in the representation.

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 iterative is the design process? Are there enough occasions 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; one 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 authority. 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 discussion. 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 design's 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.

Participatory context

Stakeholders are organized according to certain levels of participation. Scientific experts contribute valuable knowledge, but rarely meet with local inhabitants. Legislators and mayors 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 designs' 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 may complement each other, but they can equally well overpower, or even contradict, each other; the balance and outcome will, of course, vary from project to project. For instance, visual techniques are not equally interactive, and can be created and interpreted differently: GIS maps can be overlaid with hand drawn sketches, photomontages can be created using photos made by local inhabitants, and 3D models can be explored at leisure with online gaming engines. Readability will also depend on the stakeholder: participants who are intimately involved with the project might understand a design without actually 'reading' it because they know the content by heart, while an outside jury of a design competition, without such involvement, will need to interpret the design's content purely on its visual and interactive merits. The validity of content will also depend on the interpreter: an engineer will consider the feasibility of the project based on mathematical calculations, a designer may appreciate a project for its visual aesthetics, and local inhabitants may worry about the sunset being hidden by a dike. All of these values contain a certain validity, which 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 acknowledging this complexity, and by creating (and interpreting) visual representations according to the three-step analytical framework built in this research, communication will be more conscious and empathic, 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 implemented as it was intended.

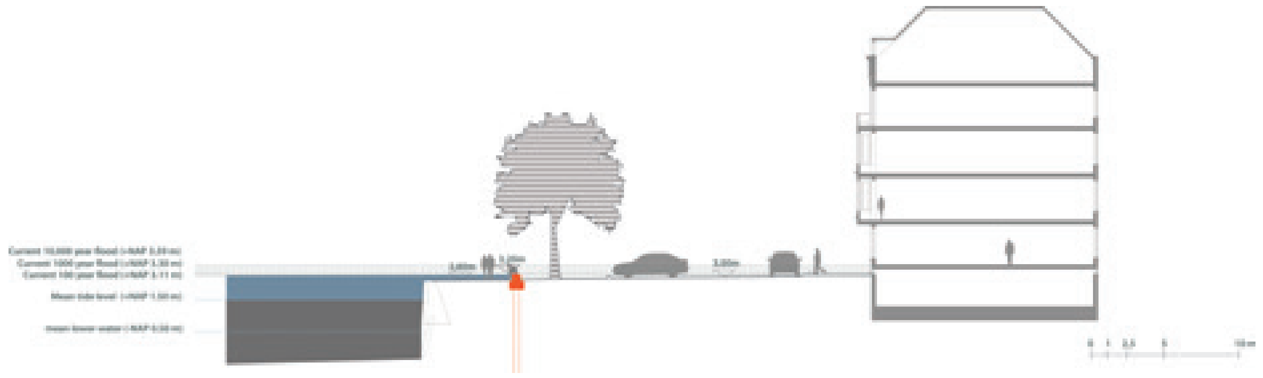


*Figure 1.
Cross section of Noordereiland: option flood protection by floodwall, small bench (image courtesy Peter van Veelen).*

*Figure 2.
Cross section of Noordereiland: option flood protection by new quay wall and sheet pile construction (image courtesy Peter van Veelen).*

*Figure 3.
Cross section of Noordereiland: option flood protection by large bench and boulevard (image courtesy Peter van Veelen).*

Peter van Veelen

ADAPTIVE PLANNING FOR RESILIENT URBAN WATERFRONTS

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*Dissertation title:
'Adaptive planning for resilient coastal waterfronts: Linking flood risk reduction with urban development in Rotterdam and New York City.'*

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

A major challenge of adapting existing coastal urban areas is that it requires anticipating long-term trends and changes that easily exceeds 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 keep 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. Therefore, the main research question of my research is twofold: "How can we adapt existing coastal urban waterfront areas to changing climatic circumstances and how can we take this adaptation process as an opportunity for creating added value?"

To answer the research question, this research applied a resilience based planning method (the Adaptive Pathways Method, see Figures 4 and 5) to develop and assess adaptation pathways at the level of neighbourhood development at two flood prone waterfront cases in Rotterdam and one in New York City. APM is a structured, iterative approach based on defining the conditions under which policy objectives are no longer attainable and adaptation is required, and the assessment of sequences of adaptation actions enabling policy makers to explore options for adapting and develop adaptive strategies. Although the APM has been successfully applied to large-scale strategic delta planning projects (e.g., 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 adaptation actions available ranging from small-scale building-to-building adaptation 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 waterfronts, 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 restraints 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 limited potential to build resilience from household redevelopment or renovation on the long run even when new complementary policies and regulative instruments that support building-level resilience would be developed. District-

Figure 4.
Adaptive Pathways Method (APM) Dynamics.

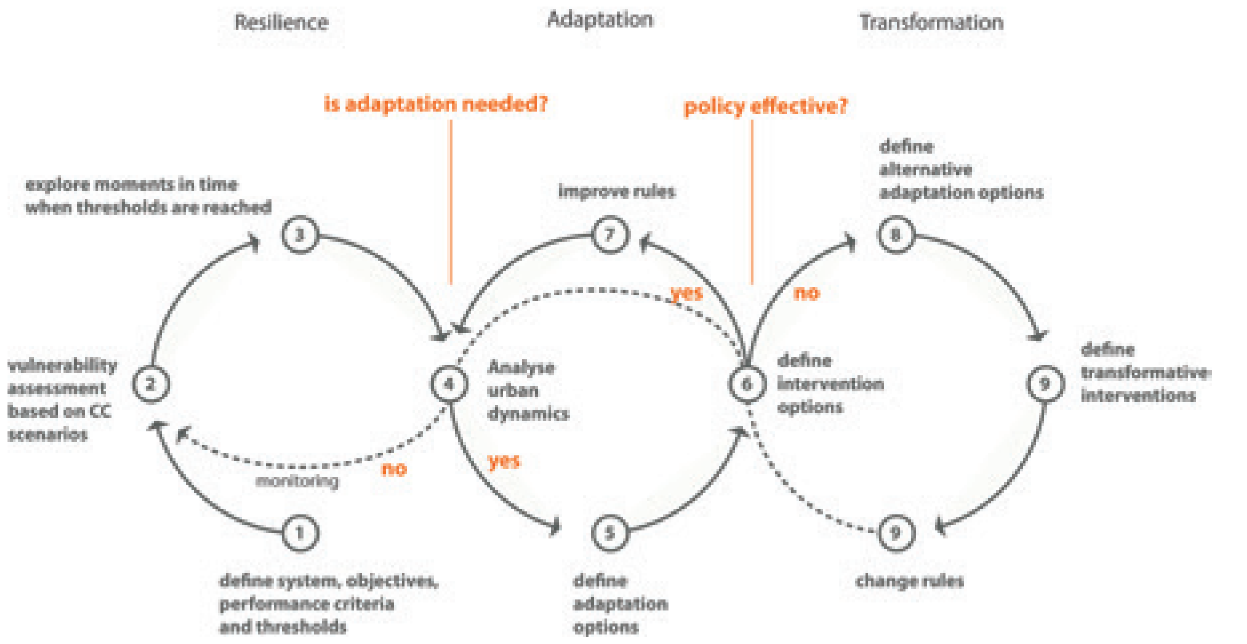
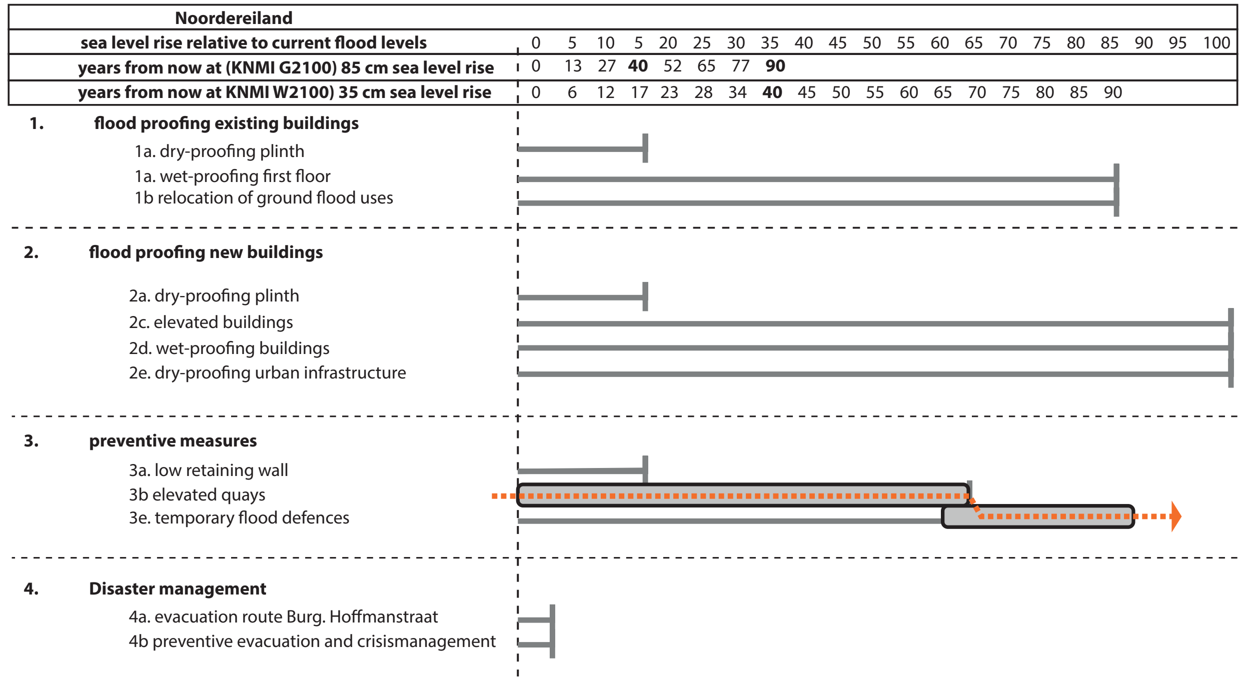


Figure 5.
Adaptive Pathways Method (APM) applied to Rotterdam flood prone neighborhood Noordereiland.



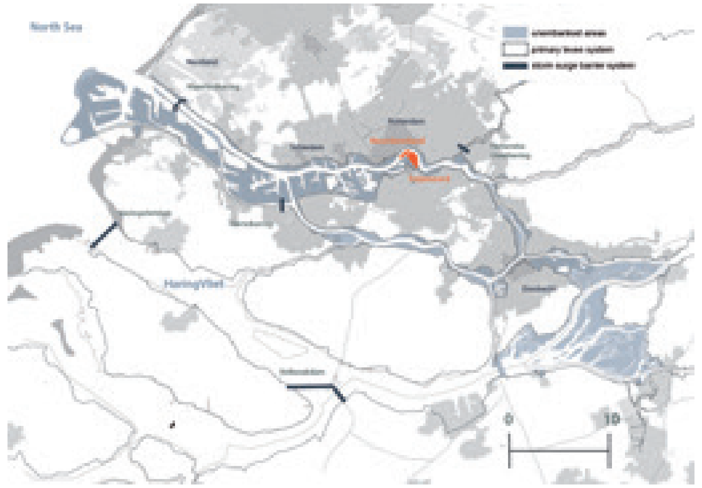
wide flood protection is effective both in terms of flood risk and is economically beneficial, but requires large-scale transformations of the waterfront zone to seize opportunities to develop integrated protection at low costs. Additionally, a multipurpose flood protection strategy often needs financial 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 effects strongly depend 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 in reality – as clearly shown in the case studies— there is no smooth transfer between alternatives. In addition to this, the method ignores the dynamic aspect of urban development, renovation and change, and opportunities for adaptation that might arise from it. For example, retrofitting wet proofing measures to buildings is less expensive when it is part of a large-scale renovation. Arguably, understanding the dynamics of urban development, redevelopment and management of urban assets and the opportunities this brings for climate resilient urban design is essential in adaptation planning.

A more effective frame, introduced in this research (Figure 5), is to build pathways based on identifying adaptation intervention points, which are defined as 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) showed that it helps to identify key interventions (e.g., spatial, legal or financial) that are needed to unlock the potential of adaptation options. The method helps bridging the gap between adaptation planning and urban development and management.



Figures 6 and 7. Case study locations in New York City (Red Hook) and Rotterdam City (Noordereiland and Feijenoord).

Peter van Veelen

CASE STUDIES: ROTTERDAM AND NEW YORK

DIFFERENT STRATEGIES TO COMMUNITY BASED ADAPTATION TO FLOOD RISK

Although storm at the North Sea produces moderate flood levels compared to the hurricane-impacted storm surge flood levels at the East Coast, Rotterdam and New York 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 slow rising storm surge flooding that causes relatively shallow and short-lived inundations.

The New York - New Jersey estuary is particularly vulnerable for storm surge flooding because of the orientation of Long Island Sound and the wedge-shaped entrance to the New York Harbor bay, which creates two natural funnels that drive sea water into the Western Sound and Upper East River, and up to the Battery in New York City during storms (Bowman et al., 2005). Also, the effects of climate change are felt more intensively at the New York City-New 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 high-energy waves and extreme water levels before it reaches the urbanised coasts.

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 discharge is a more dominant factor in waterfront flooding, particularly for the upstream cities as Dordrecht. Both metropolitan regions share the need for adapting their coastal urban waterfronts to increasing flood risks in the near future and to developing flexible strategies that allow 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 resilience and disaster management (short-term relief programmes and evacuation strategies) and recovery after a flood, less on disaster avoidance and prevention as is the dominant approach in the Netherlands.

An essential part of the US flood management strategy is the federally operated National Flood Insurance Program (NFIP). This program enables property owners in flood prone areas to insure damage of flood risk, as long as they meet the basic requirements 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 the 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 local flood risk and ignore the flood risks arising from critical systems vulnerability.

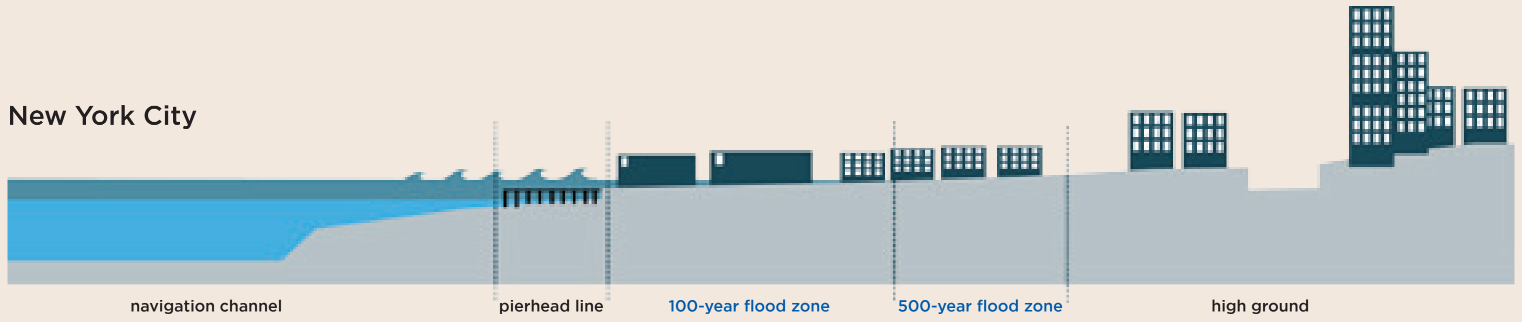
Community based adaptation
Notwithstanding the differences in response to increasing flood risk, we also see a comparative adaptation approach developing: both cities reach out to the community level.

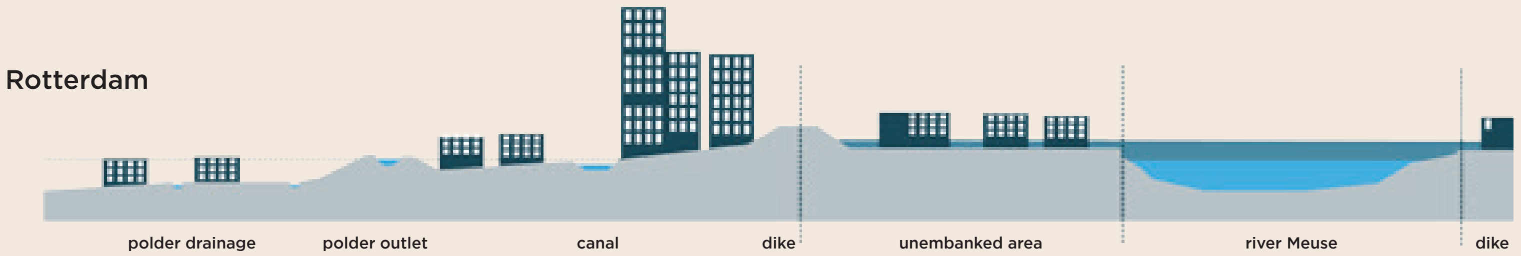
To stimulate homeowners to invest in flood resilience, the New York City Department of City Planning recently updated the zoning ordinance and the City's building codes (NYCDCP, 2013). One of the adjustments made is an extension of the opportunities to recapture lost floor space due to wet-flood proofing actions, by adding an equivalent amount of floor area to the building. Furthermore, inspired by the Rebuild by Design competition that was launched in 2013, several areas in New York currently have integrated flood-protection schemes under development. In these projects, close collaboration with the needs of the local community is sought.

In Rotterdam, alternative adaptation measures are developed as well; such as dry-proofing buildings, or district-wide flood protection integrated in urban renewal and waterfront renovation programs. The city of Rotterdam developed together with nearby city of Dordrecht a community information program to raise flood risk awareness and to stimulate homeowners to invest in flood resilience.

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

This text is an adapted version of chapter 5 of the dissertation 'Adaptive planning for resilient coastal waterfronts', Peter van Veelen (2016).





ROTTERDAM, RHINE ESTUARY REGION: A DELTA LANDSCAPE IN REVERSE

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 fluvial 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 unembanked alluvial areas that are almost entirely urbanized and not protected by the primary flood defence system. In the larger metropolitan Rijnmond-Drechtsteden region more than 2.020 ha of land is located in the 100-year flood zone between the North Sea and the city of Dordrecht (RWS, 2009), of which a large part is urbanized or in use for industrial activities. Approx. 65,000 people live in the unembanked area of some 200 ha. (Veerbeek et al., 2010).

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 next decades the risk of flooding is expected to increase due to rising sea levels and subsidence, as well because of these port areas, due to their position close to the city and river are attractive places for urban development.

NEW YORK, 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 then 2,5 m above mean sea level making these areas vulnerable to coastal flooding during major storm events (Rosenzweig et al., 2010).

The most vulnerable area for flooding is the waterfront of Lower Manhattan, including the financial and business district, but also parts of the Brooklyn waterfront, Long Island City in Queens and the coastal zones of Staten Island, Jersey City and Hoboken. In fact, about 60,000 buildings with 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 (Findlan 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 flood zone (Aerts & Botzen 2011).

New York City's population is growing and is expected to grow in the future (NYC, 2011). The city's housing strategy is encouraging growth within the existing city boundaries by intensifying neighbourhoods; encourage transit-oriented development, and transforming underutilised formerly industrial zones (NYC, 2011). Particularly the formerly industrial sites in Brooklyn along the East River and waterfront areas in Jersey City and Hoboken offer opportunities for large-scale, high-density development, most of them located in flood prone areas.

Figure 1. (below). Scheveningen boulevard (photo courtesy Trudes Heems).

Figure 2 (page 78). The 1918 Zuiderzeewet - Law for closing off the Southern Sea (source: Nieuwland Erfgoedcentrum, Lelystad).

Nikki Brand

LEGISLATION AND REGULATION IN SPATIAL PLANNING FOR MULTIFUNCTIONAL FLOOD DEFENSE DESIGN

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 STW-MFFD program she was a Postdoc in the project 'Urban design challenges and opportunities of multifunctional flood defenses'.

Can the recent rise of Dutch multifunctional flood defenses be explained by the increased integration between the water and spatial planning sectors, which compels 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 1980s, and particularly since 2000s, indicates this hypothesis to be wrong.

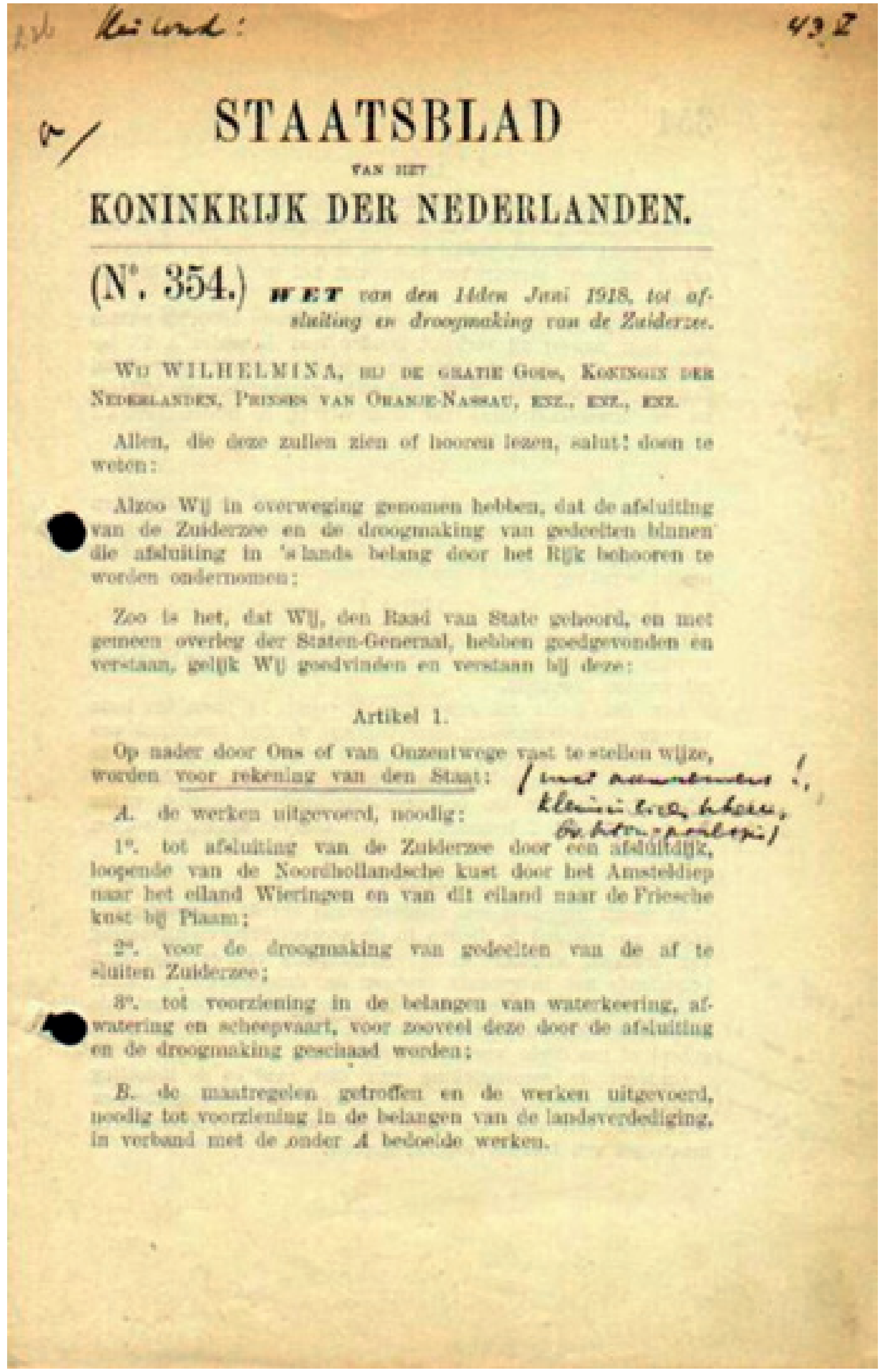
In the Netherlands, the responsibility for spatial planning is officially assigned to the three tiers of government (Kingdom, provinces and municipalities). The responsibility for water management, on the other hand, is assigned to the single-purpose authority of an independent water manager. This can be the regional Water Authority or the national agency, *Rijkswaterstaat.* The Water Authorities formally do not possess spatial planning competences. In 2003, the national policy agreement on water management in the 21st century (*Nationaal Bestuursakkoord Water 21e eeuw*) led to changes in regulation. The policy agreement aimed to safeguard space for waterstorage, a goal of the Water Authorities that required the assistance of spatial planning competences that exclusively belong to the municipality.

In theory, increased interdependency between water and spatial planning sectors could have forced Water Authorities to negotiate with municipalities. Municipalities, in exchange for accommodating the Water Authorities' needs, would expect their various interests be accommodated. 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, Katwijk'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 using 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 out the foundations for the relations between the Water Authorities with the other governmental entities of the Kingdom, the provinces and the municipalities (Driesprong, 2004). In 1850, the *Provinciewet* (Province Act) formally established that the Province should supervise flood defenses managed by regional Water Authorities. '*Waterstaatswerken*' (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 Waterstaatswerken* (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 the time, the municipality had no official role in water management, though local governments were authorized to regulate land use in the 1960s. 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 1900 *Waterstaatswet* (National Water Works Act).



STAATSBLAD

VAN HET

KONINKRIJK DER NEDERLANDEN.

(N°. 354.) *WET van den 14den Juni 1918, tot afsluiting en droogmaking van de Zuiderzee.*

WIJ WILHELMINA, BIJ DE GRATIE GODS, KONINGIN DER NEDERLANDEN, PRINSES VAN ORANJE-NASSAU, ENZ., ENZ., ENZ.

Allen, die deze zullen zien of hooren lezen, salut! doen te weten:

Alzoo Wij in overweging genomen hebben, dat de afsluiting van de Zuiderzee en de droogmaking van gedeelten binnen die afsluiting in 's lands belang door het Rijk behooren te worden ondernomen:

Zoo is het, dat Wij, den Raad van State gehoord, en met gemeen overleg der Staten-Generaal, hebben goedgevonden en verstaan, gelijk Wij goedvinden en verstaan bij deze:

Artikel 1.

Op nader door Ons of van Onzentwege vast te stellen wijze, worden voor rekening van den Staat:

A. de werken uitgevoerd, noodig:

1°. tot afsluiting van de Zuiderzee door een afsluitdijk, loopende van de Noordhollandsche kust door het Amsteldiep naar het eiland Wieringen en van dit eiland naar de Friesche kust bij Piaam;

2°. voor de droogmaking van gedeelten van de af te sluiten Zuiderzee;

3°. tot voorziening in de belangen van waterkeering, afwatering en scheepvaart, voor zooveel deze door de afsluiting en de droogmaking geschaad worden;

B. de maatregelen getroffen en de werken uitgevoerd, noodig tot voorziening in de belangen van de landsverdediging, in verband met de onder *A* bedoelde werken.

Relations between the different government entities and their responsibilities remained unchanged in the first sixty years of the 20th century. The 1921 *Zuiderzeewet* (Southern Sea Act) and the 1958 *Deltawet* (Delta Act) were both executive laws, enabling the construction of the Dutch grand feats of engineering: the Zuiderzee Works and the Delta Works. Both acts were rescinded in 2005, well after the works were completed. The 1968 *Wet op de Ruimtelijke Ordening* (Spatial Planning Act) represented a change, though at the time it did not affect water management. The act permitted the government to intervene in societal developments that had a spatial dimension, balancing and coordinating spatial claims in designated land uses (Driesprong, 2004). These land uses were to be recorded in mandatory land use plans, issued solely by the municipality (Hobma & Schutte-Postma, 2010). The act focused primarily on the procedures to be followed in spatial planning, and established a hierarchy of plans. Within the plan hierarchy only the local land use plan was binding for citizens. The local land use plan had to be adapted to the spatial or single-issue policy documents of higher-tier authorities.

Up until the late 1980s, spatial planning and water management developed separately; they were yet to integrate. In the 1990s, a revolution in flood safety and water management legislation took place. The construction and management of flood defenses was addressed in a series of Acts like the 1992 *Waterschapswet* (Water Authority Act), 1995 *Deltawet Grote Rivieren* (Delta Act Large Rivers), 1996 *Wet op de Waterkering* (Flood Defense Act), complemented by *Derde Nota Waterhuishouding*, 1989, and *Vierde Nota Waterhuishouding*, 1998 (the third and fourth Memoranda on Water Management) (Driesprong, 2004). The Flood Defense Act introduced a number of concepts that remain central to contemporary Dutch water management: the difference between primary and regional flood defenses, the introduction of national dike-rings with designated safety standards, the Basic Coastline, national hydraulic boundary conditions, and mandatory reporting by both *Rijkswaterstaat* and the Water Authorities.

Taken together, these acts had a significant impact on the relations between municipality and water manager: while the organization and obligations of the Water Authorities were increasingly regulated (limiting their independence since the 1993 Act), water managers could evade mandatory procedures regarding consultation and objections, directly issuing permits when flood defenses had to be strengthened, using the regulations from 1992 and 1995. The 1995 act regarding the large rivers, and the 1996 act addressing flood defense, both responded to the near-flood events in the early 1990s. High water on the Maas River demanded the evacuation of many citizens, and prompted awareness that flood defenses had to be strengthened to prepare for an emergency. The 1995 and 1996 acts formalized this quick route, which permitted lengthy spatial planning procedures to be skipped. The 1992 Water Authority Act stated that the Water Authority could issue requirements and prohibitions, using a policy known as the '*keur*'. In practice, the *keur* provided a legal tool with which Water Authorities could regulate land use in three spatial zones on and surrounding flood defenses. This tool was to guarantee that any new structures in these three zones would not jeopardize the integrity of the flood defense, nor the possibilities to broaden the structure in the future, should the need arise (Stowa, 2011, 2016).

Thus, the 1992 act gave Water Authorities a tool that *Rijkswaterstaat* had possessed since 1891, whereas they had previously had to rely (at least in theory) on the municipal land use plan. Anyone wanting to build anything on or 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 assumption, by the end of the twentieth century regulations strengthened the water manager's authority over land use on and near 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, in turn, increased the ability of water managers to influence spatial plans to accommodate their goals. First, in 2001, the *Bestuurlijke Notitie Watertoets* (Administrative Memorandum 'Water Assessment') made consulting water managers when drafting land use plans mandatory. Second, there has been a clear move towards simplifying and integrating regulation into a few comprehensive acts. In 2005, the Waterwet (Water Act) replaced the Water Authority Act, the Flood Defense Act and the Delta Act on the large rivers. The Water Act also formalized the 2001 requirement to consult water managers during the design of spatial plans, and introduced a variety of bureaucratic documents enabling collaboration between different governmental agencies. For the spatial planning sector, the 2008 *Wet op de ruimtelijke ordening* (Spatial planning act) and the 2011 *Besluit algemene regels ruimtelijke ordening* (Decree general regulations for spatial planning, also known as 'Barro') aimed to simplify procedures, by combining different permit systems. The permit systems of the water manager and the municipality were merged into the single *omgevingsvergunning* (environmental permit). Barro also requires the protection zones of primary flood defenses to be translated into land use plans.

Concluding remarks

The exploration of the changed dependency between water managers on the one hand and the municipality on the other does not confirm the hypothesis of an increasingly dependent water board that has to compromise in order to use municipal planning competences. Rather, water managers have used provisions in the new acts to become increasingly independent from municipalities. While these provisions require that water managers be consulted in spatial procedures, other provisions offer the opportunity to bypass the municipalities' powers when flood safety may be compromised. Spatial tools within the land use plan add another layer of spatial protection to the integrity of flood defenses. An example is the mandatory translation of protection zones into zoning overlays (*dubbelbestemming*). Originally these were only protected by the assessment process of the permit system.

What factors have been decisive for the rise of multifunctional flood defenses in the first fifteen years of the new millennium remains out of scope. It could be that lack of space in Dutch waterfronts has encouraged the combination of functions at sites that used to accommodate only one function, flood safety. It is also possible that multifunctional uses of flood defenses have been made explicit - as is the case with the Scheveningen Boulevard. However, a broader phenomenon could also be at work: the weakening of Modernism as the defining way of looking at the world around us (Janssen et al., 2014).

Modernist planning and architecture have been associated with functionality, uniformity and separation of functions. This was not only the case with spatial designs, but the way government was organized, with different ministries pursuing separate goals (Meyer et al., 2014). Although modernist thinking was challenged by the late 1970s democratization movement (Janssen et al., 2014), the shift in paradigm seems to have become more pronounced in the new millennium (Meyer et al., 2014). This is partly due to a growing awareness of quality and the environment we live in (Janssen et al., 2014), but also a movement towards plurality. In an interview about the planning process of flood defenses, a water manager at the Delfland Water Authority stated: "We do not accommodate multiple interests because it's mandatory, but because it is the right thing to do." Maybe, instead of looking at regulatory issues and the integration of water interests into spatial regulation, we should consider the recent rise of multifunctional flood defenses in the context of this larger phenomenon of increasing interaction and plurality.

Figure 1. Extensive salt marshes along the Wadden Sea dikes (Image courtesy Jantsje van Loon-Steensma).

Jantsje van Loon-Steensma

INTEGRATING SALT MARSH FORELAND INTO THE DIKE DESIGN

A WINDOW OF OPPORTUNITY FOR A SELF-MAINTAINING LEVEE

Dr. ir. Jantsje van Loon-Steensma is a researcher and lecturer of Climate Change and Flood Protection in the department of Enviromental 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 spatial quality'. Her research focuses on climate adaptation by integrating functions in flood defenses. She combines hydraulic, ecological, geographical and economical aspects in the search for climate proof, robust flood defenses that in addition to flood protection, also favor nature, landscape, heritage, recreation or economic values.

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 high 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). Salt marsh plants can thus be understood as eco-engineers, as organisms that physically change the abiotic environment (Jones et al. 1994; Hastings et al. 2007).

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 Goor 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 dikes 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

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

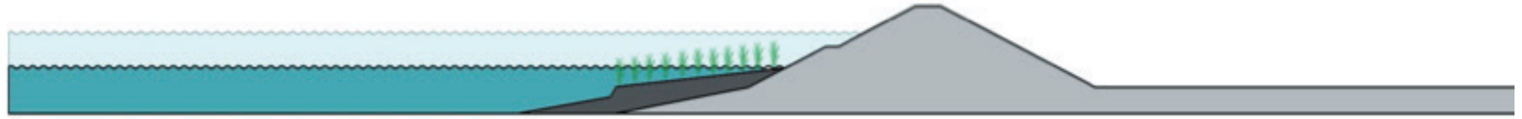


Figure 3. (above). Coastal defense system combining hard engineered infrastructure (a dike) with an adjacent dynamic ecological zone (a salt marsh) (Source: Van Loon-Steensma et al. 2014).

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 5–10 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 multifunctional flood defence 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 differences 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 will 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 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.

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 defenses' (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. Furthermore, the thesis reveals that in salt marsh restoration, the goals of flood protection and nature and habitat conservation can be mutually reinforcing.

Figure 1. Methodology.

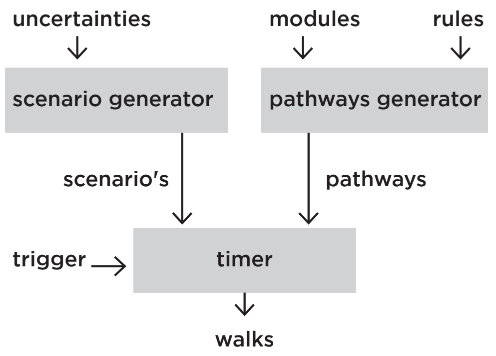
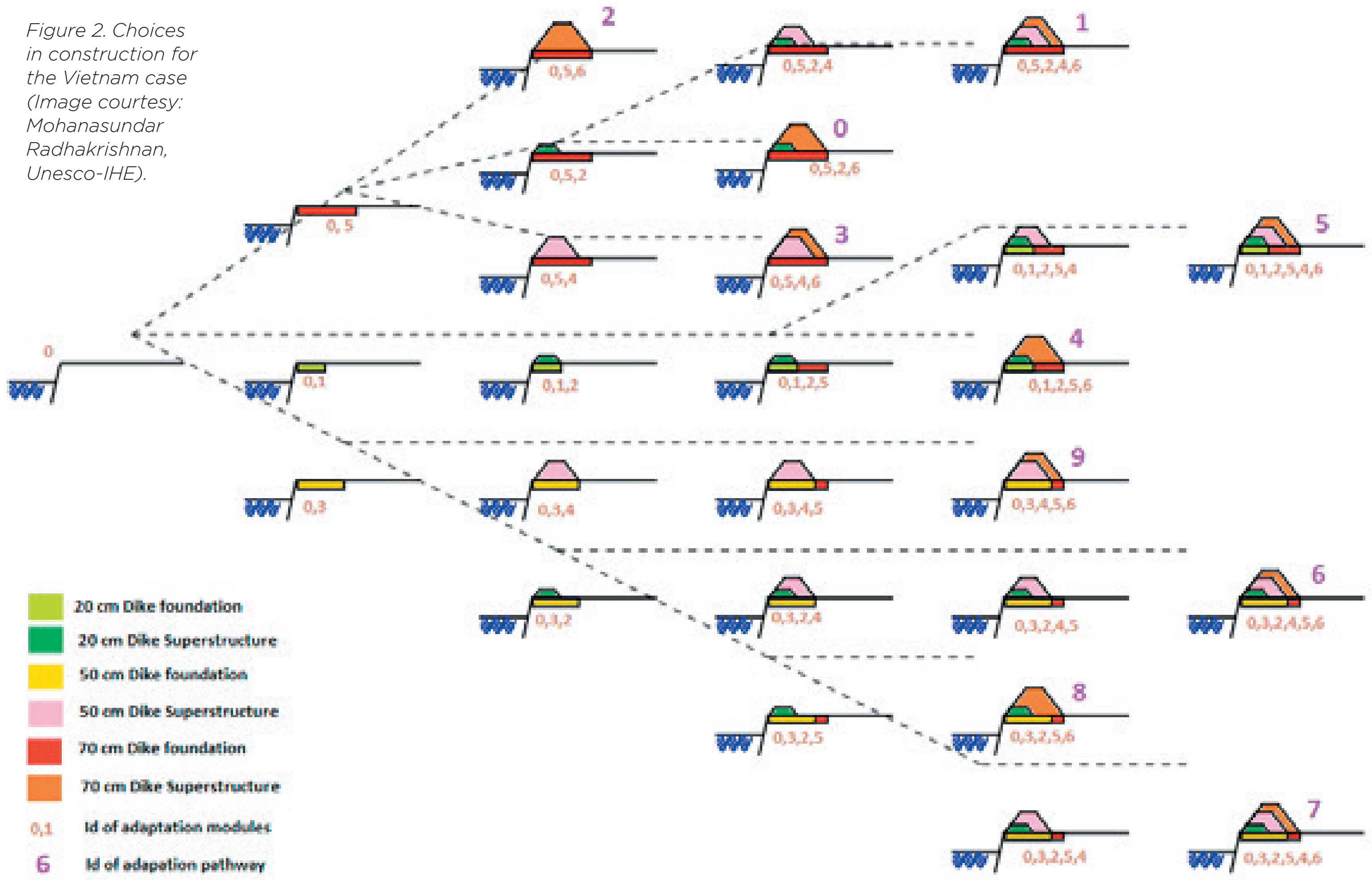


Figure 2. Choices in construction for the Vietnam case (Image courtesy: Mohanasundar Radhakrishnan, Unesco-IHE).



Tushith Islam

PARING FLEXIBLE INFRASTRUCTURE WITH ADAPTIVE PLANNING

CASE STUDY: CAN THO, VIETNAM

Dr. Tushith Islam was a Postdoc at the faculty of Technology, Policy and Management, Delft University of Technology. For the MFFD program he was part of the project 'Integrated design. Adaptivity and Robustness'.

The large-scale deployment and maintenance of infrastructure 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 preplanned adaption opens the door for new forms of infrastructure systems. This is in contrast with the current ad-hoc adaptation techniques. With simulation and robust optimization methods, it is possible to create policies that attempt to meet the multitude of values and constraints of stakeholders, with a possibility of minimizing costs in the long term (Haasnoot et al. 2013). To date, real options analysis (ROA) has been one of the leading methods for adaptive decision-making.

The application of the state of the art in ROA faces difficulties on two fronts (Neufville et al. 2006):

1. 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, if not impossible to sell.
2. Sourcing the probability information for constructing the aforementioned decision trees is difficult, if not impossible.

Furthermore, the exercising of one 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 use of modular systems for strategic planning of infrastructure systems, while addressing the need for simplifying 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 2016 until 2100 with an annual time step for the analysis (river level simulations are monthly). The exogenous scenarios used in the application are: sea level rise and gross domestic product growth percentage.

The sea level rise scenarios are combined with historic river level variation to generate potential river level futures. A transformation factor of .74 is used to transform the potential rise in sea level to river level (Wassmann et. al. 2004). The historic data is decomposed into an underlying (and rising) trend, seasonal variation, and residual noise. The trend can in turn be decomposed (using a hilbert-huang transform), into a smoother sigmoid, and a pair of chaotic oscillations. As no compelling causal explanation or regression was found for the noise or the oscillations, the curves were combined, and are used as a lookup table for generating the noise component of the future scenarios.

The GDP growth percentage data is from OECD and IIASA free data sources. The sea level rise scenarios are sourced from the latest IPCC report on the south east Asia region. The pathways of modules (the choices in construction) are visualized in Figure 2. There are six different modules under inspection of two categories; three different foundation sizes, and their associated dike heightening (50 cm, 70cm 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 values 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.'

Figure 1 (below).
Vlissingen boulevard
(Photo courtesy:
Baukje Kothuis).

Fatema (Flora) Anvarifar

CONCEPTUALIZING FLEXIBILITY FOR MULTIFUNCTIONAL FLOOD DEFENSES

Ir. Fatema (Flora) Anvarifar is a PhD candidate at Delft University of Technology, faculty of Civil Engineering & Geosciences, department of Hydraulic Engineering. In the STW-MFFD program she is part of the project 'Integrated design: Adaptivity and Robustness'. Flora is expected to graduate in 2017.

Tentative dissertation title:
'Towards flexibility in the design and management of multifunctional flood defences.'

PhD Supervisors:
Prof.dr. Wil Thissen, TU Delft
Prof.dr. Chris Zevenbergen, UNESCO-IHE

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 defenses. Often, flood defense 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 the conflict between flood protection and urbanization is by combining activities in the available space. This can be achieved by integrating urban functions into the flood defenses; these are referred to as multifunctional flood defenses.

Multifunctional flood defenses 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 defenses 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 defenses 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 thus how we can increase the flexibility of multifunctional flood defenses.

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 aimed at enhancing the consistency and clarity in discussing, identifying and evaluating flexibility for multifunctional flood defenses. 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 establishes the motivation for consideration of flexibility. This can be done by identifying the type of *change* (internal or external to the system) and *uncertainty* (e.g., 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 be specified as the *goal* of flexibility consideration (to handle the downsides or upsides of uncertainty) and the *capabilities* of flexibility to achieve its goal (via time, 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).

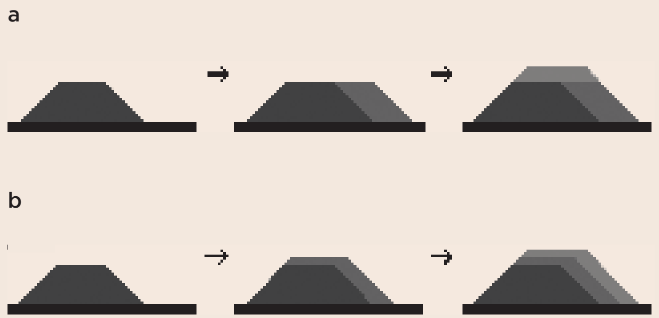
Q4. *What needs to change or be adapted?*
This question discusses the potential ways of achieving flexibility. In this research, flexibility *types* (or managerial flexibility) indicate the managerial actions and decisions that should be taken to consider and use flexibility while flexibility *enablers*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

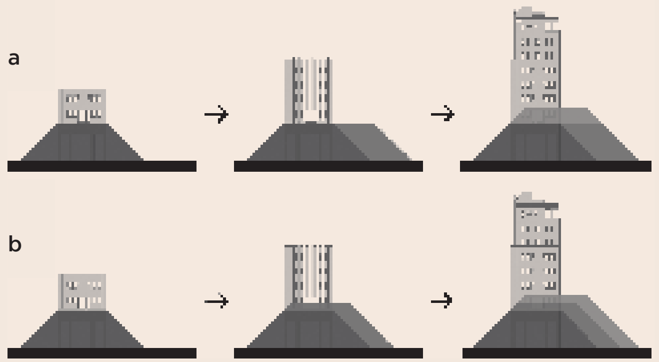
The functionality and potential of this framework is explored in an illustrative case study in Vlissingen, where a series of buildings have been constructed on top of a sea dike (see pp. 86-87). Full explanation of the framework can be found in Anvarifar et al.(2016).

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





Fatema (Flora) Anvarifar

CASE STUDY: VLISSINGEN

CONCEPTUALIZING FLEXIBILITY

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.

In this case study we have found that the framework provides a useful way to structure the discussion of flexibility for multifunctional flood defenses. This is particularly important for the designers and managers of the flood defense since the framework provides a common ground, which allows specialists from different disciplines to communicate about uncertainty and flexibility. The framework's clearly defined and consistent terms provide a common ground for discussing uncertainty and flexibility among the stakeholders involved in the design and management of multifunctional flood defenses. Additionally, the framework makes it possible to identify the areas of flexibility that need more attention and discussion. Using the framework, the challenge of increasing flexibility while combining functions becomes tractable.

The text on pages 86-89 of this volume is an adapted version of a journal article that extensively explains the frame work and the Vlisssingen case study: Anvarifar, F., Zevenbergen, C., Thissen, W., & Islam, T. (2016). Understanding flexibility for multifunctional flood defences: a conceptual framework. Journal of Water and Climate Change, 7(3), 467-484.

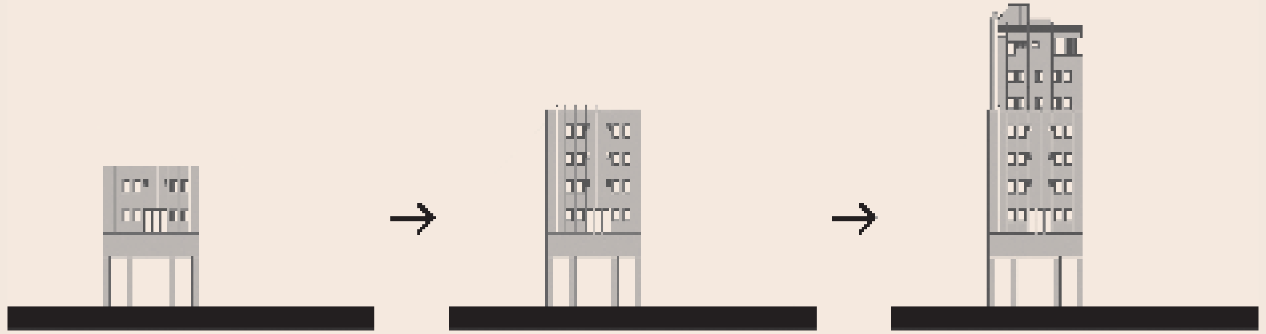
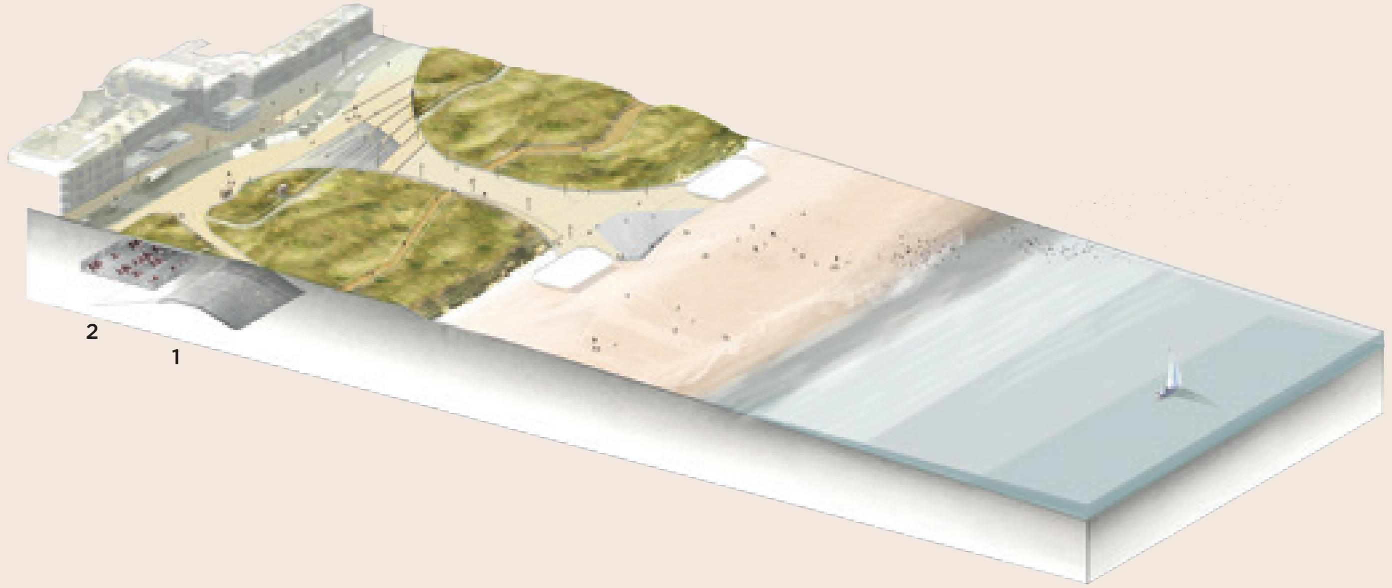
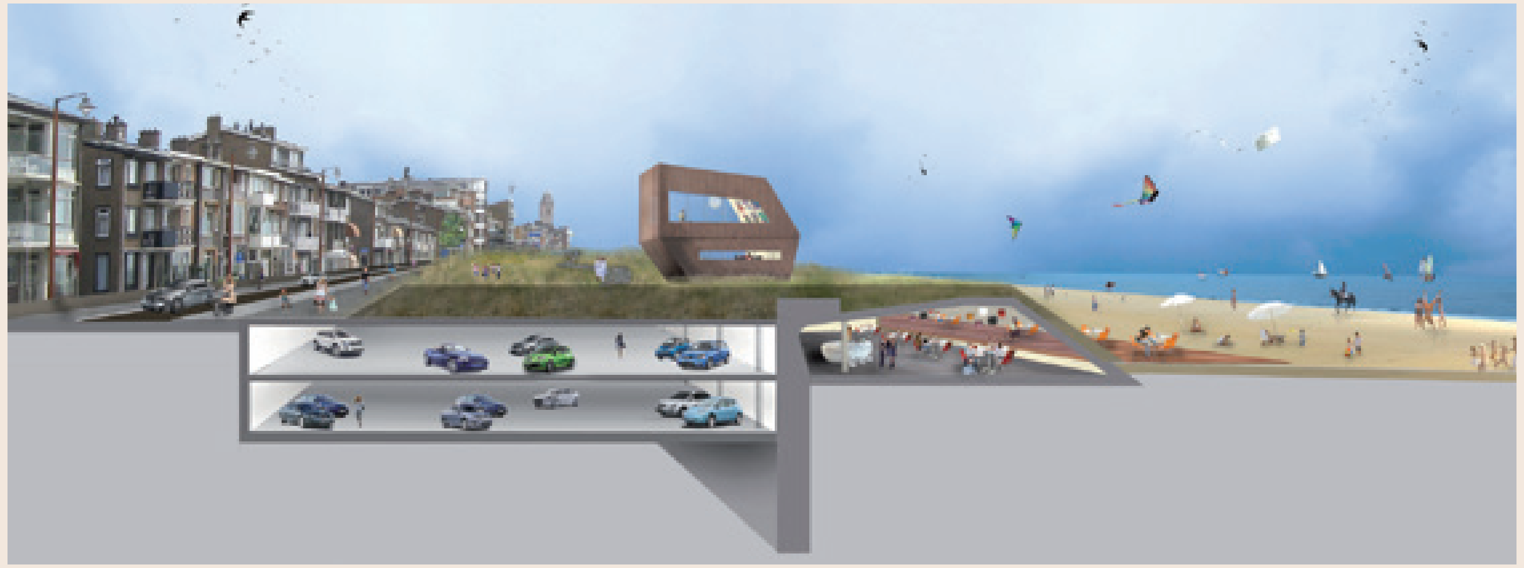


Figure 4. One possibility for enabling the option to expand the number of floors of the buildings.

Figure 1 (below). The first plan for an integral flood defense in Katwijk, including a co-located sea dike (#1) and parking garage (#2) (Image courtesy OKRA Landschapsarchitecten)

Figure 2 (below below). The second plan comprising a co-located parking garage, flood wall and restaurant (CURNET, Multi-waterwerken 2011).





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 4000 people living in the city centre. The dune-covered coastline near the town is a tourist area that lacks sufficient 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 interdepencies 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 for example a parking garage and/or restauarnt, 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-technical 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, 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 use of flood defenses, 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 functions of a multifunctional flood system and their interdependencies:

Step 1. Identifying and describing the functions.
Step 2. Generating the scenario
Step 3. Characterising the performance variability
Step 4. Identifying the potential impacts
Step 5. Synthesising 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 involved constructing a parking garage along with a new sea dike. The parking garage and the 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).

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.

Description of cases 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 tightly connected structures, with the restaurant and parking garage sharing a 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.

Figure 3. The cross sections of cases A1 and A2, in which the parking garage is located in the land-side of the dike.

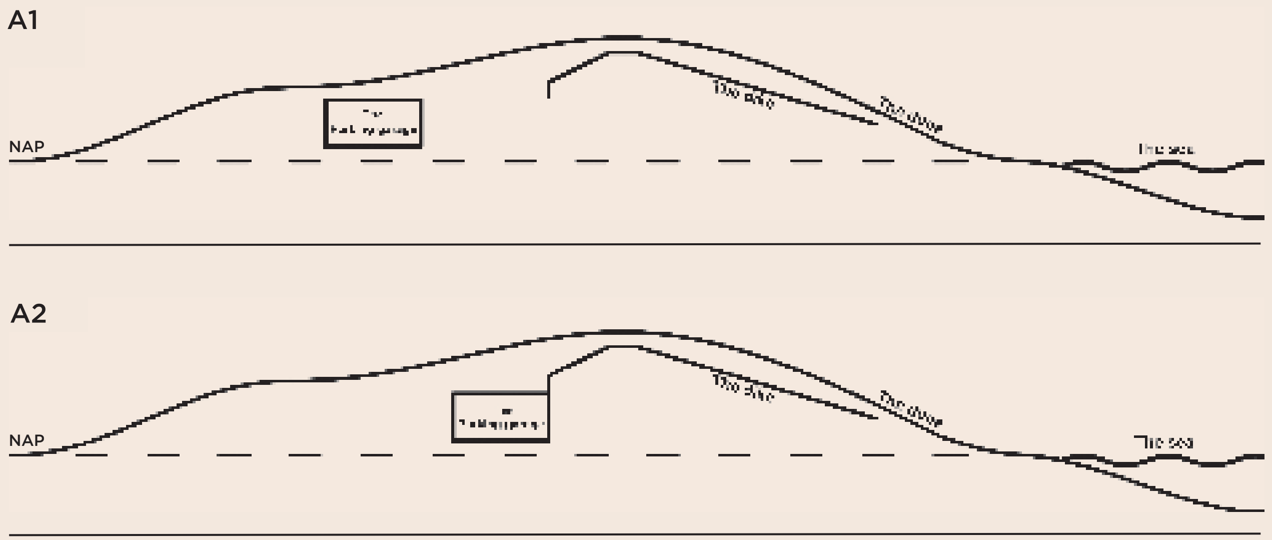
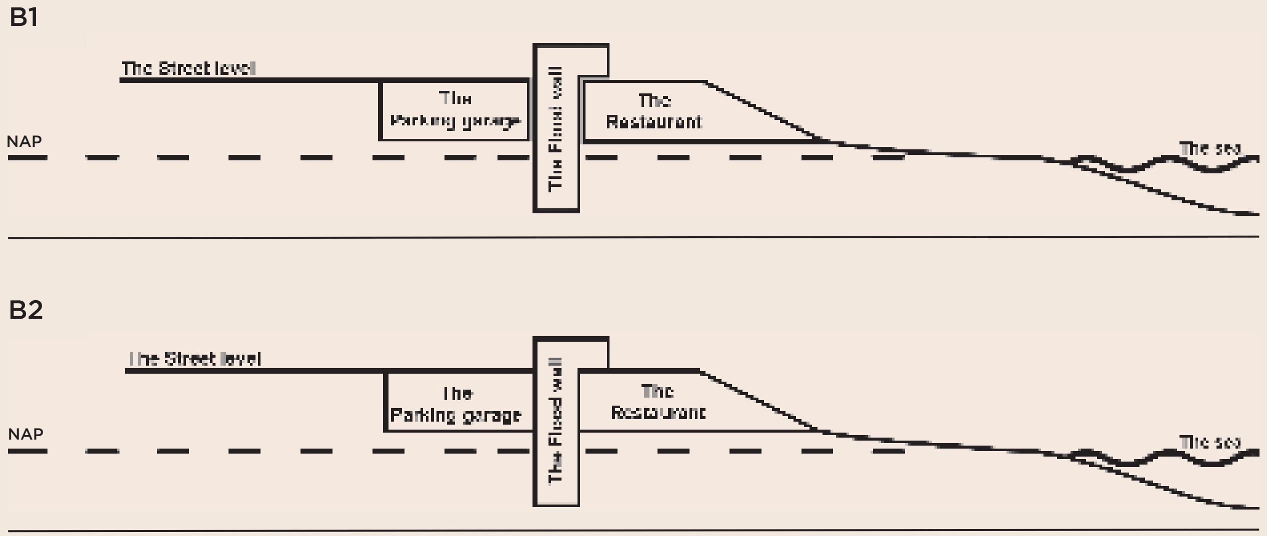


Figure 4. The cross sections of cases B1 and B2, in which the parking garage is located on the land-side of the flood wall and the restaurant is on the water side. The difference between the two alternatives is in the way the parking garage and restaurant are attached to the floodwall.



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 A1) can actually result in a lower level of safety compared to constructing them as fully connected structures (as in A2).

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 make 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.

This text is based the journal article: Anvarifar F., Voorendt, M., Zevenbergen C., Thissen W., (2017) 'An application of the Functional Resonance Analysis Method (FRAM) to risk analysis of multifunctional flood defences in the Netherlands' Journal of Reliability Engineering and System Safety. 158 (2017) 130-141.

Figure 5. Entrance of parking garage in dune in Katwijk (Photo courtesy Mark Voorendt).

WIM VAN DER KNAAP

ENLARGE(D) FLOOD DEFENSES WITH NEW ASPECTS FOR DESIGN AND PLANNING

REFLECTION

Dr.ir. Wim van der Knaap is a assistant professor of Land Use Planning at the Department of Environmental Sciences, Wageningen University & Research. In the Multifunctional Flood Defenses research program he was a co-supervisor in the project 'Contribution of MFFD's to landscape values and spatial quality'.

Why should we pay more attention to design and planning when developing multifunctional flood defenses? Isn't just enlarging and scaling up the design sufficient, like we used to do? Current approaches in the design and planning processes, also related to water issues, show that we at least need to reflect on new perspectives. For instance, in the Netherlands, a multi-layer safety strategy combined with the impacts of climate change enlarges the complexity of processes and influences their dynamics (sometimes making them slower, sometimes faster).

After each flood defense project is finished, issues of non-linearity, uncertainty and flexibility manifest themselves. Designers and planners are increasingly being asked to connect short-term projects with managing long-term goals, benefits and ambitions. The number of participants and conflicting interests seems to multiply as the risk of floods increases. At the same time, changing policy structures, and managerial and financial aspects, make flood defense design more complex. The scale on which issues have to be tackled is also becoming an issue: Is a plan only about buildings, or does it affect flood plains district wide? Do we just consider individual interests, or do we also need to address community interests? Is it possible to combine different needs? How do path dependencies and lock-ins influence the design and planning process? Are non-experts allowed (or even encouraged) to participate in the process? We need a kind of guided flexibility in the design and planning process to address all the new concerns, making room for creativity, innovation, participation, sustainability, pluralism, and diversity. The contributions in this chapter discuss many of these aspects, providing a broader perspective by linking theory and practice.

In the first contribution, Mark Voorendt emphasizes the importance of an integrated design cycle that combines several disciplines. He stresses a holistic approach, where analysis, synthesis, simulation, evaluation and decision-making are closely linked. As he says, "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 mono-disciplinary solutions." An integrated design is about creating something new by crossing boundaries, and thinking across boundaries. It is important to remember that there is a difference between using the proper tools and using the tools properly: this is the difference between just doing calculations and making a design.

Kevin Raaphorst highlights the complexity of the integral design and planning process, emphasizing the semiotic 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 each other. Raaphorst argues that the non-linearity in these processes (caused by the diversity of stakeholders and frames) requires a range of visual representations. He distinguishes three key elements which each visual representation requires to be effective in the participatory process: interactivity, readability, and validity.

Peter van Veelen focuses on the cycles and dynamics in adaptive urban planning. He proposes an elaborate Adaptive Pathway Method (APM), which includes slowly changing conditions in on-going design processes. The method distinguishes between the tactical-operational level (designed) and the strategic (planned). APM also includes different scales, from the individual household to the district; considering the path dependencies offer a multitude of opportunities for urban developments. APM seems an effective tool to link other tools, measures and goals. Case studies in 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. Nikki 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 the Netherlands, and the crucial point at which we are now standing. It shows the new paths and perspectives being taken, and highlights several aspects that need to be considered in this new phase of water planning as part of a broader societal process that embraces plurality.

Jantsje van Loon introduces flexibility and natural aspects by integrating the hard defense structure in dike design with the dynamics of vegetation and ecological zones. She creates new adaptive strategies to dampen waves and adapt to changing conditions using salt marshes. This approach shows an alternative and creative contribution in the flood safety discussion.

Tushith Islam gives a more in-depth analysis of how adaptive decision-making can deal with uncertainty, especially when designing infrastructure projects. He states that simulation and robust optimization methods can help create policies that include the various values and constraints of stakeholders, thus minimizing costs in the long term. He explored this for a MFFD case in Can-Tho, Vietnam and created several models for the path dependencies of decision-making. These models offer more insights into the impact of uncertainties on the decision-making process.

Finally, Flora 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), she proposes a co-locating approach for long-term, capital-intensive and irreversible investment interventions, based on flexibility. As there is no consensus about flexibility, she proposes a working definition to provide common ground for involved stakeholders to communicate: "Flexibility is a system attribute that enables responding to changing conditions, in order to reduce the negative consequences, and to exploit the positive upsides 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 used to address uncertainty, the approach can actually increase the integral design and planning flexibility, reveals areas that need more attention, ultimately making the design processes more productive.

We can conclude that to deal with multi-functional flood defenses 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 and planning process. By expanding design and planning approaches to include the many participants and processes involved, we make the entire process more complicated, challenging, but ultimately more rewarding.

Figure 1. (below). Planning & design Room for the River, Lent (Image courtesy Rijkswaterstaat beeldbank).

Figure 2 (below below). Multifunctional Waal bypass at Lent (Photo courtesy Johan Roerink, Rijkswaterstaat).

Han Meyer

HOW INFRASTRUCTURE CAN SUPPORT AND DESTROY THE PUBLIC DOMAIN OF THE CITY

REFLECTION

Prof. dr.ir. Han Meyer is emeritus professor of Urban Compositions at the faculty of Architecture and the Built Environment, Delft University of Technology. In the Multifunctional Flood Defenses research program he was a supervisor in the project 'Urban design challenges and opportunities of multifunctional flood defenses'.

Triumph of the City is a famous book by Harvard professor Edward Glaeser, describing the city as the most important engine of prosperity, economic development, culture and innovation. The invention of cities was the best thing mankind ever did (Glaeser, 2011).

In general, Glaeser is right. Looking to the long-term development of cities, we see not only a growth in size and population, but also a substantial improvement of prosperity and the quality of life. People live longer, have fewer diseases, have higher income, more free time, more possibilities to enjoy life. This improvement of the quality of life stimulates the economy, because happy people are more productive than sad people. In turn, the stimulated economy improves the quality of life, and so on. Cities are not only the result of a growing economy; they are also the condition for on-going innovation and economic development.

However, if you take a closer look at the development of cities, you will see that the time-line is rather capricious, with many ups and downs. Some of these ups and downs are caused by influences that are difficult for city authorities to manage, like worldwide economic crises or natural disasters. But a lot of the ups and downs are certainly the result of interventions by local authorities, planners, designers and engineers. A recent example of a substantial downward direction in the development of cities was the period of the 1950s and 1960s. That is striking, because it was a rather optimistic period, leaving behind the horror of the World-War II, with growing national economies and the promise of a prosperous new future, which also included a substantial modernization of our cities. The dominating policy of modernization was based on the ideas of the Modern Movement, advocated by famous architects like Le Corbusier and Sigfried Giedion (Giedion, 1941). Their plea was to make cities more spacious by a new balance between large open spaces and built volumes (mainly tower-buildings), and to make cities more accessible by introducing new infrastructures for traffic and transport like highways and subways. For the Netherlands, we can add: making cities safer by building new flood defense structures.

The strong emphasis on new infrastructures resulted in the construction of large-scale motorways, often cutting straight through urban fabrics, 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 southwest of the Netherlands in 1953. It is true that these dikes created more safety against floods, but they also blocked the relation of originally water-oriented cities with the river 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 better 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 descending poverty. The City of New York, considered the capital of the modern world of the 20th century, faced bankruptcy in the 1970s. Also in the Netherlands, cities like Amsterdam and Rotterdam lost more than 25% of their population between 1965 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 infrastructure. Cities like Barcelona, Paris, New York and San Francisco were front-runners in exploring new spatial concepts, which decreased the dominant role of large-scale infrastructures in the urban environments and paid more attention to the design of attractive urban spaces. People started to like city life again. The population figures of cities turned from shrinkage to growth.

In the Netherlands, this urban renaissance started with new waterfront projects like the Kop van Zuid in Rotterdam and Eastern Docklands in Amsterdam. The vacant waterfront areas, left behind by the port-industry in the 1970s and 1980s, created a great opportunity to restore the city and re-orient it to the water. The presence of water, the view on the water, and the use of water for public transport were discovered as some of the most important trump cards of Dutch cities. Also in the next future, more waterfront areas will be redeveloped, for instance the more than 1000-hectare 'City Ports' in Rotterdam.

Figure 1 (right). Construction of the new flood defense 'Maasboulevard' in Rotterdam, 1955. (Photo by J.F.H.Roovers)

Figure 2 (below left). 'Kop van Zuid' in Rotterdam still in use as port area, 1975. (Photo by Aerocamera Hofmeester)

Figure 3 (below right). 'Kop van Zuid' in Rotterdam after transformation to a new central business and residential district, 2013. (Photo by Aeroview Dick Sellenraad)

From this perspective, a change of attitude concerning flood defense systems was and is crucial. Flood defense systems can make or break the relation between city and water. The new Delta program of the Dutch government addressed the need to update the whole national flood defense system, in order to maintain safety in the future. The necessity to pay attention to spatial quality, and to integrate new flood defense structures in the urban context is clearly mentioned in the Delta program (Ministry of Infrastructure & Environment, 2015).

But mentioning and applying are two things. That is why this research program on multifunctional flood defenses (MFFD) can be considered extremely important. The technical and spatial possibilities of combining long-term flood safety and spatial quality are crucial for all river- and seaside cities. The MFFD research program is not only important because it shows several possibilities for this combination, but it is also important as an expression of a changing culture in science, design, and engineering. 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 common solutions. This surely will contribute to a 'triumph of the city'.

THREE | GOVERNANCE & KNOWLEDGE TRANSFER

Figure 1. South west Delta of the Netherlands, including Grevelingen, Volkerak and Zoommeer (Image courtesy NASA-GSFC-METI-ERSDAC-JAROS).

Perspective of an end user: Petra Meijboom, Rijksvastgoedbedrijf

COMBINING INTERESTS IN A MULTI-ACTOR PROCESS

INTERVIEW

Drs. Petra Meijboom, MSc MRE, is a project manager at the Central Government Real Estate Agency (Rijksvastgoedbedrijf RVB, formerly Rijksvastgoed en Ontwikkelingsbedrijf RVOB). The RVB is responsible for managing and mainting the largest and most diverse property portfolio in the Netherlands. The agency deploys real estate to realize governmental goals, in cooperation with, and with an eye for the environment. The RVB was a user of the knowledge produced in the STW-Multifunctional Flood Defenses program project 'Governance and finance of multifunctional flood defenses'. Petra took part in a case study done by Julieta Matos-Castaño, an action research project that contributed to the development of the Dilemma Cube tool (see pages 102-105).

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."

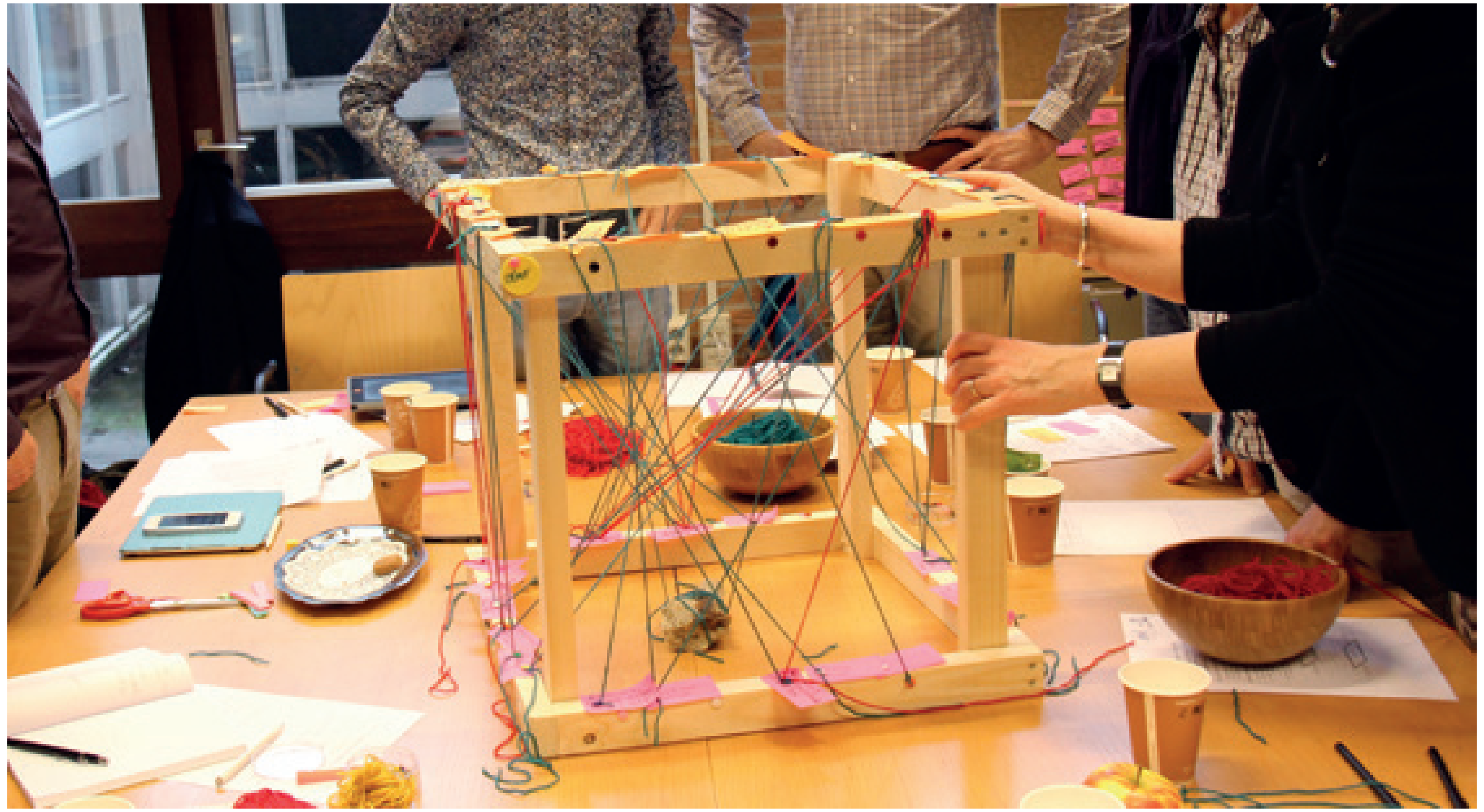
What specific kind of knowledge is needed for integral design of a multifunctional flood defense?
"For us not so much hard knowledge and skills. We need more soft knowledge and tools that help stakeholders to open up to questions like 'Who are the stakeholders in this specific area?' and 'What do they 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 in negotiations for a very long time."

How did the academic research project match with your organization's practical needs?
"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 better 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."

Figure 1 (below). The Dilemma Cube in action in a workshop session of a multi-functional flood defense project (Photo courtesy Julieta Matos Castaño).

Figure 2 (below below). Questions guiding the exploration of the influence of frames, dilemmas and collaboration tools on the selection of functional combinations (Image courtesy flaticon.com).



What is the influence of multiple interpretations on the identification and selection of functional combinations?

What are the dilemmas that participants encounter, while selecting and identifying functional combinations?

How can a collaboration tool help to create awareness about the dilemmas?

Julieta Matos Castaño

EXPLORING COMPLEMENTARITY AS AN OPPORTUNITY IN MULTIFUNCTIONAL PROJECTS

THE DILEMMA CUBE: A TOOL FOR MULTIFUNCTIONAL DESIGN COLLABORATION

Dr. Julieta Matos Castaño currently works as a consultant. She was a PhD candidate in the STW-MFFD program at the department of Construction Management & Engineering, faculty of Engineering Technology, University of Twente. She took part in the project 'Governance and finance of MFFD' and graduated in 2016.

Dissertation title: 'Frames and dilemmas in multifunctional projects.'

PhD Supervisors: Prof.dr. Geert Dewulf, University of Twente Prof.dr. Timo Hartmann, University of Twente

This text is an adapted version of an extensive publication on this tool in: Matos Castaño, J., van Amstel, F., Hartmann, T., & Dewulf, G. (2017). 'Making dilemmas explicit through the use of a cognitive mapping collaboration tool.' In: Futures, 87, 37-49. Elsevier, copyright 2017. Available online: http://www.sciencedirect.com/science/journal/00163287/87

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 could 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.
- *Diversity*: combining functions requires the involvement of multiple actors, from different organizations, with 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. Not 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 a context of scarce resources? The potential alternatives are weighted and evaluated from different perspectives. Developing multifunctional projects requires an awareness of the multiple frames of reference involved in the decision-making process.

Unfortunately, dilemmas frequently lead to paralysis and indecision, mainly because actors are not aware of what caused the dilemmas in the first place. To address this problem, we developed a tool: 'The Dilemma Cube'. The Dilemma Cube is a collaboration

Figure 3.
Key features of the Dilemma Cube (Image courtesy flaticon.com)

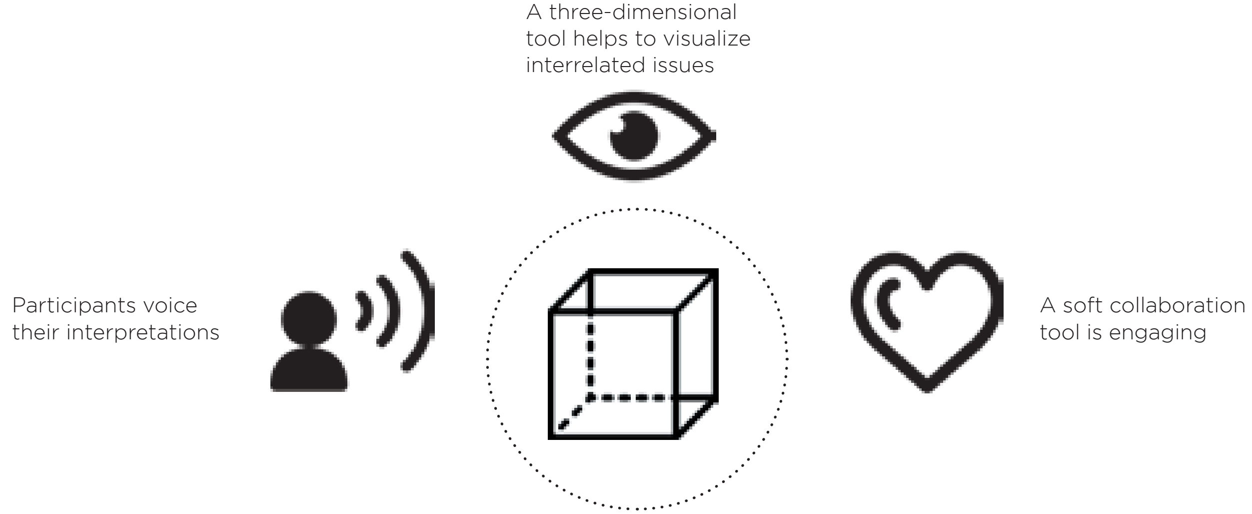
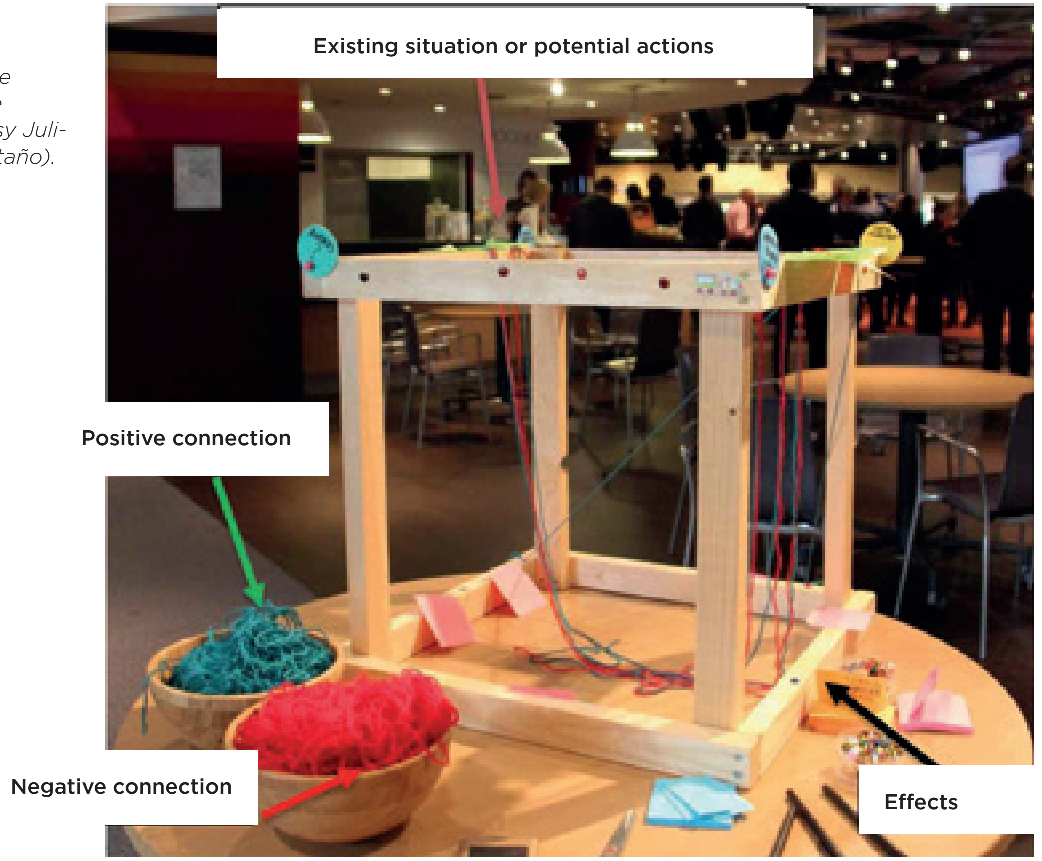


Figure 4.
Explanatory elements of the Dilemma Cube (Photo courtesy Julieta Matos Castaño).



tool designed for use in a workshop setting; it helps participants to share their interpretations about the issues at stake and create awareness of the existing dilemmas.

It is important to remember that while dilemmas may be associated with indecision, they also offer the opportunity of looking at situations from different perspectives. Rather than being a source of conflict, though, 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,
- What kind of dilemmas actors encounter,
- Which strategies can help actors to overcome these dilemmas.

The Dilemma Cube makes explicit these aspects of dilemmas in a multi-actor context.

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 share 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 connection associated to it, there is a dilemma. 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 dilemmas explicit and encourages inclusive interaction among participants in three ways:
1. Taking turns encourages participants to voice their interpretations about what they consider relevant in a given situation. Having the opportunity of adding one action, one effect and one connection per round, participants need to filter what is important to them. This way, participants concentrate on their priorities and a focused discussion results.
2. The three-dimensional nature of the Dilemma Cube helps to visualize how issues are interrelated in multifunctional projects. An action associated with a function has consequences for other functions, and these are often interdependent and interrelated. Since actors share their interpretations, the Dilemma Cube helps to visualize interrelations that actors had not previously perceived.
3. The Dilemma Cube is a low-tech collaboration tool. Unlike some digital collaboration tools, the tangible nature of the cube and the way it is used produces an engaging experience for participants. Adding the content to the cube, 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.

Knowing the origin of dilemmas helps to identify potential conflicts. Once the dilemmas have been identified, the Dilemma Cube can also support the search for strategies to overcome the dilemmas and bridge the seemingly competing demands of different actors, in this way avoiding (or solving) conflicts.

We had the opportunity of organizing a workshop session for a multifunctional flood defense project (an anonymous case) in which we used the Dilemma Cube . This case dealt with the reinforcement of a flood defense and integrating it with other functions, namely nature, recreation, housing. Actors were exploring different combinations of functions that would satisfy regional and local demands. During the workshop session, the Dilemma Cube helped to identify six dilemmas related to the priorities of the project, revealing competing interpretations about which issues were most important, and identifying tensions originating from the positive and negative effects of different functions. Using the Dilemma Cube created awareness among the participants, and they were able to recognize the different perspectives of the other actors.

The Dilemma Cube helps to make dilemmas explicit because it allows actors to determine what is important to them, share their interpretations with other actors, and visualize the effects of different actions across different functions. This approach shows the relevance of tools that incorporate multiple interpretations about a given issue. Collaboration tools that allow participants to voice and share their interpretations can be a valuable complement to other design tools used to identify project alternatives and analyze their feasibility and desirability.

Figure 1 (right). The Dutch 'layer model' (De Hoog et al. 1998) consists of
1. occupation layer,
2. networks layer,
3. subsoil layer.
The model is predominantly used by Dutch spatial planners. Flood defenses are part of the occupation layer.

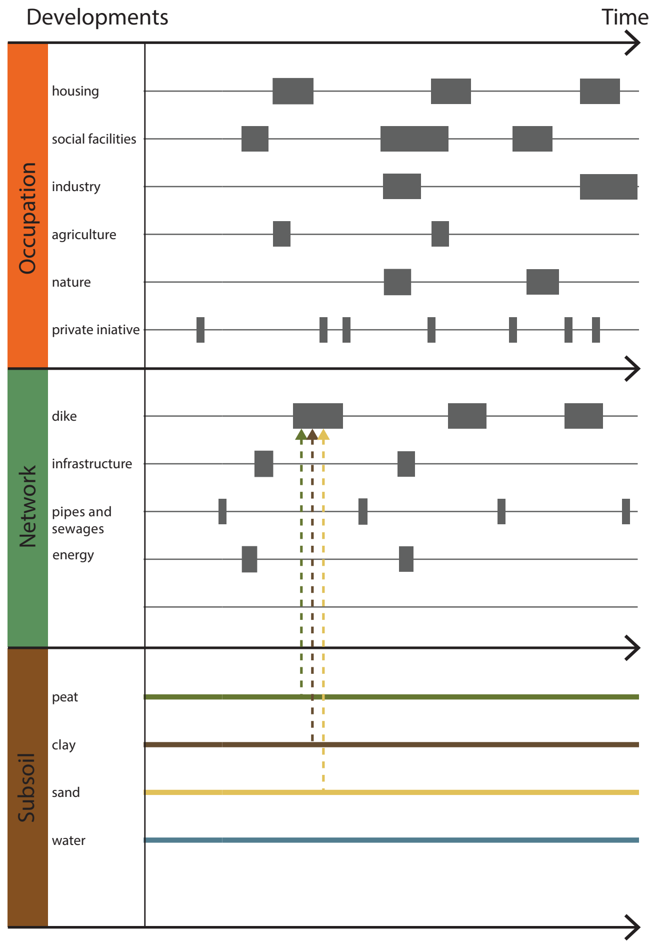
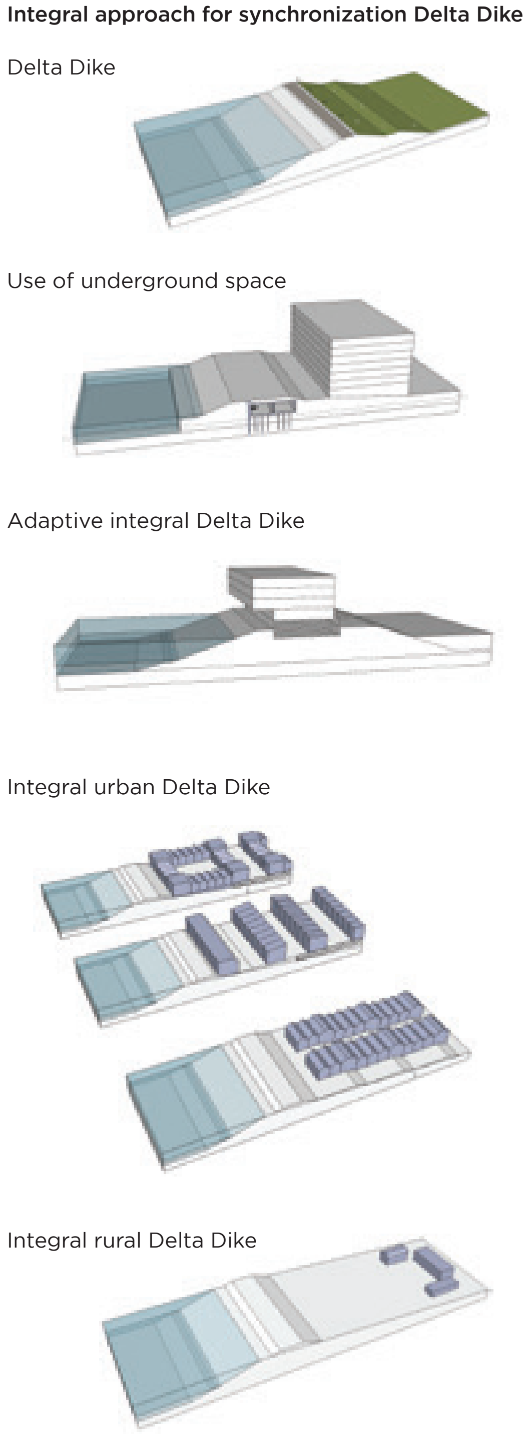


Figure 2 (far right). Integral approach for synchronization Delta Dike.



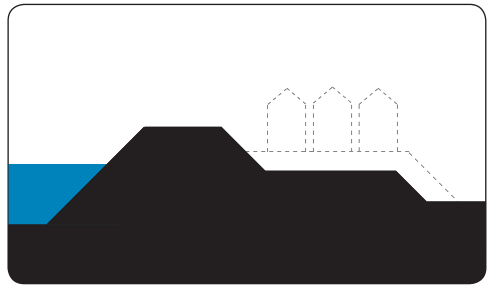


Figure 3. Schematic representation showing anticipated developments.

Ellen Tromp

LEVEES IN A CHANGING ENVIRONMENT

SYNCHRONIZING AND ANTICIPATING LOCAL CHALLENGES

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(Tentative) dissertation title:
'Enhancing knowledge transfer and uptake in the design processes of flood defences' (forthcoming, 2018)

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In recent years, spatial planning and flood risk management (FRM) have been further coupled, thus creating opportunities to incorporate water management measures in urban construction/reconstruction and landscaping. In addition, it is essential to find more than just technical solutions to potential flooding problems, and look for strategies that also address governance, funding and more integrated design processes. Research in recent years has identified two dominant strategies - *synchronization* and *anticipation* - based on the question whether there is a flood risk issue and/or a spatial development plan and on the degree to which a flexible approach is available that will allow separate developments to be synchronized. These strategies can be used in both urban and rural areas.

Research (Tromp et al., 2014) has shown that opportunities are created in the physical area around a dike if time and space perspectives are both considered. The subsurface changes physically at a rate slower than the rate of network change, which is in turn slower than changes in physical structures on the surface layer (Figure 1). Dutch dikes are designed for a period between 50-100 years. The lifetime of the built environment (housing) is generally 30-50 years, but changes are always possible due to the desires and demands of local residents. Furthermore, some buildings have longer lifetimes because they represent the cultural heritage

However, dikes are often reinforced earlier than their expected lifetime. This raises the question whether changes to dikes and the other developments coincide in time. As improvements to flood defenses and spatial development cannot always be carried out at the same time, we need to identify opportunities for flexibility in future spatial development. Important spatial developments may thus take place independently of each other (Figure 3):
- Dike reinforcements can anticipate future spatial developments.
- Spatial developments can anticipate future flood defense developments such as dike upgrades.

Two strategies were identified (Figure 4, and Tables 1 & 2, page 108). In Strategy 1, developments are synchronized. When this is not possible, the challenge is to create enough space to anticipate possible future developments (Strategy 2).

Strategy 1: Synchronization
Basically, synchronization means linking the timetables of two or more stakeholders and collaboratively defining the budget, operational approaches, cost-sharing, and maintenance plan. Synchronization will allow stakeholders to coordinate and combine activities and developments.

In some cases, synchronization may need to be 'forced', with developments being accelerated or delayed to allow them to run concurrently. In practice, investments at an early stage make joint developments more likely. Among other things, synchronization depends on flexibility in time and budget. Table A describes the benefits and obstacles of this strategy, presenting aspects that are specifically applicable in the Netherlands.

Strategy 2: Anticipation
When synchronization is not an option, two other possibilities exist. The first is a sectoral approach in which the two developments are separate. The second option is an anticipatory approach, which can in some cases lead to cost benefits, as well as generating surplus value for society as a whole. Depending on the time frame, either flood risk management or spatial development will be the starting point for the anticipatory approach.

Different benefits and obstacles of this strategy can be identified for each time frame (short, medium and long term). Table B presents these, and considers institutional, financial and organizational aspects. Different spatial designs can be developed for each strategy. Figure 4 shows how this can work.

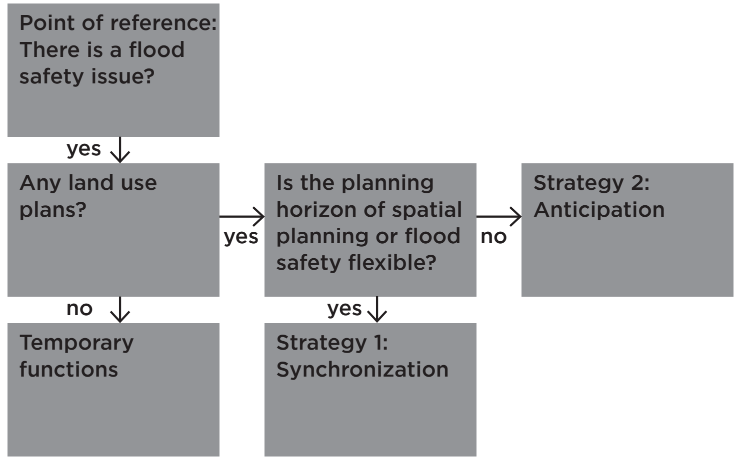
This research project delivered the following key findings:

1. Collaboration between organizations is essential in both the synchronized strategy and the anticipatory strategy. This means that agendas, policy frameworks, and legislation applying to one organization must adapt to those of other organizations. The aim is to work towards an integrated approach. In the case of water authorities, this means that they must adopt a pro-active approach to identifying and understanding the interests of other parties.

Figure 4. (below). The different strategies explained.

Table 1. (below below). Synchronization strategy.

Table 2 (right). Anticipation strategy.



Strategy 1: Synchronization	
Opportunities	Creating surplus value for environment Increasing public support Solution with local and financial benefits
Obstacles	Dependent on third parties Possibly conflicting individual and public interests
Institutional aspects	New law as legal instrument for integral approach Formal project decision at managerial level needed to ensure integral exploration Political involvement based on agreements (co-deciding, co-producing)
Financial aspects	No flexibility in current debate Positive stimulus for cooperation required
Organizational aspects	Administrative flexibility, recognition and support needed for integral approach Integral project manager needed, different competences Involvement of triple helix required, public-private partnerships

Strategy 2: Anticipation			
Time scale for flood risk management	**Short term (0-12 years)**	**Medium term (12-24 years)**	**Long term (>24 years)**
Opportunities	More synergy, delaying dike reinforcement by taking temporary measures Ability to facilitate future spatial development	Temporary functions in anticipation of future developments Adaptive building, anticipating flood risk management needs	Adaptive building is feasible Ability to facilitate future spatial development
Obstacles	Outlay must precede returns and reside with different stakeholders. Stakeholders are not aware of each other's agendas	Temporary use of land is difficult to anchor in legislation Desire for adaptive building cannot be rooted in plans	Difficult of anticipating developments at this time scale because of possible changes in legislation and regulation Execution of measures should be within a given time frame
Institutional aspects	New legislation as legal instrument for integral approach		
Financial aspects	No stimulus to encourage the anticipation of future development. Funds controlled by the water authority, or by a public investment company within a framework of public control, could be an option. This creates an entity that facilitates the management of ingoing en outgoing financial resources so that beneficiaries (including non-risk-driven participants) can obtain a return on their investment. In the anticipatory strategy, there is a potentially long time lag between outlay and return. This time lag should be kept to a minimum.		
Organizational aspects	Different views of the integral approach On-going cooperation between public stakeholders. Political and government agendas need to include, on an on-going basis, development issues involving a combination of spatial planning and flood risk management. This generates interdependency between public stakeholders. Furthermore, a complementary advisory/consultancy role for all stakeholders establishes bonds between the partners involved. Communication is important due to the dynamics and complexity of the task		

2. Water authorities need to develop a spatial 'dike vision', a strategic, long-term plan based on a lifecycle analysis. This makes the water authority's agenda clear for a longer period of time and makes it easier to seek shared opportunities with other stakeholders, with potential win-win situations as a result, introducing flexibility and enhancing the role of the water authority as a network partner. A dike vision can be an important element in integrated planning processes and it makes the water authority an active partner in the spatial environment at the strategic level. Such strategic long term planning can already be found in the area vision documents of the Dutch National Delta Program, which was developed with the national, provincial and municipal government authorities.

3. Funding: Regional authorities can invest in spatial development and flood risk management, provided that benefits emerge over time. This buffer does not develop by itself. Benefits can be produced by in a variety of ways: for instance, profits from wind turbines can be used later to pay for the more complex statutory assessments. Locating spatial developments 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; by controlling risks and uncertainties, they enable private investors to participate in integrated development of riverbanks and coastal zones on the basis of flood risk management.

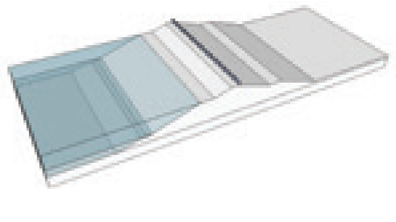
4. Active building policy for space on and next to flood defenses. More space for development can be created when there is an understanding of how 'simple' building techniques can create more flexibility for future reinforcements. Since the area around a dike is a special environment, it makes sense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

In sum, the creation of flexible strategic planning requires both water authorities and municipalities to show willingness and start working 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.

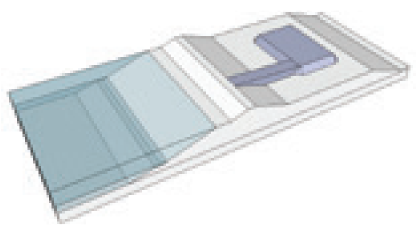
Figure 5. Examples for anticipatory strategy

Short term (0-12 years)

Delaying the dike reinforcement by taking temporary measures. Possible solutions include temporary constructions as sand bags and flood barriers.

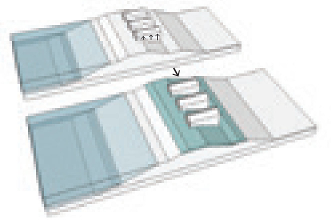


Creating more synergy. Often these are incidental measurements where anticipation is possible.

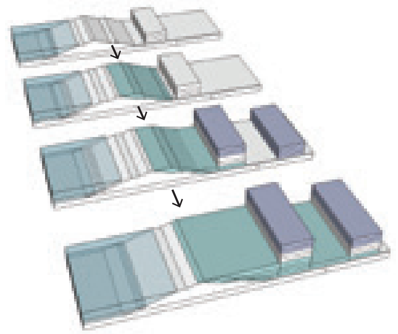


Medium term (12-24 years)

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 jacked up to allow strengthening of the dike.

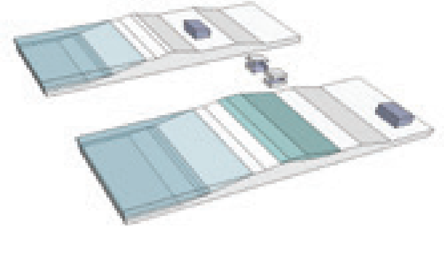


Ground floors are reserved for future dike reinforcements.

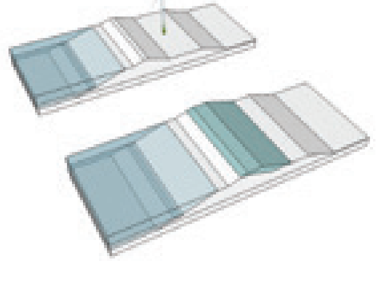


Long term (>24 years)

A building can be moved to another location in the event of a dike reinforcement.



For areas where anticipation is required for the long term, opportunities arise to allow new functions, e.g., wind turbines.



Ellen Tromp

CASE STUDY: KINDERDIJK - SCHOONHOVENSEVEER

DIKE REINFORCEMENT LEKDIJK

The dike reinforcement project Kinderdijk – Schoonhovenseveer (KIS) is part of the Lekdijk, a primary flood defense that directly protects two major polders in its hinterland from flooding by the Rhine: the Alblasserwaard and the Vijfheerenlanden polders. 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 1). Beyond the dike, part of the floodplains is a nature conservation area. The local population is aging, and village shops, businesses, and local activities are slowly disappearing. There is a shortage of housing for young people.

The Dutch regional water authorities regularly monitor the flood defenses that fall under their jurisdiction, and perform periodical 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 (see Figure 2). At the end of each phase, the plan is formally reviewed before final approval by the DFPP-2 Program Board.

The soil under this dike consists of layers of clay and peat on top of a Holocene sand layer, resulting in macrostability problems and forming an impediment to traditional dike reinforcement. As a result of previous dike reinforcements, many historic and characteristic houses are now situated against the dike or partly on it.

A number of businesses would like to expand, such as the Streefkerk Marina. Moreover, the municipality of Molenwaard identified a number of developments to improve the social facilities of the village Streefkerk and enhance the landscape quality as well. The municipality initiated a process to develop an integrated, long-term planning vision that connects these objectives with plans for dike reinforcement and third-party plans.

No further dike reinforcement is currently possible, without removing a substantial number of houses, since the houses in KIS are typically located within 30m of the dike. Recognizing how much dike strengthening projects can inconvenience residents, the KIS project manager considered using innovative techniques that might reduce the problems. The Rivierenland decision-making process included numerous opportunities for different stakeholders to interact. The project involves developing a multi-purpose levee; and changes were made in the proposed tender to enhance the use of innovative dike strengthening techniques during construction.

In our research, this case study was analyzed using the sender–receiver framework. We saw that different barriers and failure mechanisms occur at different interaction moments (see Figure 3). The problems seem to depend on which stakeholders are involved, the role they play in the whole design process, and the knowledge gap between the sender and receiver. Within a given interaction, we also saw that the sender and receiver roles change, with the sender becoming the receiver and vice versa. The transfer of knowledge occurs as part of a communication process and not in isolation.

The success of knowledge transfer depends on four matters:
- Relation between the two parties,
- Degree of a knowledge 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 homes behind the current dike, the dike would need to be reinforced in the direction of the river. Camouflaging the dike by over-dimensioning the crest gives the best chances to combine flood protection with all the other ambitions and plans. The dike would offer space for new accommodations or even a new town center oriented towards the river and the marina. To prevent the new buildings being damaged by future flood protection tasks (or even having to be removed), the design has to be very robust.

In the current design, both an over-dimensioned 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 governments found that their joint plans 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 plan. Currently, some parts of the plan, such as the walking promenade and cycling path, are currently being built. The marina will be responsible for developing the area on top of the multi-purpose levee. While developing the project, the municipality attempted to maintain a constructive relationship with Rivierenland. Some difficult decisions had to be made, with financial consequences, as well as consequences for the planning; e.g the decoupling of the joint plans, as the legal changes for the improvement of the spatial quality were not organized in time for the dike strengthening.

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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 trying to include available local knowledge in this specific project. This process helped to implement the project successfully, with consent from the local stakeholders. During the construction the contractor actively involves local stakeholders to keep them informed about the process, while using social media and events.

Figure 1 (right). Ribbon development along the Lekdijk at Kinderdijk.

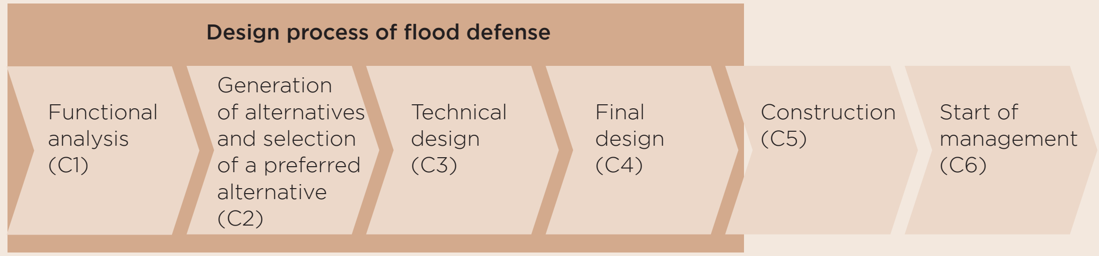


Figure 2 (mid). The different phases in a design process of a flood defense (DFPP-2, 2011)

Figure 3 (bottom). Example of the diagnosis with the Sender-Receiver framework.

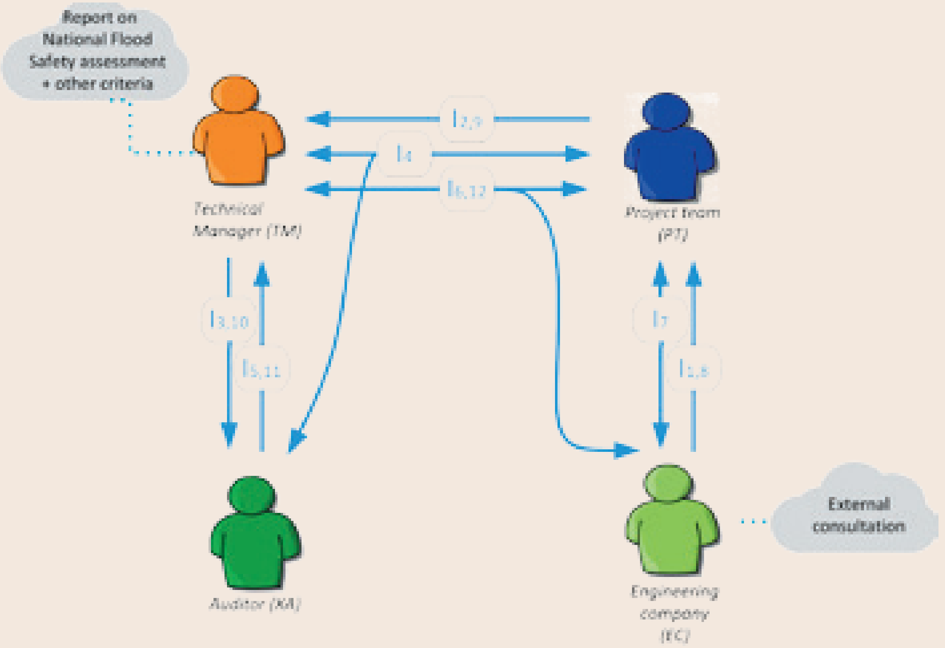


Figure 1.
Three elements of the Sender-Receiver framework.

Figure 2.
Single knowledge transfer transaction in the Sender-Receiver framework for knowledge transfer and uptake.
S = Sender
K = Knowledge
B = Barrier(s)
T = Trust
R = Receiver
N = Knowledge need
G = Grounds
F = Failure Mechanism(s)
U = Knowledge Uptake

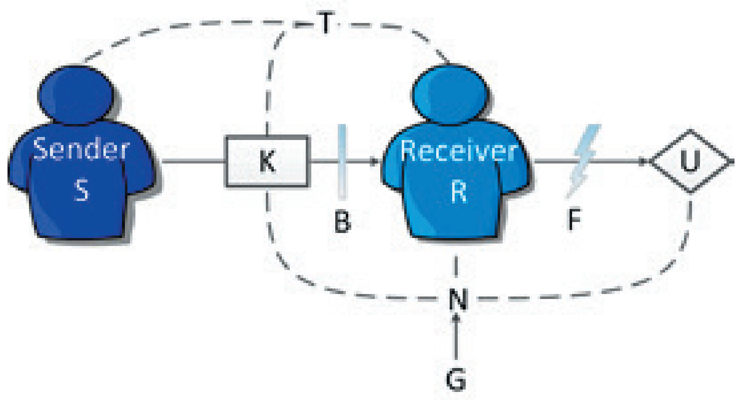
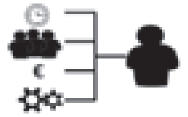


Figure 3.
Barriers blocking knowledge uptake and transfer.

Barriers blocking knowledge uptake and transfer		
B1. **Cognitive barriers**	*Cognitive barriers* occur when receiver R lacks prerequisite knowledge, or experiences cognitive dissonance, when the knowledge provided does not fit R's understanding of the real world. Differences in assumptions and frames of reference, or poor basic communication skills on the part of sender S and/or receiver R, may cause messages to be distorted.	
B2. **Institutional barriers**	*Institutional barriers* arise when receiver R understands knowledge K, but cannot act upon it because such action is incompatible with current practices, or conflicts with some core values held by R or key stakeholders. The strength of these barriers is proportional to the degree an institution is able to adapt, and thus accommodate proposed changes.	
B3. **Resource-related barriers**	*Resource-related barriers* occur when receiver R foresees financial consequences (e.g., when knowledge K includes measures that significantly improve safety, but are expensive), or potential risks (e.g., when K concerns a novel technology, or a policy that may lead to legal claims.)	

Ellen Tromp

ENHANCING KNOWLEDGE TRANSFER AND UPTAKE IN THE DESIGN PROCESS OF FLOOD DEFENSES

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Flood risk management (FRM) has become a complex sociotechnical issue, one that requires a wide range of expertise from science, engineering, and behavioral disciplines. Any intervention in the flood defense system must meet the requirements of many different stakeholders. Although all stakeholders have a clear and common interest in enhancing safety from flooding, individual and organizational interests can diverge widely.

In the Netherlands, FRM entails mitigating flood risk by building dikes, dams and other hydraulic structures to regulate the water. Every 12 years all the Dutch primary flood defenses are tested to ensure they meet the statutory safety standards. When a flood defense fails to meet the standards, it is placed on the Dutch Flood Protection Program, and the Dutch water authorities are, among others responsible for strengthening the dikes.

As municipalities and private parties add functions on dikes, spatially integrating the dike into its surroundings becomes more important. Recently, regulations have changed, increasing the role of the Dutch water authorities as partners in spatial planning. Despite their changed role and growing pressure from other stakeholders, national and regional water authorities remain conservative: innovative techniques are rarely applied. Although the Netherlands is a worldwide leader in FRM research, actual policy appears inert, and many opportunities to innovate are missed.

In order to enhance knowledge transfer and uptake, the policy analyst / process designer must be able to diagnose a situation and foresee the consequences of an intervention. The framework developed helps to assist the analyst / designer to observe, diagnose and (ultimately) intervene in the knowledge uptake (see Figure 1).

As shown in Figure 2, in a single knowledge transfer interaction, knowledge K is transferred by a sender S to a receiver R. In a sequence of interactions, parties can change roles: the sender becomes a receiver and vice versa, or the receiver becomes a sender in interaction with a new receiver. Uptake of knowledge U can include a range from sharing knowledge through presentations or documents, to changes in policy in response to new insights. Recent changes in Dutch flood policy led to assessments against statutory standards every twelve years, instead of every five years.

We identify three preconditions for the transfer of knowledge:
P1 Sender S must have knowledge K that is relevant to receiver R; and
P2 Sender S must be willing to share knowledge K; which entails that
P3 Sender S must trust receiver R
(Connelly & Kelloway, 2000; Davenport & Prusak, 1998; Podolny & Baron, 1997).

For knowledge uptake U, we identify three more preconditions:
P4 Receiver R must have a particular knowledge need N;
P5 The knowledge K needs to fit this need (at least partially), but is not yet available to the receiver; and
P6 The receiver R must find the transferred knowledge (or some of it) trustworthy.

Levin & Cross (2004) found that knowledge transfer is more effective when the receiver views the knowledge source as being both benevolent and competent. We therefore differentiate between two types of trust T:

benevolence-based trust (the belief that sender S will not intentionally harm receiver R) and competence-based trust (the belief that sender S is knowledgeable about a given subject area). Interpersonal trust (Rotter, 1967) may not be necessary at the start of knowledge sharing, but it may develop over time as a result of knowledge transfer (Kramer, 1999; Ford, 2004).

The receiver's need N for knowledge K may have different grounds G. A decision-maker may, for example, commission an environmental impact assessment on substantive grounds (e.g., to improve the design of a dike, or to better understand the risk of a technological innovation), on formal grounds (e.g., because the analysis is required by law), or for strategic reasons (e.g., to defer a decision, or to gain support from some stakeholder group). These grounds may also affect the knowledge uptake.

Knowledge transfer and uptake may be blocked due to three types of barrier: cognitive, institutional and resource related barriers (see Figure 3). Even when these barriers do not arise, or can be overcome, other failure mechanisms can impede knowledge uptake:

F1 *Incorrect use*: knowledge K is used by receiver R in different ways as for strategic reasons sender S did not intend, or because S misunderstood the grounds for R's knowledge need.

F2 *Diffidence*: Receiver R interacts with another actor, who questions the knowledge, thus weakening trust T, which dissuades R from taking up knowledge K.

F3 *No relay*: Receiver R does take up knowledge K, then R becomes sender S2 and interacts with a new receiver R2. Uptake of knowledge can fail if R2 is not receptive.

The proposed framework appears to function as intended, and helped us identify and clarify 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 uptake of knowledge. We also expect that our sender-receiver model can help us to better understand the role of 'knowledge brokers'.

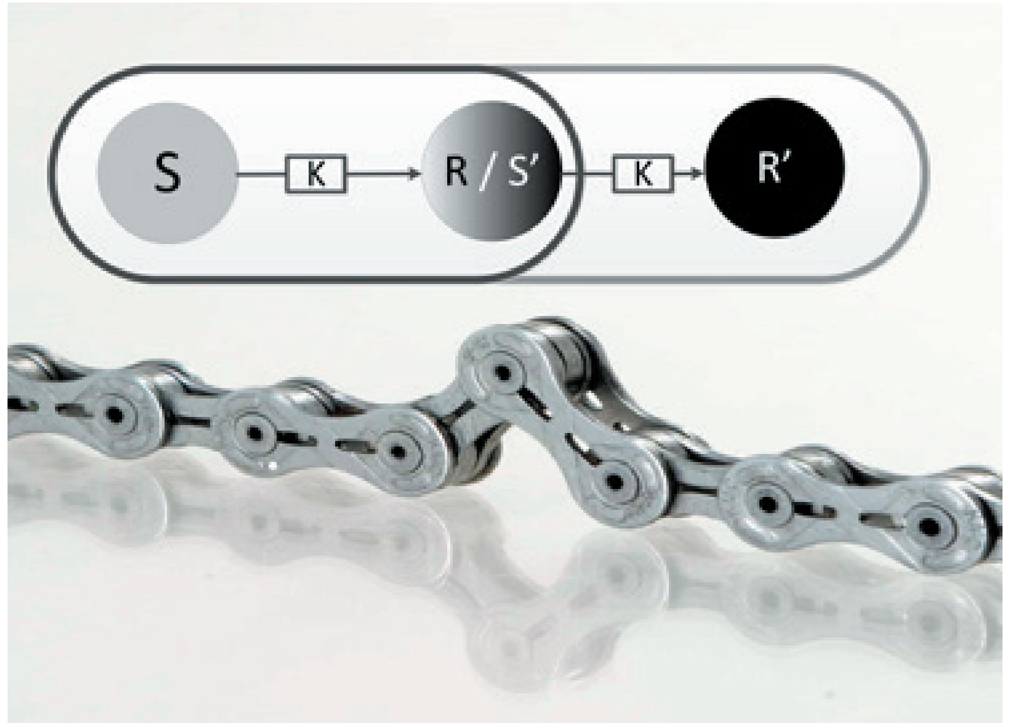

Figure 4 (left). Dike strenghtening at Kinderdijk - Schoonhovense Veer (Case study see page 110-111; Photo courtesy Ellen Tromp).

Figure 5 (right). Knowledge transfer and uptake is as strong as the weakest link.

Trudes Heems

MULTI-ACTOR GOVERNANCE

MAKING SENSE AND MANAGING SENSITIVITIES WHILE DEVELOPING MFFD

Dr. Trudes Heems was a Postdoc in the STW-MFFD program at the Faculty of Technology, Policy & Management, TU Delft in the project 'Integrated design'. Currently she works as an independent researcher, investigating the impact of tourism on historical towns in Europe.

Figure 1. The 'so-called Samenwerkingsverband-doos' ('first aid cooperation kit').

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 so that land use, responsibilities, financing, 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 concepts 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. Actors may start talking past each other, 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 participants/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.

Figure 2. The checklist, with seven inspirational cases for project leaders of integrated spatial projects.

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 multi-actor sensemaking, the process in which actors give meaning to experiences. In this case, the actors need to identify and understand the problems associated with the project, the different functions that could be involved, and the practices necessary to achieve the project. During the process, sensitivities need to be managed, and barriers to communication, collaboration and action need to be overcome. In this way 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 (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 a few representatives from companies and research institutions. The informal settings of these meetings were found to encourage the processes of sensemaking, and the development of innovative solutions. In this setting, practitioners were interested in the diverse perspectives of other actors, and were intrinsically motivated to think about ways to remove barriers to collaboration. The process stimulated the exchange of knowledge and experiences between actors from different backgrounds, as well as leading to broader networking.[1]

In the learning communities, different ambitions were considered relevant and legitimate. Each meeting focused on a different theme, and cases were presented and discussed. Given the practical approach of the practitioners in the learning communities, it was easy to convert knowledge directly into practical proposals for integrated spatial projects . The learning communities can act to link national policy development and local execution of policy in daily practice.

However, the research also showed that it is still difficult to implement insights and solutions in daily practice. The informal settings and neutral organization created many opportunities for sensemaking, but contributed less to daily practice. To implement insights and solutions in their own organization (e.g., Water Authorities, 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] (Figures 2 and 3). In collaboration with the Dutch Ministry of Infrastructure and the Environment and the MFFD research program, they created a checklist for project leaders of integrated spatial projects, as well as a physical 'first aid cooperation kit'[3]. The kit presents the checklist, seven inspirational cases, and contact data for local experts, all presented around seven themes that are important for successful collaboration in integrated spatial projects. The kit was enthusiastically received by almost 30 project leaders of the Dutch flood protection program.

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 infromation on the toolkit please contact Jan Dirk van Duijvenbode at Rijkswaterstaat (jandirk.van.duijvenbode@rws.nl) or Trudes Heems (trudesheems@hotmail.com).

Daniel Hogendoorn

KNOWLEDGE TRANSFER: COMPLEXITIES WITH SIMULTANEOUS TASKS AND OPPOSING INTERESTS

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(Tentative) dissertation title: 'The experience of difficulty in modern governing. Explored through urban, flood and climate cases of evidence-making.'

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Figure 1: Jubilee River, Great Britain (Photo courtesy James Petts).

As the name implies, multifunctional flood defenses (MFFDs) are flood defenses that also incorporate different functions and purposes. MFFDs are objects designed to offer systematic, 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. Whenever things are made complex, novel systematic 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 Bruin & 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, allotting sufficient resources to deal with, by shaping intergroup learning. Though the question of how groups deal with intergroup difficulties and the lessons they learn is 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 interactions between disparate groups increases, the difficulties that need to be resolved also increase, whereas the resources remain the same. Therefore, when designing MFFDs, alternatives for learning need to be considered when intergroup difficulty arises. In contrast to what we had hoped, synthesis is difficult and cannot be fully expected.

Knowledge transfer

When many groups collaborate, it brings a wealth of insights together, since each group is trained in a specific type of knowledge that serves a specific purpose. Each group can therefore gain from interacting with the others. The transfer of knowledge between groups can lead to innovation and serendipitous discoveries. But each group also brings its own concepts and worldview, which are necessary for them to operate and act as a group. Such concepts affect the inferences people make and how they understand each other, which is necessary for cooperation; such shared meaning is necessary for concerted group action, because it determines what needs to be done to achieve a goal. Having similar concepts harmonizes expectations, but when different groups with different concepts need to work together this may interfere with habitual chains of inference. Since people attach affect to their inferences, knowledge transfer between different groups can become frustrating and difficult, in particular when the cooperation continues over a long period, as in the case of MFFDs. In MFFD design, the disparate groups need to interact for the entire design phase, but in some cases the interaction continues for the entire lifespan of the object.

When we discuss knowledge transfer and developing shared knowledge, we assume that both groups learn. But learning is demanding. In the Dakpark case, the study groups used other - apparently less demanding - common-sense tactics to deal with the difficulty of sharing knowledge, while still serving their interests: they enlisted experts, imposed rules, substituted common language, and used simple heuristics when they could not agree or were confused. Enlisting experts outsources the difficulties, but it costs extra money and may add other interests to the design. Imposing rules clarifies a situation, regulating knowledge and action and decreasing perceived uncertainty. But it also cuts out complexity, which could affect the final project, leaving it misaligned to its surroundings. Substituting common language is a way of dealing with difficult concepts which we do not understand and do not make the effort to learn. Though this makes our intentions clear, permitting us to continue cooperating, it can obscure the fact that we have not learned, and we may make decisions based on false confidence. And finally, using heuristics that are easy to remember and apply is a way of dealing with the confusion of dealing with too many sub-tasks at once. When different groups cooperate, resources are almost always limited, and the intent of the parties is often uncertain. Sometimes, a group may use deceptive behavior and confuse the other with irrelevant knowledge to stall the learning process for short-term advantage. As a response, other members of other groups may adopt simple heuristics for simplicity, but excluding the possibility of knowledge transfer.

Since MFFDs are developed and maintained, the groups apparently find a modus operandi. While this may serve all the group's interests, this is not guaranteed and might present a too rosy picture. In some cases, the modus operandi actually becomes dysfunctional, making groups incapable of learning. Based on the cases, we identified a set of conditions that explain why the groups work together in the way they do. Learning frequently appears to take place to protect a group's resources at the expense of actually contributing to the flood defense function. For example, in the English Environment agency, learning adapted in response to the demands of the English central government, at the expense of addressing local uncertainties.

Designers, users, and affected communities

The concept of MFFD is appealing, since it dovetails the interests of different groups by combining functions. Yet, the ultimate consequences are not in the planning sessions. The consequences are for the parties that operate the MFFD, and those protected or otherwise affected by it. This introduces a matter of ethics in knowledge transfer. Many of the costs and concerns of intergroup conduct can be foreseen, but not precisely calculated. It is possible that the difficulties which users will face are deemphasized during quantified cost-benefit and risk-assessments. There were many clear examples in the case studies of coordination problems, frustrating delays and conflicts, which developed after construction, in the maintenance and exploitation of the project. In some cases, designers faced incentives that made them careless about future users. Since the lifecycle of the MFFD is long, and the decision-making process comparatively short, what seems like a good idea in the short run, may have less favorable outcomes during the lifecycle, since the surroundings of the MFFD can radically change over time. Considering that the primary concern of MFFDs is to prevent flooding, this disparity between present and future interests needs to be considered.

We can see preventing the harm of flooding as an objective ethical concern. But there are other ethical factors that should be considered. For example, the shops in the Roof Park MFFD threatened local shops in a relatively impoverished neighborhood. This happened despite the fact that public money was invested in the project with the idea of stimulating the neighborhood economy, even though there was resistance to changing the existing flood defense. Similarly, the multifunctional Jubilee River project in Britain ended up causing flooding and changing the flood risk, harming less well-off groups. This is not directly attributable to the different interests involved, but to the selection of heuristics and certain types of knowledge formation that fit well from central government perspective, but which are less able to deal with local uncertainties and ethical concerns.

The challenges of interdependency

Like any landscape intervention, the MFFD enters an existing situation. Designs have to adapt to the current situation and environment. This brings difficulties when a new MFFD encounters existing stakeholders who were not considered

when it was proposed, as the designers did not know about these stakeholders. The existing stakeholders will form relations with the incoming groups, based on their reactions to the material developments as well as to the social interactions. It takes effort to fit the MFFD into the context of existing developments and practices, and it is important that no one group has to compromise too much; this process can change the intended functions of the MFFD. Adjusting and adapting are a challenge, and the process means that the interdependence between all the parties involved in the MFFD will increase. As stakeholders learn and recognize the different interests, their 'world' becomes riskier and less predictable, and they will often respond by trying to impose norms and rules on each other to recover some predictability. Interdependence means that stakeholders live in increasingly deep uncertainty about the consequences of their own actions, even with the best intentions.

The difference between establishing intention and meaning

When stakeholders have to interact with other groups that are also accustomed to making independent decisions, this results in deep, mutual, uncertainties. These difficulties can be of two kinds: difficulties establishing intention and difficulties establishing meaning. 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 mutual, or is it limited to the group? Are both groups committed to that outcome? Is their commitment equally long? Within a group, members develop pragmatic signals to rapidly share information, and if these are mutually understood, different groups can form shared narratives and intention.

Once shared intention has been created, a shared meaning can be developed. Unfortunately, forming shared meaning, which includes knowledge transfer, incurs its own difficulties. The knowledge must be sufficient to include all relevant relations to allow effective functioning of the project. Sorting relevance is not easy to achieve, since there is a trade-off between the difficulty of settling intention and the relevant knowledge and appropriate evidence used to persuade. While the intention may have high levels of complexity, the knowledge must be readily memorable, and accessible enough that it can be shared between individuals and between groups. In other words, effective sharing of meaning implies that the knowledge can be readily processed. This means that different individuals must adapt their intentions, perhaps even simplifying them in order to share meaning. When widely divergent groups cooperate, the transfer of knowledge is fraught with difficulty, because intentions need to be expressed and understood for a shared meaning to result—this can be a complicated process of communication and translation.

When different groups are clear about their intentions and the process, they can cooperate well both socially and practically. When this occurs, this is the ideal situation, where the MFFD functions well in all aspects. This clarity can, however, erode when different groups, parts of different networks, are interdependent over a long period. The more interconnected they become, the more different expressions of intention can compromise the shared meaning and continued knowledge formation. This is exactly what we can observe in MFFDs over time.

The positive effects of knowledge transfer

Dutch civil engineers have traditionally insisted on simple flood defenses, because they are easy to manage and modify during design and maintenance. Yet, simple defenses have also caused unintended damage to the environment or the aesthetics of the landscape. Moreover, they imply intensive involvement by a hierarchical government. Multifunctional flood defenses would involve more groups, permitting a better management of the surroundings. There are signs of a changing culture, partly because technology is making complexity easier to manage. This complexity will also place demands on designs, ensuring that knowledge will expand and technological solutions are developed.

Such innovation has positive effects, and successful examples of MFFDs will overcome much reluctance, encouraging groups to look beyond their own narrow interests. Individuals or groups are willing to make personal sacrifices when they see a larger collective benefit resulting, and this is also the case with MFFDs. Of course, this only works when coöperation amplifies the aims and simplifies the governance process. For example, if adding functions persuades more parties to commit to reducing flood risk, this amplifies an aim. Similarly, if engineers and nature managers work together, for example by including a tidal marsh in the MFFD, the two functions strengthen each group's core aims over time, making a strong argument for knowledge transfer and interdependence.

Conclusion

The assumption behind the MFFD concept is that the synergy of different stakeholders working together both reduces flood risk and produces social, economic and environmental advantages. However, organizations, like human individuals, have limited flexibility and learn new tasks slowly. This accounts for many of the difficulties MFFDs encounter, though they are not always immediately apparent. Not only do organizations learn slowly but also they have different tasks, which may interfere. Groups develop strategic behaviors when they meet (Ten Heuvelhof 2010; 2016), to make it easier for them to assess the other's intentions and meaning. This allows them to learn to deal with the difficulties that emerge during the interdependent process of creating and managing the MFFD.

When designing MFFDs, we assume that the combined effort will be less than if each function were developed separately. To do this, groups have to align interests and expectations, and optimize their tasks, developing a normative way of dealing. Unfortunately, the process causes uncertainties and ambiguities, as well as ethical problems, though dealing with these problems does not necessarily lead to learning. Luckily, groups can choose tactical alternatives, design approaches to maintain action, or make discursive choices that ease intergroup contact, even if some meaning is lost.

*Figure 1:
Flooding Cherry
Burton, Yorkshire,
Great Britain (Photo
courtesy Zozzie9t9)*

Daniel Hogendoorn

CASE STUDY: GREAT BRITAIN

THE BRITISH ENVIRONMENT AGENCY: FLOODS IN ENGLAND

England floods frequently. While the damage is mostly economic, the number of floods and their geographic dispersion is surprising. England is 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 in 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 preached in Whitehall, the locus of English central government, in the 1990's. This 'New Public Management'-philosophy envisioned the EA as flexible, but able to keep public responsibilities. Instead, the EA proved to suffer from standing in an asymmetric dependency relation with groups at the central level, with little capacity to govern the local level.

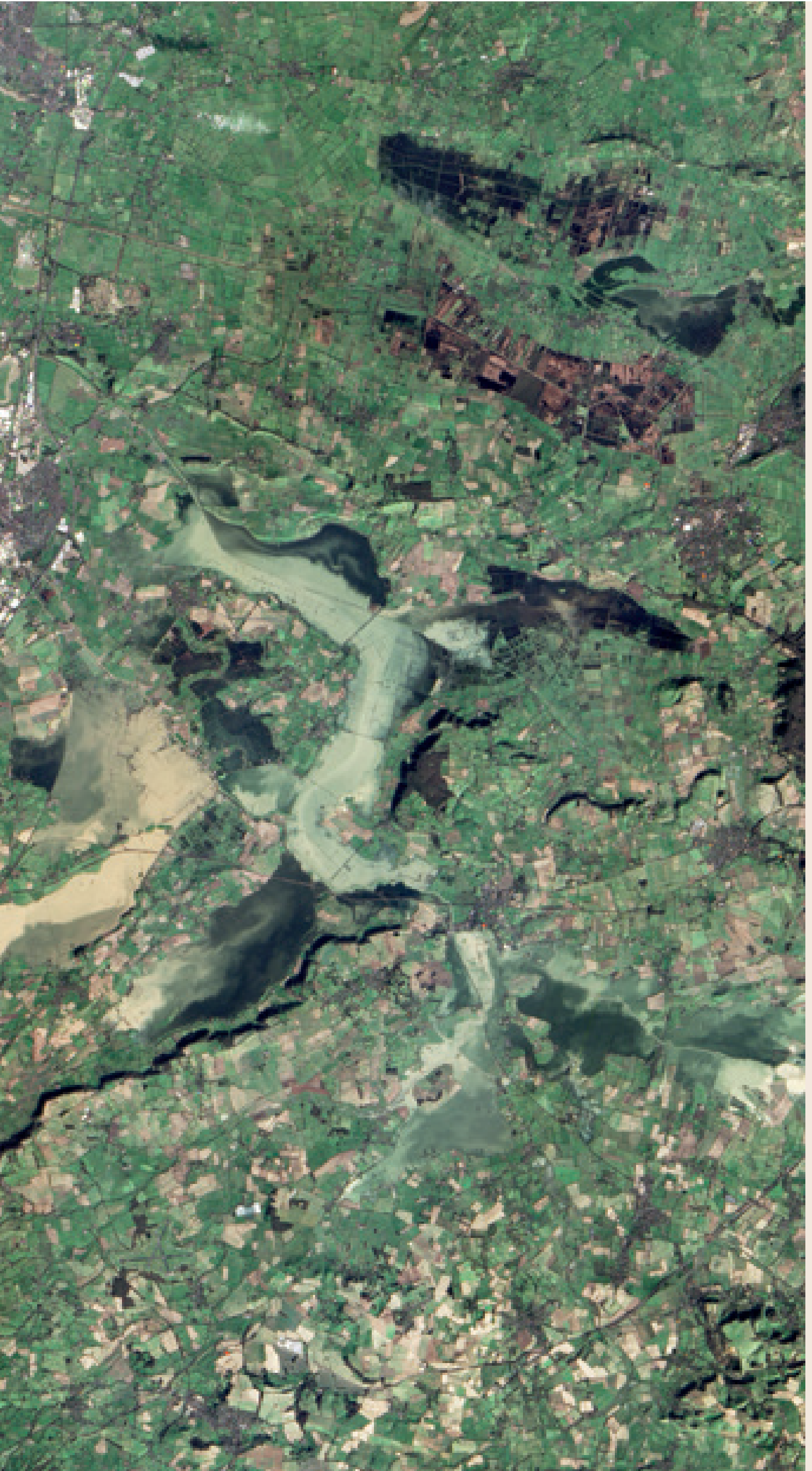
The EA depends first on the Treasury, the setter of UK's central budgets. Apart from frequent cut, until recently the EA had to compete for its flood budget annually. This complicated long-term planning and prevented a systems-view. While the budget-cycle has now changed, it shows the fragilities of being dependent on other organizations for finance, organizations that do not share the same responsibilities and thus priorities. The EA also depends on the Cabinet. During mediagenic flood events, the Cabinet rerouted resources overriding the EAs judgment. For example, more visible dredging in picturesque Somerset over investments in Hull deemed priority by the EA (Hogendoorn 2017). The cabinet has also reformed the EA's organization, by appointing EA-management with expertise in business and diplomacy rather than technical expertise in the environment, in line with novel priorities at the level of the Cabinet and Treasury. The EA's dependency is also apparent in its lack of control. The EA has no enforcement power. While England is enormously permissive to individuals and local authorities, it makes the EA responsible. At the same time, the EA proved constrained. It can make requests and issue warnings if the requests are not heeded. The EA is, however, responsible for flood management. Other local interests, such as housing development or farming, can compromise flood safety. In addition, the EA is itself constrained in its choices by centrally located groups that have different responsibilities. The Treasury has imposed rules requiring localized cost-benefit analyses, preventing a systems-view.

Where the English central government has invested in expertise at the EA, it has focused on methods that can effectively deal with uncertainties that can be assessed centrally. Such 'science-driven' methods often rely on easy to manage technology rather than hard to control and compare local assessments. For example, the Met Office uses a novel supercomputer to forecast floods for the EA. Another approach for dealing with 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 can spot relevant problems arising quickly.

The role of a MFFD
A multifunctional flood defense based for its design and maintenance in various local stakeholders, as a thought-experiment, might be of a little help here (though would need institutional changes).
The noted fragilities in governing stem



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 level,
- align anticipations according to shared responsibilities, and
- increase the exchange of views by necessity so 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 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 via 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 MFFD's, 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 Rowsell 2011). Local governments would, from this view, best be legally required to monitor and enforce flood risk and satisfy 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.

Figure 2 (left). Floods in southwestern England, an area known as the Somerset Levels, February 2014.

Figure 3 (right). The same area in November 2013. (Photo courtesy for both images: Jesse Allen and Robert Simmon, NASA Earth Observatory).

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

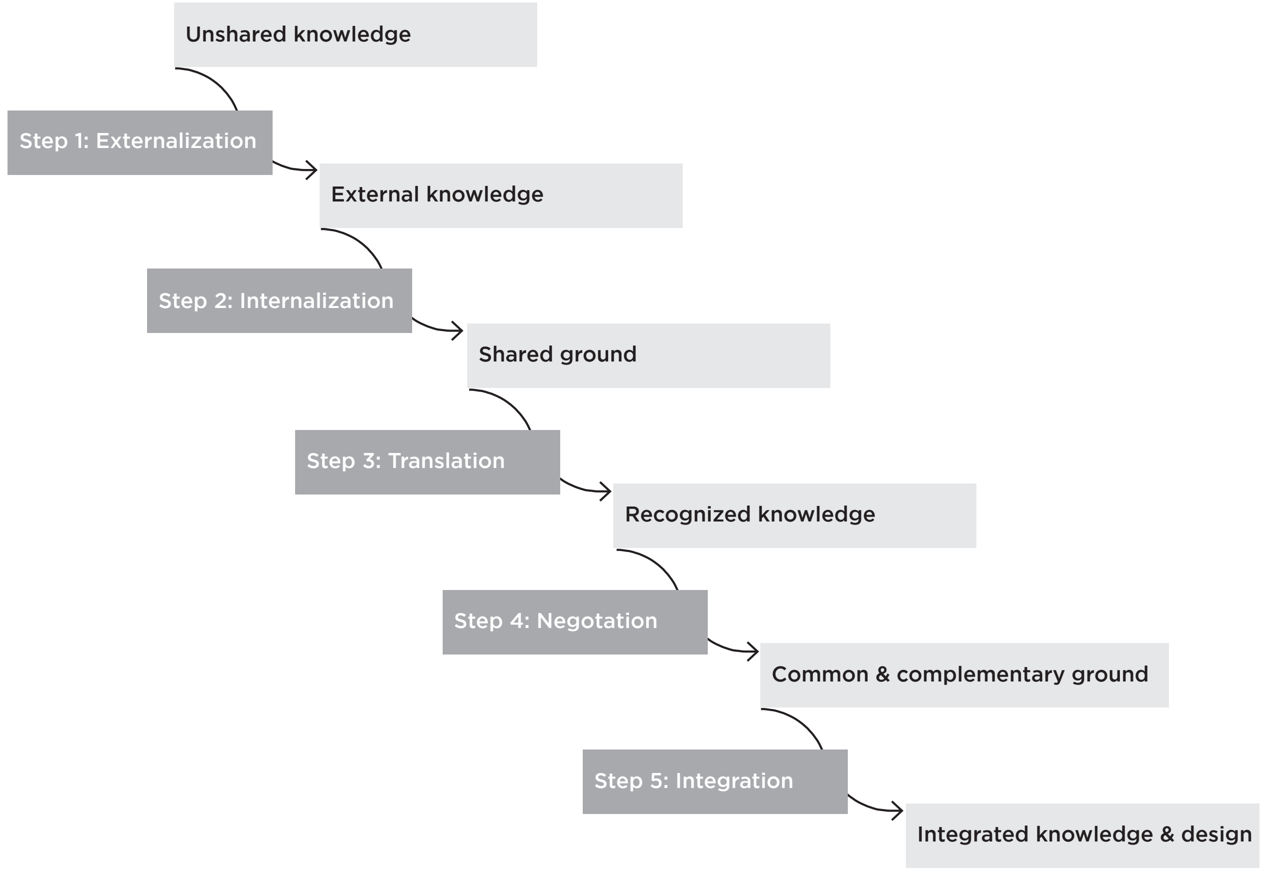


Figure 2 (left below). WAKI Step 1: Knowledge externalization by means of mini-lectures for colleagues.

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

Baukje Kothuis

WORKING TOWARDS ACADEMIC KNOWLEDGE INTEGRATION

FACILITATING INTEGRAL DESIGN OF MULTIFUNCTIONAL FLOOD DEFENSES

Dr. Baukje Kothuis was a Postdoc in the STW-MFFD 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 NWO Program 'Integral & sustainable design of ports in Africa' and for TU Delft and Texas-based universities as an independent consultant and co-PI in the NSF-PIRE research and education exchange program 'Coastal Flood Risk Reduction' to develop partnerships for international research and education.

The MFFD research program aims for integral design of multifunctional flood defenses. A team of academic researchers from multiple disciplinary backgrounds would integrate their knowledge to reach this goal. The aim of the current research project was to design and organize an interactive trajectory by means of Action Research to facilitate the collaboration process within the research 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 interweave 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), created for knowledge integration in an ICT project. The five-step model, now called the Working-towards-Academic-Knowledge-Integration-model (WAKI, Figure 1), reflects the steps we found to be productive and valuable for integrating activities in the MFFD program.

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 still shallow, since 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-interpretability 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, architectural models, games, 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.

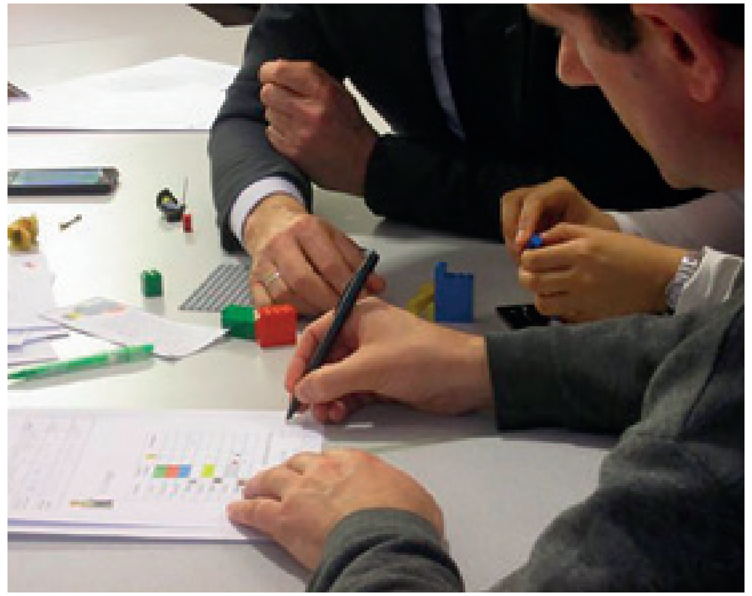
In the collaborative design process, these five steps are often iterated and do not always occur in this precise order. Designing, like many other creative activities, is a 'messy process'.

Figure 4 (below left). WAKI Step 3: Knowledge translation. Calculating with Lego©-game techical, environmental, social, and financial input.

Figure 5 (below right). WAKI Step 4: Knowledge negotiation. Workshop collecting, connecting and negotiating research-input and -output needs.

Figure 6 (below below left). WAKI Step 4: Knowledge negotiation. Choose optimal location for wind turbines on or near dike.

Figure 7 (below below right). WAKI Step 5: Knowledge integration.



AKI practices in MFFD program

We developed several ways to support knowledge integration within the MFFD program. This included three overarching and regularly recurring activities:

- Three-monthly *Program Reflection Days* (RDs) with all researchers in the program (PhDs and postdocs), often with the Program Leader, the MFFD Project Officer from STW, and - when relevant - various project leaders and supervisors. The RDs 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 develop activities to practically facilitate the knowledge integration process within the full research team. For the last goal, the PDMs worked fairly well. Although the postdocs 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. UDs were also only 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 UDs were successful in persuading researchers to summarize and communicate their work at various stages and for different audiences (including their MFFD colleagues). Users who did participate were generally positive about what they learned and could communicate during UDs.

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 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 tinker with 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-interpretabilities. However, collectively creating tangible objects often lead to an 'aha experience', making researchers aware of these disciplinary boundaries and better able to transcend them.

In the MFFD project, this pattern was clear with the maquette-game of wind turbines on 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 their knowledge, they were able to achieve a collective outcome.

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, additions, or maybe even remove parts. There is often a tendency to make serious games for knowledge integration ever more perfect, for example by using the most sophisticated simulations. Of course, this demonstrates professionalism, but it also has an adverse effect on knowledge integration. For participants, the perfection suggests that everything has already been thought of and is 'correct', which constrains new contributions.

This means that a topographic map with rough, hand-sketched contours provides a better base 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 toys, Lego© or 'play-Slime©' is more likely to prompt them to contribute and share than asking them to 'move blocks' virtually in a professional pre-designed environment on an iPad.In many 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.

Baukje Kothuis

SOME TOOLS FOR KNOWLEDGE INTEGRATION IN A MULTIDISCIPLINARY RESEARCH PROGRAM

Various interesting tools were used and/or developed to stimulate knowledge integration in the Multifunctional Flood Defenses program. This chapter will present a diverse collection of these tools, hopefully stimulating others to consider using some of them in future.

REFLECTION DAYS
During the five years of the MFFD program, Reflection Days were planned every three to four months. They were organized in rotation, each time by two or three researchers. In this way,

- All researchers had to think of the potential needs and the inputs of others in the team (creating awareness of the full range of research being done);
- Everyone was responsible, at least at one time or another, for the integration process (promoting a group process);
- A wider range of activities was developed than if only one person had organized all the RDs (which also made it more attractive and fun to participate);
- All the universities were visited, including those where fewer researchers were based (creating a more equal recognition of contributions).

Every Reflection Day included the following:
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 in its different manifestations. These visits include meetings with local practitioners, policymakers and/or other involved stakeholders, who served as guides and explained the MFFD. The intention was to see and learn something new, create shared experiences (building collective memories and trust), and connect to the 'real world' where our academic designs are supposed to land.

2. Activities to communicate specific knowledge about the discipline
These activities permitted researchers to share knowledge content with their colleagues in the program (accommodating steps 1 & 2 in the WAKI process, see page 128). For example:
- *Mini lectures*. These started with two or three researchers per Reflection Day presenting their discipline-specific knowledge concerning design of a MFFD. Later in the program, these mini lectures become presentations about the cases and research findings in the project. The lectures were kept short to allow ample time for discussion.
- *Speed-dating Plus*. These were five minute two-person meetings to explain research and/or a case-study to a colleague; after the meeting, participants had five minutes to write at least three things they had learned from their colleague, after which they found a new partner. After three meetings, we joined in a plenary setting, where everybody shared the 3x3 things they had learned, followed by discussion,
- *World Café* - see the following page for an extensive explanation.

3. 'Informal' activities: The goal of these activities was to develop personal ties and mutual trust, vital factors for collaboration in integral 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 example is 'cooking a full course dinner in teams': Start with the whole group deciding on the dinner theme, then split in smaller groups for different courses and have these small teams go out to buy the food within a budget. Subsequent negotiation about use of kitchen space, order of courses, time management, table laying and setting, and all things that (almost) go wrong, automatically provokes multiple interactions and requires different skills and knowledge. Enjoying the final dinner together provides a collective story for the duration of the program.

CO-DESIGNING TANGIBLE OBJECTS
In the course of the MFFD program, several groups of researchers from different disciplines designed tangible objects, and unanimously declared this had helped them most to more fully understand and integrate knowledge from their various backgrounds. During Reflection Days, this tangible co-design was also attempted as a group-exercise. Two examples of these co-design efforts became games:

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 people happy? 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, environment and nature, recreation, and housing, all involve different costs, but don't have the same priority for everyone. The game components consist of Lego© blocks, and as on-site 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 how MFFD stakeholders think. In practice, players are more interested in winning then in learning. As one of the developer said: 'Sometimes they can even become angry because they want to achieve something that is not possible, just like in real life. Or because they do not agree with the criteria, for example, if the environment can take priority over safety'. The game was used in several workshops with professionals, and on policy information days.
(Project by Julieta Matos Castaño and Juan Pablo Aguilar-López.)

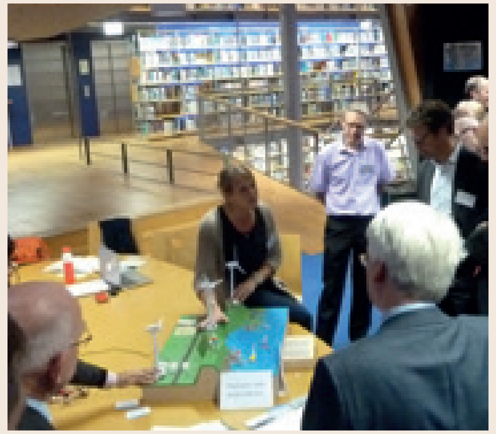


Figure 1. Explaining 'Wind turbines on a dike' technology & planning strategy game.

Figure 2. The 'MFFD-Decisions' Lego© game in initial development stage.

'Wind turbines on a dike' game
Wind turbines on dikes are economically attractive, but the wider consequences of such structures are relatively unknown. To address this, not only the risks of technical failure were discussed while developing this game (Hölscher investigated the effect of vibrations, Chen studied wave run up, and Aguilar-López transition constructions); and governance challenges were addressed (Kothuis considered stakeholder and policy issues, and Anvarifar investigated the deep uncertainties and flexibility issues in design and planning).

Based on this combined knowledge, the researchers co-designed an 'Electro© Game' with 25 potential locations ('holes') to put three wind turbines. The goal is to find the optimal combination of locations. Each location presents various challenges and every combination means new challenges. Each of these challenges lights up with a green or red light as soon as the player puts the turbine in one of the 25 holes. Knowledge integration was realized in two ways:

1. Internal: amongst researchers while developing the model, by discussing technology, governance and planning for the design, and then rating of scores.
2. External: in discussions with stakeholders, explaining what the game does and how it could be used in their field.

(Project by Paul Hölscher and Baukje Kothuis)

WORLD CAFE
The aim of the World Café is to promote a substantive discussion with a large group of people, using the diversity of participants. First, a problem or topic is discussed and reframed in constantly changing small groups, and finally it is presented from multi-disciplinary perspectives in a plenary session, permitting further elaboration and discussion.

The World Café starts by defining a shared problem (this might also be set on beforehand), which is then posed as a question by the facilitator. Small groups, seated at distinct tables, discuss the problem. At each table, there is a secretary, who may join the discussion, but spends most of the time recording the progress of the discussion in succinct 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 themselves disagreeing about something, be discussing an exciting new idea, or they may conclude they don't find the issue that important. The participants then have five minutes to frame a question that captures this new point. The secretary writes down the question.

The facilitator, who keeps track of time, interrupts again after five minutes (making 20 minutes in total). He/she asks the people to move to new tables, reshuffling the groups. Each participant is now sitting with new people (try to avoid sitting with others from the previous group). 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 question on a whiteboard. With the help of the group, the various evolutionary 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 more 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 WAKI-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 provoking recurring discussion about concepts and definitions. In our case the starting question was: 'What is a Multifunctional Flood Defense?'
(See also: Juanita Brown (2005). The World Café. Shaping our futures through conversations that matter. San Francisco: Berrett-Kohler)

Timo Hartmann

HOW MUCH TIME DO WE ACTUALLY HAVE TO DEVELOP MULTIFUNCTIONALITY?

REFLECTION

Prof.dr.ir. 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'.

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 5m 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 (the focus of large parts of the MFFD-program), but also almost always multi-functional. This multi-functionality is, of course, nothing new, in particular not in urban contexts, where flood defenses were always integrated into the existing urban fabric. However, this multi-functionality is a driver of complexity, both in terms of system-related technical aspects and in terms of the social and economic environments that these projects need to be realized in.

The projects in this third work package of the MFFD program show that, in addition to grasping 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 the multi-functional urban context. This is obvious in the case studies we conducted within the MFFD program. The planning, design, and engineering work on cases such as the Roof Park in Rotterdam, the Grevelingen-Volkerak-Zoommeer, or the Kinderdijk-Schoonhovenseveer started long before the four year MFFD program began and, with the exception of the Roof Park, none of them were even close to finished when the program ended in 2017. Considering that we can expect further sea-level rise 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. On the contrary, implementing new and innovative technical solutions is often hindered by long planning cycles. Can we even speak of innovative technologies if the innovations are only implemented decades later? Our case studies show that the true problem in our planning cycles does not stem 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 innovative technologies are rarely applied; while Trudes Heems found that the collaboration required on complex multi-functional projects is 'intense' and not 'as straightforward as it might appear'. In his provocative analysis of the UK situation, Daniel Hogendoorn described how governance structures can lead to inflexibilities in addressing pressing issues at local levels in a timely fashion.

So in some sense, all the researchers in this project have dealt with time and how social and governance issues can delay project progress. Considering the pressing needs to upgrade our worldwide flood defense systems, these are delays that can no longer be afforded. The MFFD program has therefore raised the awareness of the social and governance issues that slow down the realization of projects, such as the failure to apply new innovations, the need for intense collaboration, and the problems with top-down governance schemes. I can only suggest that the interested reader take a closer look at some of the project results, which this book can only briefly summarize.

Raising awareness is, of course, a very important first step towards overcoming the existing problems. But our efforts go beyond simply raising awareness and pointing out problems. Each of the research projects also developed suggestions for speeding up planning and engineering cycles. These range from suggestions for governing complex multi-functional flood defense project environments, to theoretical frameworks helping project practitioners to grasp and structure their project environments better, 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 a next generation of researchers that will provide more and more such stepping stones. Stepping-stones that will allow us to accelerate projects, so that we are able to react to the pressing challenge of sea level rise, and quickly.

Figure 1. Extreme high river discharge at the Waal in 1995. (Image courtesy Rijkswaterstaat Beeldbank)

Wil Thissen

MULTIFUNCTIONAL FLOOD DEFENSES: CHALLENGES FOR GOVERNANCE

REFLECTION

Prof.dr.ir. Wil Thissen is professor emeritus at Faculty of Technology, Policy and Management, TU Delf,. He is involved in various research projects in the fields of coastal and delta planning, and teaches at UNESCO-IHE Delft. In the Multifunctional Flood Defenses research program he was a supervisor in the project 'Adaptivity and Robustness'.

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 Scheveningen. These developments were not planned as such, but emerged as a consequence of often-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 clear 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 the world café or a game-like setting), an appropriate boundary object (such as a dilemma cube, a map, a touch table, or a joint 'model'), and adequate facilitation or knowledge brokerage. But while integrating knowledge is crucial, similar attention must be paid to including and integrating stakeholder perceptions and interests. Societal stakeholders bring their own perspective and knowledge, in addition to specific means and desires, some of which may be incompatible or even conflicting. For most MFFD situations, a variety of public organizations will be involved, including water boards, municipalities, regional planning agencies, and these will also come with their own sometimes implicit frames and preferences (Carton, 2007; Carton and Thissen, 2009).

Ideally, knowledge or science-based inputs can be used to identify the boundaries of feasible solutions, assess the pros and cons of alternative solutions or designs, and create innovative solutions or designs that benefit most, if not all, stakeholders. However, as several authors in this book have pointed out, establishing a basic level of trust between the different parties involved is a conditio sine qua non. Without trust, different participants will not be open to the perspectives of others. Still, establishing trust is challenging, as actors may be inclined to use their knowledge selectively, and behave strategically to further their own interests.

On top of the challenges of multi-actor, multi-stakeholder, multi-disciplinary processes comes the challenge of complexity and uncertainty: complexity, because MFFDs display interdependencies, both technical and managerial, in their daily development and evolution. Uncertainty comes in because both physical and socio-technical conditions may change significantly, and in unpredictable ways, over the lifetime of a MFFD. This will require, on the one hand, attention to including flexibility and adaptive capacity in the design phase of a MFFD, and on the other, the capability of the management and governance system to acknowledge uncertainty, and to be flexible, to learn and adapt in response to future changes, something which is at odds with the traditional culture of establishing fixed rules in flood management.

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' experience and development towards systems thinking, integration, participation and co-design in water and coastal management, 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.

Figure 1. Multifunctional flood defense in Dusseldorf, Germany; with at the left the northern car traffic tunnel entrance and at the right the Rheinwerft quay along the river Rhine.(Photo courtesy Mark Voorendt)

FOUR | PROGRAM CASE STUDIES

Baukje Kothuis

STRUGGLES AND JOY OF MULTIDISCIPLINARY COLLABORATION

PROGRAM CASES IN THE MFFD RESEARCH PROGRAM

Designing multifunctional flood defenses requires the input of knowledge from multiple disciplines, as has been frequently mentioned in this book. Researchers from multiple disciplines were employed in the MFFD-program, and they almost universally expressed a keen desire to collaborate. Different ways of collaboration were tried, explored, worked out; some were discarded as less useful, while others developed into useful products (see for example the 'MFFD-decisions' LEGO©-game and the 'Wind-turbines-on-dike' Electro©-game; p. 133).

One of the ways we stimulated multidisciplinary collaboration in the MFFD program was using what we called a 'Program Case'. This was a case study in which researchers from different disciplines worked together on one specific case location, aiming to deliver input for an integral design that addressed the specific challenges of that specific case. This sounds easy enough: look into the same case together, and deliver combined input for an integral design. This kind of collaborative work happens all the time in design, engineering and management consulting companies. Unfortunately, we learned that it can be quite difficult to achieve the same collaboration in an academic research program. Why was this so? Several issues can help to explain this:

1. Asking our researchers to share one of their individual case studies with other researchers posed the problem that it could potentially disturb carefully developed relationships. This became especially obvious in the Texas Program Case. Local contacts sometimes got confused who they were working with, and some even complained they were 'overfed' with researchers. Clearly, a Program Case with researchers from different faculties and universities needs to be managed carefully, with respect for existing and future relationships.

2. In the MFFD program, as in most academic research programs , there was hardly any time to initiate and manage collaboration activities, and the necessary expertise to do this was not provided. Conscientious Program Case management not only requires much time, but also knowledge of research and group processes, skill in managing organizations and people, and genuine engagement in and knowledge of the research topic. Postdocs are often assigned such management tasks; however, they are not selected on these skills, and as these activities do not provide material for publication, they may or often can not give this task priority. Luckily, some provision was made for this in the MFFD program, although it was by no means sufficient for all the input that the postdocs nevertheless delivered.

3. A third reason why multidisciplinary collaboration is difficult in the setting of an academic research program, is the different timelines. Not all researchers start at the same time (application and selection procedures are often not synchronous); and researchers sometimes get pregnant, sick, or decide to stop their PhD or get another job (in which case a new researcher has to start all over again). This means that researchers are often not in the same phase of research. When one researcher is looking for a case, another might still be writing their research proposal.

4. These different timelines also hinder collaborative academic publications based on the multidisciplinary Program Case: not all researchers in the group are ready to publish at the same moment. Additionally, it turned out to be extremely difficult to find the right journal for collaborative academic publications -or in some cases any journal at all. Journals from one discipline would refuse, commenting things like: 'Sorry, but this paper contains too many governance-related aspects', or 'Interesting, but this is far too planning-oriented for our readers.' Even finding a multidisciplinary journal was often problematic. For one thing, there are not many multidisciplinary journals; and secondly, those that exist are often not as highly thought of as 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 then working alone and requires supervising authors from the different disciplines. Co-writers always have to balance and bargain on the content of the paper, but with a co-author from another discipline, the discussions often already start on the use of certain concepts, definitions, and imagery, which can be quite different between disciplines. We discovered that for example the meaning of the words 'design', 'flood defense system', and 'multifunctional flood defense' can cause hours of discussion between researchers from hydraulic engineering, delta urbanism, multi actor governance, and landscape architecture. Co-publishing with a researcher from another discipline requires a lot of stance and sometimes even sacrifice to publish in 'less recognized' journals; and at times it turns out to be downright impossible.

5. Finally, there are time constraints. Researchers, especially PhD-students, have to finish their projects on time. In the Netherlands PhD research gets funded for a limited time, usually 4 years. Not only does each university want PhDs to finish as soon as possible (since the university gets granted about 90,000 euro for every PhD graduation), but the students themselves would rather not linger, as they will have no more income. Spending extra time on a multidisciplinary case study that might not lead to a publication and generally takes substantially more time to conduct than an individual case study will be less popular with PhDs and supervisors alike.

Despite having encountered all these difficulties, the MFFD-research team nevertheless managed quite well, bringing two groups together and fulfill the promises made in the program proposal, sticking to the conviction that multifunctional flood defense design requires multidisciplinary knowledge and collaboration. Two Program Case studies were conducted within the MFFD research program: the Rotterdam Roof Park and the Houston Galveston Bay Region in Texas, USA.

The Rotterdam Roof Park Program Case was a retrospective case study, as the strengthening of the flood defense, the construction of the adjacent shopping mall, and the development of the park above the mall and connecting it to the flood defense, had just finished when the MFFD program started.

An urban planner, a hydraulic engineer and a landscape architect worked together to create a framework for spatial dimensions of multifunctional flood defenses, using the Roof Park as one of their cases, publishing a co-authored book chapter based on their effort (Van Veelen, Voorendt & Van der Zwet 2015). Two other researchers collaborated on evaluating and analyzing the design process and the multi-stakeholder challenges within this process, from a policy/governance and an economic/management perspective. Although they were unable to get their collaborative research outcomes co-published, both of them could use the work as a case study in their respective dissertations (Matos Castaño 2016; Hogendoorn 2017 forthcoming). And finally, another landscape architect, starting his research later, considered the visual representations of the Roof Park, adding a new perspective to the case, further enlightening the design process and the multi-stakeholder issues in a multifunctional flood defense design (Raaphorst 2017).

The second program case was the Houston Galveston Bay Region in Texas; this was based on action research. Plans for a multifunctional flood risk reduction solution for this area are still in full swing. After Hurricane Ike destroyed millions of dollars in infrastructure and left thousands of residents homeless in 2008, local universities came up with different solutions for ways to reduce future flood risk. However, a combined and unified design has still not been made. In this MFFD Program Case, engineers and the social scientists approached the problem from a systems perspective. A geographer and a policy researcher collaborated to understand the impact of political values and institutional constraints on flood risk exposure, which in turn will determine the space engineers and architects have to implement their plans (Brand & Hogendoorn 2014). A hydraulic engineer worked on optimizing an integral flood defense system from an economic perspective (Dupuits et al. 2017), and an environmental engineer considered how adding nature-based flood protection measures could enhance functions of the rural environment (Van Loon pagew 149). Finally, together with researchers from policy systems and coastal engineering, a design anthropologist, coastal engineer and systems engineer co-developed a tool to include local stakeholder values in the design for multiple functions of a flood defense (Kothuis et al. 2014).

Although these studies and approaches are quite divergent, bringing all the research efforts together in this chapter shows how the MFFD program delivers an informative retrospective on the Roof Park design and useful input for future design efforts of a multifunctional flood defense system in the Houston Galveston Bay Region. This program case also led to a book, further collaboration in a research program funded by the US National Science Foundation, and several research commissions from local clients.

Over and above these accomplishments, both the researchers who collaborated in the Program Cases and the users of the knowledge developed in the case, said that not only did they learn a lot, but they also enjoyed the endeavor, considering it an enriching experience.

PROGRAM CASE: HOUSTON GALVESTON BAY REGION, TEXAS, USA

Nikki Brand, Baukje Kothuis

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 'Urban design challenges and opportunities of MFFD's up to 2015. She initiated the Texas Program Case in 2012 and has been involved ever since. Brand currently works as a researcher in the program 'Spatial Planning & strategy' and as an independent consultant in the NSF-PIRE Research and Education Exchange Program for Texas-based universities and TU Delft.

Dr. Baukje Kothuis was a Postdoc in the STW-MFFD 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 NWO Program 'Integral & sustainable design of ports in Africa' and for TU Delft and Texas-based universities as an independent consultant and co-PI in the NSF-PIRE research and education exchange program 'Coastal Flood Risk Reduction' to develop partnerships for international research and education.

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.

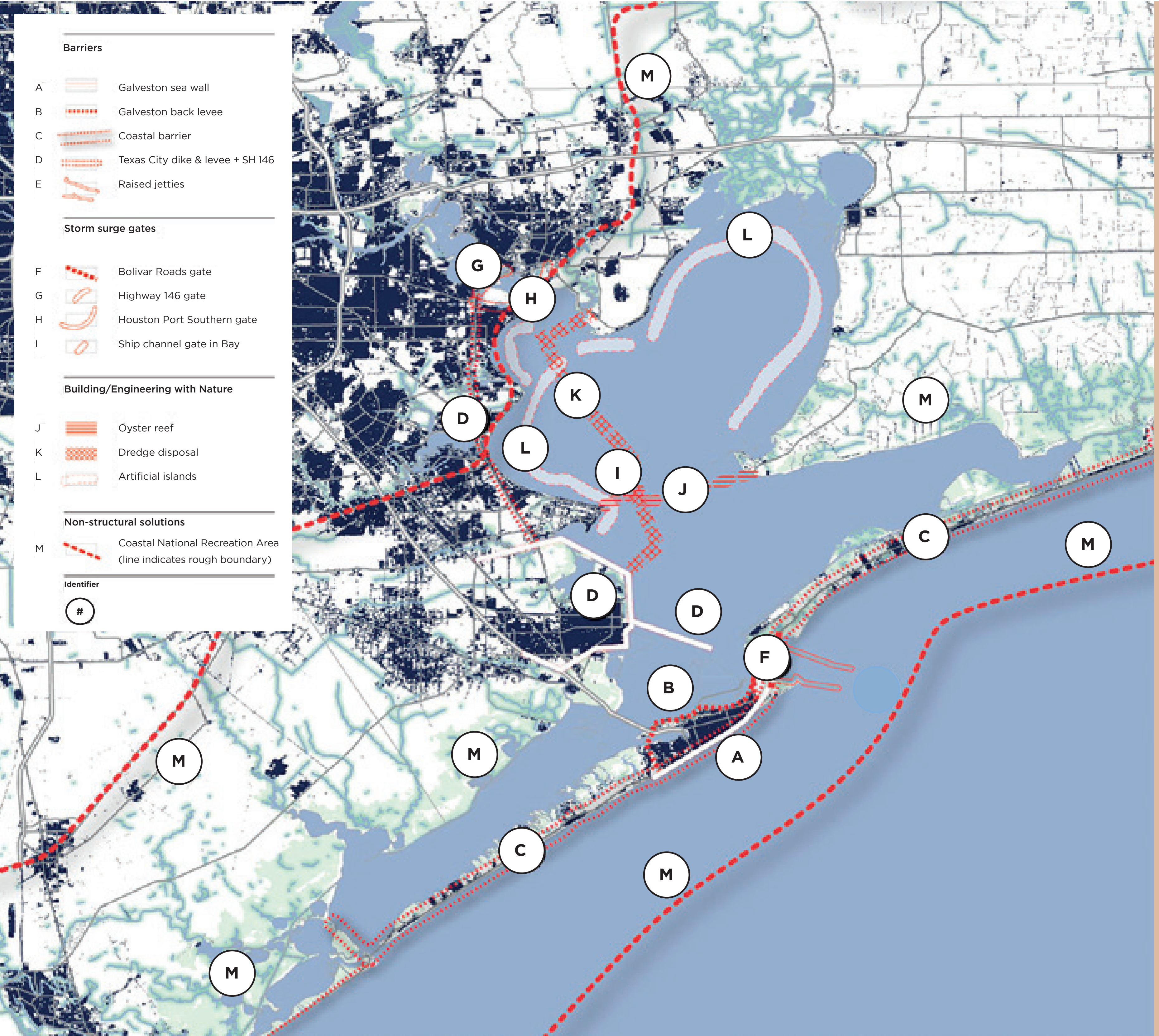
The Houston Galveston Bay Region in Texas is the fourth largest metropolis in the US, housing the largest petrochemical harbor in North America. Houston is located inland on Galveston Bay, and as a city, is notorious for not having land use controls. The city has expanded rapidly by incremental building 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 events claim lives and damage livelihoods on a yearly basis, the region lacks a comprehensive flood safety system. With the exception of Galveston's historical sea wall and the Texas City Levee, the region has no structural flood defenses. Flood risk is mitigated primarily by evacuation programs, using an infrastructure network unable to cope with the demand, thus making evacuation potentially lethal too. In 2005, the exodus of 2.5 million people from the region to avoid Hurricane Rita, claimed a shocking 107 lives. The region's flood risk issues remain urgent, and the possibilities to reduce these risks via the traditional approach of emergency management and recovery has reached its limits.

In response to Ike - the hurricane that devastated Galveston but just missed Houston's petrochemical complex - two university-based groups in the region studied and promoted flood risk reduction strategies. The first, based at Texas A&M Galveston, supported the concept of the so-called Ike Dike: a land barrier on Galveston and Bolivar Islands combined with flood gates, inspired by the Dutch Delta Works. The second, based at Rice University and known as the SSPEED-center, focused on a series of projects based on urgency and environmental concerns. While a floodgate across the Ship Channel would protect the petrochemical port from surge, a large national park known as the Lone Star National Recreational Area (LSNRA) would stop building activities in the flood zone and provide economic opportunities for leisure. The ecology of Galveston Bay would then remain untouched. As architecture professor Tom Colbert was a participant in SSPEED from the very beginning, adding spatial quality via architectural design was part of SSPEED's approach too. While the SSPEED center built its first contacts with Dutch knowledge via the architecture, ecology and governance routes, Texas A&M engaged with TU Delft's hydraulic engineers. The two were able to meet thanks to the MFFD research program.

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 challenge turned out to be so large, and the demand for knowledge and support so great, it could not be served by the MFFD program alone. MFFD researchers became part of a larger research consortium

Figure 1 (below). Gathering debris on Galveston Seawall one week after hurricane Ike in September 2008 (Photo courtesy: Jocelyn Augustino, FEMA).



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 formal 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.

Figure 2 (left). Map of Houston Galveston Bay Region showing various proposed interventions for local and regional flood risk reduction.

Figure 3 (right). Residences at the Bay side of Galveston Island; built on stilts to mitigate flood risk and comply to food risk insurance requirements (Photo courtesy Baukje Kothuis).

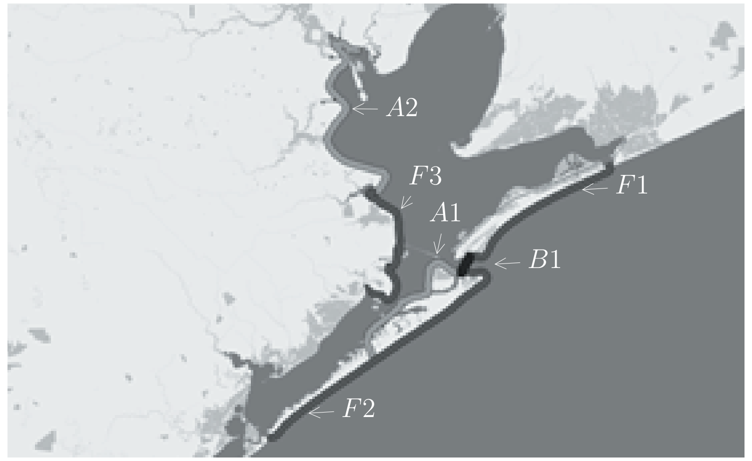


Figure 1. Galveston Bay area with contours indicating the defense types for the hypothetical application. from OpenStreetMap (©OpenStreetMap contributors, http://www.openstreetmap.org/copyright).

Three types of defenses:
A1, A2: a rear defense
B1: a front defense
F1, F2, F3: a defense with a fixed safety level
(Note that the contours are indicative)

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.

With influence of a front defense			Without influence of a front defense		
Year	**Defense**	**Height increase**	**Year**	**Defense**	**Height increase**
0	A1	From 0 to 5 meter	0	A1	From 0 to 6 meter
160	A1	From 5 to 7 meter	70	A1	From 6 to 9 meter
			130	A1	From 9 to 12 meter
0	A2	From 0 to 7 meter	190	A1	From 12 to 15 meter
150	A2	From 7 to 10 meter			
			0	A2	From 0 to 9 meter
30	B1	From 0 to 7 meter	80	A2	From 9 to 13 meter
100	B1	From 7 to 11 meter	160	A2	From 13 to 17 meter
170	B1	From 11 to 15 meter			

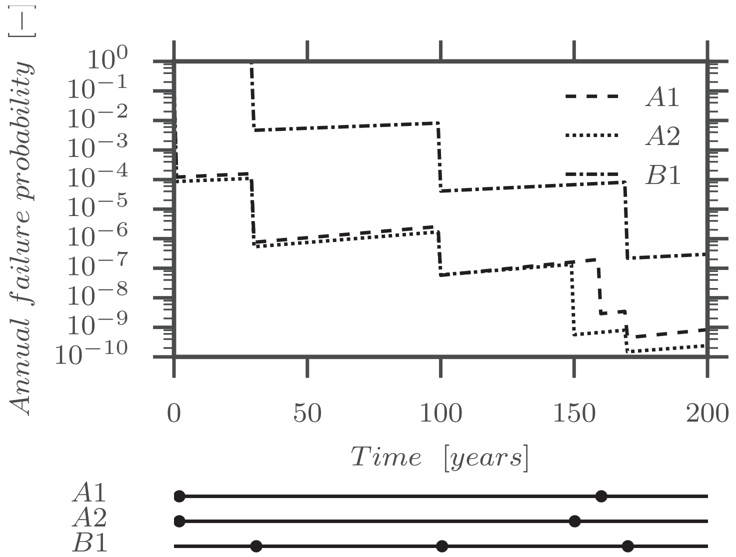


*Figure 2. Safety values in tie for flood defenses B1, A1 and A2 of Table 4, **with** the influence of a front defense. The corresponding timing of the investments per defense is shown as well.*

Guy Dupuits

FLOOD RISK REDUCTION SYSTEMS OPTIMIZATION

PROTECTING GALVESTON BAY SHORES AND THE BARRIER ISLANDS

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(Tentative) dissertation title: 'Economic optimization of flood defense systems with multiple lines of defense.'

PhD Supervisors:
Prof.dr.ir. Matthijs Kok, TU Delft
Dr.ir. Timo Schweckendiek, TU Delft

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.

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 a 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 can 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.

Figure 3. Overview of necessary steps in the numerical framework used to obtain economical optimal values for a coastal flood defense system

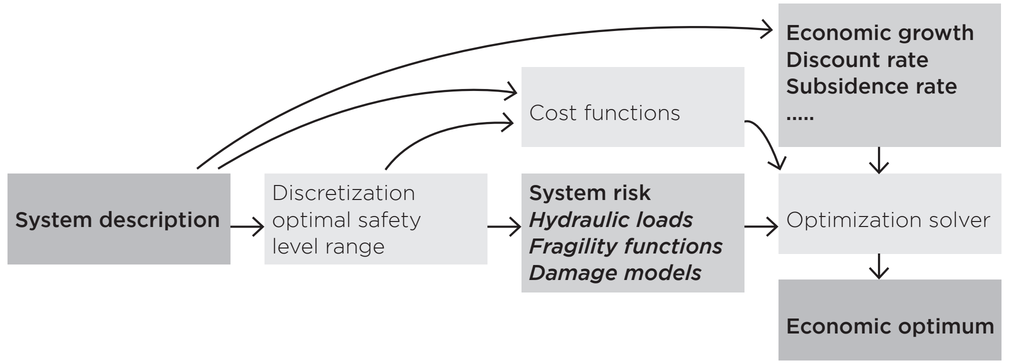


Figure 1 (top). Salt marsh along the Wadden Sea at Nieuwlandsreid, the Netherlands (Photo courtesy Jantsje van Loon-Steensma).

Figure 2 (bottom). Dune restoration project along Gulf Coast, Galveston Island, Texas, USA. (Photo courtesy Jantsje van Loon-Steensma).

Figure 3 (page 152, top). Salt marsh at Galveston Island, Texas, USA, with great egret (ardea alba) and watch tower (Photo courtesy Baukje Kothuis).

Figure 4 (page 152 bottom). Recreational use of salt marsh area at Galveston State Park, Texas, USA (Photo courtesy Baukje Kothuis).

Jantsje van Loon-Steensma

ENHANCING VALUES AND FUNCTIONS OF THE RURAL ENVIRONMENT BY MULTIFUNCTIONAL FLOOD DEFENSES

INSPIRATION FROM THE DUTCH WADDEN SEA REGION AND THE TEXAS COAST

Dr.ir. Jantsje van Loon-Steensma is a researcher and lecturer of Climate Change and Flood Protection in the department of Enviromental 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 spatial quality'. Her research focuses on climate adaptation by integrating functions in flood defenses. She combines hydraulic, ecological, geographical and economical aspects in the search for climate proof, robust flood defenses that in addition to flood protection, also favor nature, landscape, heritage, recreation or economic values.

Multifunctional flood defenses are often considered promising options to deal with spatial scarcity and integrate different stakes in densely populated and intensively used urban areas. In rural areas, as well, interests, values and stakes may compete at the intersection of land and water, and they may also compete for space. For example, many deltaic 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 its biodiversity, it also requires protection from storm surges. In these rural areas, the concept of multifunctional flood defenses 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 defenses 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 the site of oil and natural gas extraction , and host vital petrochemical industries. Furthermore, they both serve an important recreation and tourist 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 sedimentation on the seaward side of these dikes produced new salt marshes, new dikes were built to reclaim these areas for agriculture (for both grazing and arable land). Centuries of land reclamation 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 coasts 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

defend the islands and mainland against flooding by the Wadden Sea (excluding the Afsluitdijk, the barrier dike that created Lake IJssel in 1932). On the northern side of the barrier islands, facing the North Sea, the primary flood defense consists of dunes (>10 m high) and wide sandy beaches which the Public Works Department of the Dutch Ministry of Infrastructure and Environment actively maintains by dune protection programs and sand nourishment. At present, the dikes along the Wadden Sea coast are variously dimensioned to withstand extreme situations with a probable return frequency of once in 2,000 years - 10,000 years, with crests well above extreme storm surge levels (~4–5 m above NAP, Ministerie van Verkeer en Waterstaat 2007) and expected wave run-up. Because the Wadden Sea has a wave damping effect, flood defenses along the Wadden Sea coastline are designed for much lower extreme wave heights (~1–2.8 m) than the flood defenses (namely, the dunes) on the North Sea side of the islands (~10–11 m, Ministerie van Verkeer en Waterstaat 2007).

However, climate change is altering the hydraulic conditions (e.g., surge level, wave height, wind direction) that are associated with these extreme situations. This, together with the ongoing need to improve the dikes, initiated a search for new flood protection designs and ideas. The 'business as usual' strategy to improve flood protection in the Wadden Sea region has been to raise the dikes, without deliberately integrating other functions into the dike design. Due to the strict national and international nature protection policy concerning the Wadden Sea (including its salt marshes), seaward expansion of the dikes is not allowed. But how about including these salt marshes into the dike design?

Salt marshes provide characteristic and valuable habitats (see e.g., Adam, 1990) and have a natural flood-protection potential because they dissipate wave energy (e.g., Costanza et al., 2008; Gedan et al., 2011; Shephard et al., 2011). Lower wave height and reduced wave energy could have important implications for the required dike dimensions (in particular, dike slope and height) and the need for dike slope and toe protection structures (such as hard revetments and rocks). In addition, the presence of salt marshes could have a favorable effect on other aspects of dike design, such as improving dike stability and reducing piping (Venema et al., 2012).

Integrating the salt-marsh foreland into the dike design thus offers a challenging opportunity to combine or even strengthen the Wadden region's unique nature and landscape values with flood protection. This idea was further explored in the Delta Program Wadden Region (Van Loon-Steensma et al., 2012) and in the MFFD program, and is now included in a major dike research program being implemented by Water Authorities in the north of the Netherlands. Integrating salt-marsh foreland into the dike design implies not only a widening of the physical flood defense, but also a shift towards a broader flood protection concept that includes other functions and values as well.

Flood protection along the Texas Coast

The Texas coastline also comprises an elongated stretch of barrier islands and peninsulas, which form the border between the Gulf of Mexico and several bays and estuaries. The bays and estuaries are fed by numerous rivers that drain rainwater from higher inland areas into the Gulf of Mexico, and are flanked by extensive wetlands consisting of salt, brackish and freshwater marshes, grass meadows, prairies and forested wetland and floodplain forests (Blackburn, 2004). As in the Wadden Sea, the shallow bays and estuaries are highly productive areas, attracting numerous birds and making the area an important stopover area for migrating birds on the Central Flyway (a major route for birds migrating from North America to Middle and South America). Wetlands inundated by coastal flood tides or flooding rivers are protected for their biodiversity and habitat, both in the framework of the Ramsar Convention and the US Clean Water Act.

The Texas coastal area was originally inhabited (very sparsely) by Karankawa Indians. European penetration of the Texas coast started in the 16th century. In the 19th century, the city of Galveston was an important port (and port of entrance for immigrants), connected by rail to the US hinterland, via

Houston. After the devastating hurricane of 1900, however, the port facilities were shifted to a more sheltered location inside Galveston Bay (the current Houston port). A channel was dredged to connect the new port with the Gulf, and a seawall was constructed to protect the city of Galveston from future flooding by hurricanes.

In the 19th century, the area was already recognized as a good agricultural area, for crops such as cotton and sugar cane; this attracted new settlers and entrepreneurs and resulted in the development of the coastal area around Galveston Bay. The low-lying area around Texas City was purchased around 1890 for the purpose of developing a port and industrial center (Campbell & Moncla 1998). A channel was subsequently dredged and a railway connection added, and the population steadily increased. In order to prevent the channel from silting, between 1910 and 1915 a dike was constructed that would divert the silt-bearing current from the channel. This dike would later be improved to protect the petro-chemical industry that developed steadily from 1930 on. Huge petro-chemical industries have since developed around Houston and other locations along the coast, such as the Freeport industrial area. This area is protected from surges by a dike, as are some other industrial areas and settlements. As flood protection is currently designed for a 1/100 year event and flooding occurs with each major hurricane passing the region, several ideas have been proposed to protect the Houston-Galveston Bay Region from flooding; these include different structural measures such as the Ike-Dike on Galveston island, and dams and barriers along the Houston Ship Channel.

Apart from these intensively urbanized and industrialized locations, until recently, extensive stretches of the Texas coastal fringe have remained almost pristine. The seaward side of the barrier islands and peninsulas consists of a beach with low sand dunes (1-5 m), while the bay and estuarine side have grass meadows and marshes (sometimes grazed by cattle). The coastal fringes on the mainland side of the bays and estuaries, also have extensive marshes and grass meadows, which transform landward into prairies with patchy vegetation of grass and bushes. The river floodplains also often contain bottomland forest. A substantial part of the wetland area and bottomland forest along the Texas coast is currently federal or state protected. The majority of the prairie land, on the other hand, is privately owned, primarily used for ranching, but with some homes interspersed. Some wet prairies are also farmed for rice, which requires an actively managed water system. Because of the modest tides in the area, the extensive flat, low lying coastal rural area is only inundated by seawater during extreme conditions associated with hurricanes. No structural flood prevention measures are in place in these areas, though a hurricane evacuation route is indicated by signs.

The sandy strip adjacent to the Gulf is a popular recreation and tourism destination. Especially on Galveston Island and the Bolivar Peninsula, both being close to Houston, numerous beach houses have been constructed very close to the beach. These houses are built on stilts to protect them against coastal flooding caused by hurricanes. Sometimes the owners of these vacation houses have tried to stimulate dune formation in order to protect their houses. The trend of building beach houses is continuing, resulting in an increasing transformation of former natural beach and dune area into a recreational and residential area. Even the marsh area along the bays and estuaries near Galveston is increasingly being used for housing, transforming these wetlands into recreational and residential areas as well.

Although building on stilts and stimulating dunes provides some protection against flooding, a substantial number of beach houses is severely damaged each time there is a hurricane. However, such damage has not hindered development of the coastal fringe, because flood damage is generally covered by flood insurance. Concern about the flood risk associated with these developments and their negative impact on nature values has led to the idea to preserve the coastal zone with its mosaic of wetland habitats for nature conservation purposes and to mitigate hurricane damage, at the same time providing the greater Houston area with opportunities for outdoor recreation for (Blackburn, 2013).

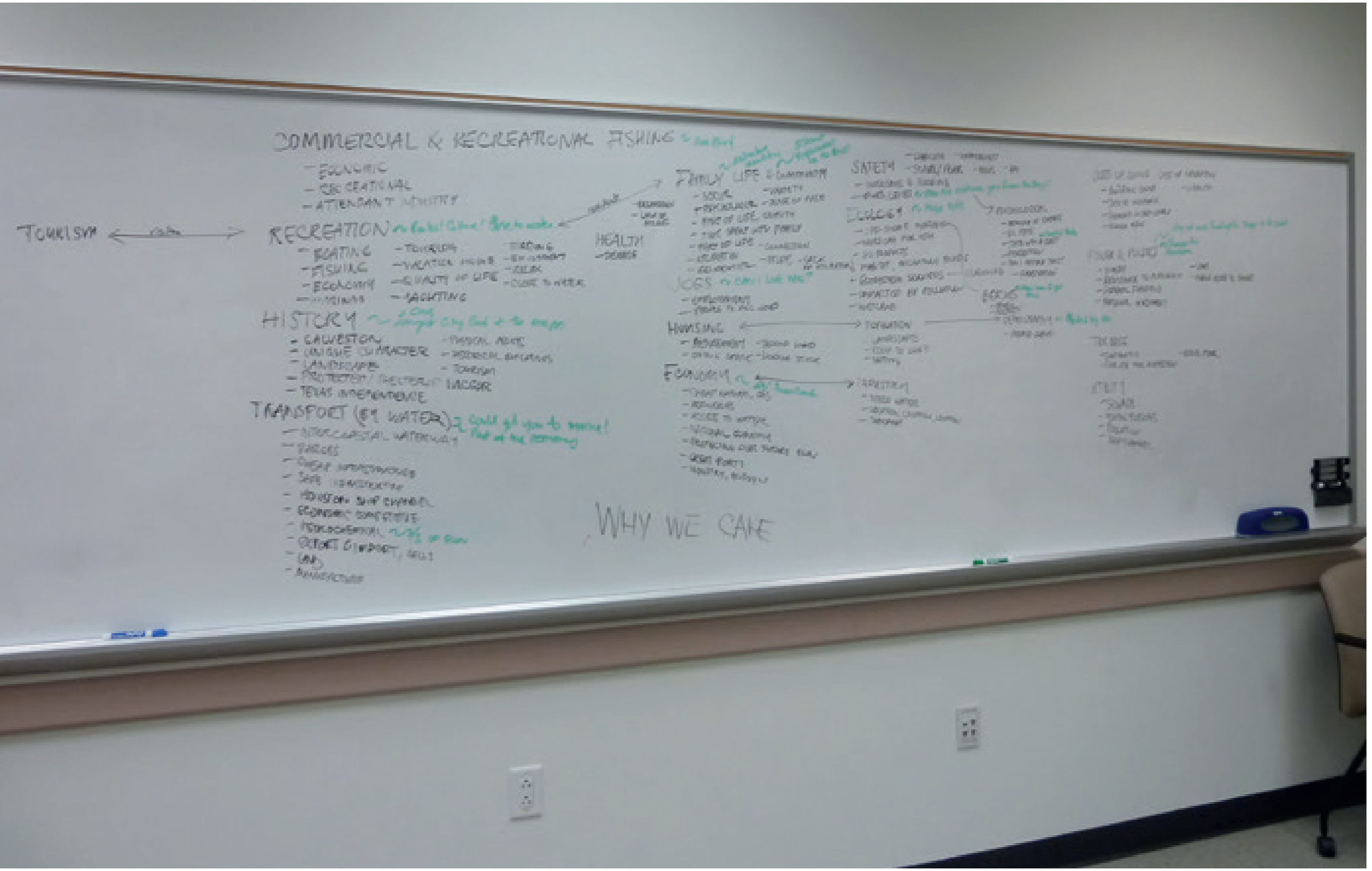
Including wetland habitats in flood protection

Currently there is an increasing interest in integrating natural habitats in flood defense schemes in both the Wadden Sea region and the Texas coastal region. Nevertheless, there are major differences between the approaches suggested, rooted in the different flood hazards and natural features of the regions, but also in differences in policy, governance structure, and attitude toward flood risk.

In the Netherlands, preventing floods still forms the core of the Dutch flood safety management strategy. This flood prevention strategy is the result of centuries of flood protection practices and lessons learned from historical flood disasters. The size of dikes is determined based on a cost-benefit analysis, with crests built well above the expected extreme storm surge levels and wave run-up. Integrating salt-marsh foreland into the dike design would only result in adjusted dike dimensions (in particular, dike slope and height) and affect the need for dike slope and toe protection structures (e.g., hard revetments and rocks). Nevertheless, such a multifunctional design for a wider dike zone would be beneficial for both nature and landscape values of the Wadden Sea region.

In Texas, on the other hand, the idea to include wetland habitats in the flood protection strategy for rural areas favors a spatial flood risk strategy. Assigning coastal wetlands, prairies and bottomland for nature conservation could prevent their becoming built up. With no permanent construction or vacation homes (beach houses) present, the risks associated with a flood would diminish substantially. However, this implies a shift from a narrow recovery based strategy (based on insurance) towards a broader multifunctional spatial planning strategy across the coastal zone.

Figure 1. Systems and values at stake in the Houson Galveston Bay area, as expressed by participants of CIGAS Workshop October 2014, Texas, USA.



Baukje Kothuis

STAKEHOLDER VALUE INCLUSIVE DESIGN

USING THE CONTESTED ISSUES GAME STRUCTURING APPROACH (CIGAS) IN TEXAS

Dr. Baukje Kothuis was a Postdoc in the STW-MFFD program at the Faculty of Technology, Policy & Management, TU Delft in the project 'Integrated design'. Currently she works at Faculty of Civil Engineering & Geosciences as a researcher in the NWO Program 'Integral & sustainable design of ports in Africa' and for TU Delft and Texas-based universities as an independent consultant and co-PI in the NSF-PIRE research and education exchange program 'Coastal Flood Risk Reduction' to develop partnerships for international research and education.

If we want to incorporate multiple functions in a flood defense structure, system or strategy, it is imperative that we consider the different and often diverging interests and values of involved stakeholders. Since these interests and values are not always self-evident, stakeholder consultations are a vital part of an integrated and sustainable design trajectory for a multifunctional flood defense (MFFD). However, consulting stakeholders can be done in many ways; this can range from 'informing' stakeholders to actually facilitating them to express their local knowledge and values, and deriving design strategies based on this input. In the Texas case, MFFD researchers had the opportunity to continue developing a new tool: the Contested Issues GAme Structuring approach (CIGAS).

In the Houston Galveston Bay Region, many issues need to be addressed when designing a flood protection strategy: technological aspects, ecological and environmental factors, and social issues (Blackburn et al., 2014; Sebastian et al., 2014). Not surprisingly, the stakeholders represent a large and extremely diverse group. In 2012 - when the MFFD research group became involved in this case - several stakeholders were already vehemently arguing about the 'best solution' for the region. This heated debate was further inflamed by the local press, and representatives of local governments as well as politicians. On several occasions, individual stakeholders held bilateral consultations; and larger configurations of stakeholders met each other at hearings or informative meetings where emotions often ran high. The debate mainly focused on the pros and cons of structural solutions, such as building flood barriers in the Ship Channel at Houston Port and Bolivar Roads, or creating extensive levee systems along the barrier islands and the West Bay area. Although all parties seemed to want to find a solution that protected the Houston Galveston Bay region and provided extra functions and benefits for the majority of stakeholders in, a solution that satisfied all or most stakeholders seemed far away. The decision-making process was at an impasse.

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 (Slinger et al. 2014). Accordingly, the team proposed conducting a workshop along these same lines in the HGB region. The intention was two-fold: First, to approach the disputed issues in Texas from a different angle (value-based instead of solution-based), with the intention of creating commitment for joint action. And second, to explore the boundaries and merits of the CIGAS stakeholder consultation method in a new environment. The main stakeholders were kind enough to grant this request, and generously helped to facilitate the endeavor.

In October 2014, we conducted a CIGAS workshop in Houston and Seabrook City, Texas. Sixteen participants attended. 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 to explore the different values and interests held by the stakeholders, and to consider potential outcomes for the contested environment. As input, the workshop uses knowledge of the local biophysical and social systems,

The CIGAS-approach was first introduced in 2011 in South Africa in the Great Brak region by Jill Slinger, Scott Cunningham and Leon Hermans (see Slinger 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). The approach has also been applied in the Netherlands (Energetic North Sea, 2015), on Texel (CoC-oChannel, 2016), and in Ghana (Sustainable Port Development, 2017). Please contact j.h.slinger@tudelft.nl or b.l.m.kothuis@tudelft.nl for further information on applying it in your field.

We would like to express our gratitude to Jim Blackburn, who was indispensable to us in executing this CIGAS workshop.

Table 1 (below).Three major coalitions of stakeholders - CIGAS Workshop October 2014, Texas, USA.

Table 2 (below below). Four outcomes on the Pareto Optimum - CIGAS Workshop October 2014, Texas, USA.

Three major coalitions of stakeholders - CIGAS Workshop October 2014

Local interests	National interests	Infrastructural interests
- State and local government - Citizens on the water front - Citizens in the surge zone - Environmental and tourism interests	- Federal government - U.S. Army Corps of Engineers - Industrial and port interests - Flood insurers - American people	- Infrastructure provision - Emergency response teams

Four outcomes on the Pareto Optimum - CIGAS Workshop October 2014

Outcome	Description
An Enhanced and Rejuvenated Relationship with Nature	Flood protection is designed with principles of eco-tourism, and broad public access to environmental and recreational resources. A priority is given to ecological health over safety and urban development.
Self-Reliant Communities	Flood protection is designed in multiple layers, with an emphasis on the needs and contingencies of local communities. A priority is given to individuals and communities to assess their own risk and develop their own appropriate responses.
The Over-Engineered Solution	Flood protection is designed to be comprehensive and all-encompassing. The resultant designs involve large and capital intensive structures which emphasize hard infrastructure over soft. Safety is a high priority.
Waiting for the Next One	Flood protection is minimal, and primarily focused on industrial zones where there are obvious economic and environmental losses to be addressed. Urban expansion continues apace, with more and more citizens living and working in the flood zones.

and the effects that the infrastructure measures might have.

A brief description of the approach used in a CIGAS workshop is provided below. An extensive overview of the method can be found in Cunningham et al. (2014) and its application in Texas in Kothuis et al. (2014).

Building group trust is an important aspect of a workshop where sensitive issues are at stake. Asking participants to express their true values and interests in an environment where 'adversaries' are expected, is a delicate process, and will not occur when trust is absent. For this reason, the CIGAS method starts by personalizing the group to the individual scale. Participants are viewed as more than a representative of an organization or school of thought; they are also inhabitants, vacationers, home owners, who are connected to the Houston Galveston Bay region by family, tradition, sport, work, passion, religion, culturally, etc. The workshop facilitates this personalization by asking participants to introduce themselves to the group by drawing on a large map where they live, where they originally come from, and their area of interest and/or expertise (Step 1. 'Map-exercise', see Figure 2 next page). This step often yields unexpected personal connections at the individual level; and at the group level, it creates distinct visual insights into the composition of the current group. In the Texas case, it became immediately clear to the workshop participants that the east side of HGB was not represented; this was something they took into account in the remainder of the workshop when addressing and representing stakeholders.

The 'real' work then commences with participants deciding as a group what the main stakeholder configurations are (Step 2. 'Who cares?', see Table 1, page 156), and which systems and values are at stake (Step 3. 'Why do they care?' see Figure 1). Both steps help participants become further aware of complexities and multiple interests, creating the design space needed for step 4. In this fourth step, participants split up in smaller, multi-expertise groups and are requested to envision alternative futures for HGB, which reduce flood risk or protect the area. At this stage, they are asked *not* to consider the design or technical implementation of the defense. Instead, participants are invited to imagine the outcomes for the HGB they would happily dream about (utopian outcomes) and the outcomes that would represent their worst nightmares (dystopian outcomes). These outcomes may extend way beyond the current technological state-of-the-art, they do not need to be politically correct or please everyone, and they do not need to be feasible in the short term. The only limitation is 'physically impossible' (e.g., coloring the sea pink because it matches my swimsuit). In the Texas-group, some of the names given to the outcomes represent the broad out-of-the-box thinking this step induced for the participants: e.g., 'Waiting for the Next One', 'Yo-Yo Houston' and 'Cabaret'. This broad spectrum, although probably not directly translatable into actual designs, is nevertheless very important for flood risk reduction experts in that it stretches their imagination and extends their design space.

In Step 5 ('Outcomes') each group presents their outcomes to all workshop participants; this often produces laughter and recognition. Utopias and dystopias are described using drawings, maps, constructions, schedules, sometimes even poetry or songs, and are each given a distinctive name. In Step 6 ('Ranking'), the participants rank each outcome from the perspective of the stakeholders they identified in Step 2. Though every participant could rank outcomes according to their personal perspective, not all the identified stakeholders may be present in the workshop group. To provide a more inclusive listing, participants step in the shoes of the identified stakeholders and rank outcomes from each stakeholder's perspective. The disadvantage is that this generates perceived rankings, which will be less accurate; the advantage, on the other hand, is that it creates further awareness of the multiple interests and values at stake.

Next, Pareto-optima calculations are made of various combinations of these outcomes (Step 7. 'Pareto optima'). Potential conflicts are addressed by identifying the design space along the Pareto frontiers. Feasible coalitions of stakeholders and potential clusters of actions to reach a combined outcome are identified. The calculations and modeling in this step are done by the workshop facilitators and presented to the participants the next day. In this last step (Step 8. 'Exploring joint action'), participants discuss the design space, feasible coalitions of stakeholders, and potential clusters of actions based on the workshop activities in Step 1-6. They thus explore the space for commitment to joint action.

Workshop Outcome and Follow Up
The workshop provided insight into the contested situation by exploring the following three central issues:

- 'Who is affected by flooding?'
Workshop participants identified eleven groups of stakeholders; in further discussion, participants grouped these stakeholders into three major coalitions (see Table 1).

- 'What do the stakeholders care about?'
Participants discussed and described the systems and values important to them, which are shown in Figure 1, page 154). Based upon the stakeholders and values involved, they subsequently designed the utopian and dystopian possible 'outcomes' of the Houston Galveston Bay region. These took the form of 'rich pictures' of possible flood control measures and their impact on infrastructure, the economy, citizens, and the environment. Four of the seven scenarios discussed in the workshop are outlined in Table 2.

- 'How are stakeholder values embedded in the outcomes?'
After developing the outcomes, participants rated the outcomes according to the needs and priorities of each of the stakeholders. Not surprisingly, representatives of the different stakeholders favored the outcomes to differing degrees. The perceived alignment in priorities across stakeholders led to a recognition of coalitions and common interests, and also an appreciation of the issues on which the various coalitions diverge.

The workshop revealed irreconcilable differences between stakeholders in terms of preferred outcomes. Of course, these differences must be treated with care, since choosing a single outcome may favor one stakeholder at the expense of others. The goal of the workshop is not to take sides, but rather to develop a common understanding of the problem and a commitment to further action. One possible route forward is to eliminate the lose-lose outcomes, enabling participants to focus on the wins. Possible winning solutions (for at least one of the identified stakeholders) are identified in Table 1. The workshop also addressed the themes of coalition formation, bargaining and stakeholder management. A full report of the workshop can be found in Kothuis et al. (2014).

The workshop participants recognized the importance of developing joint action; in this sense, the workshop was a success. They also agreed that the workshop provided an incentive to form a platform where key-players 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, much remains to be done: for example, a follow-up workshop focusing more on functional engineering requirements to further explore potential flood risk strategy design based on the values and interests expressed by the local stakeholders in the CIGAS-Texas workshop.

Figure 2. Map exercise at CIGAS Workshop October 2014, Texas, USA.

Figure 1.
Galveston Island, residential area and dunes along the Mexican Gulf coast (Photo courtesy Baukje Kothuis).

Nikki Brand

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

GALVESTON ISLAND'S FLOOD RISK CHALLENGE

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Galveston Island 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 storm surges, most notably the 1900 Great Galveston Hurricane, and Hurricane Ike in 2008. The 1900 hurricane left an estimated 6-8000 dead and prompted the elevation of the entire city by approximately 10 feet, plus the construction of the Galveston Sea Wall on the Gulf-side (Bellis Bixel & Hayes Turner, 2000; Wright-Gidley & Marines, 2008). The back and west end of the island remain unprotected, and as a result were flooded during Hurricane Ike in 2008.

Given its vulnerability and key importance to stopping storm surge for the region, Galveston Island 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 haphazard: a patchwork 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 or the Texas City levee, were only built under exceptional circumstances: after a flood event, and with considerable financial support from federal agencies.

An enquiry into Galveston's governance arrangement for flood risk reduction
In contrast with the Netherlands, where flood risk reduction has focused on prevention, constructing a flood defense in Texas may thus face considerable obstacles. Future strategies may still go in the other direction, with spatial measures that reduce vulnerability to flooding, rather than preventing it. As such it's worth investigating governance and planning as boundary conditions for the first two components of the multi-layered safety approach: prevention and spatial planning (STOWA, 2017). What kind of agencies are involved in flood risk reduction and spatial policy on Galveston Island? And does this local governance arrangement for flood risk reduction favor prevention or spatial planning? To answer these questions, desk research and in-depth interviews with local representatives and experts were combined, the detailed results of which have already been published (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
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 Texas A&M University of Galveston. Galveston's governance arrangement for flood risk reduction is composed of a variety of different local agencies, ranging from multiple-purpose authorities (the City of Galveston and Jamaica Beach) to single-purpose authorities (the Galveston Park Board of Trustees) and private non-profit organizations (Galveston Economic Deveop op-ment Partnership) 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.

Figure 2. Galveston Island, West end, after hurricane Ike, 2008 (Photo courtesy FEMA, Jocelyn Augustino)

Figure 3. Galveston City (Photo courtesy NASA)

The only agency that explicitly mentions safety from flooding in its directives is the Texas General Land Office, a state authority (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 jurisdiction on the island is a complex matter. With the exception of Jamaica Beach, which has its own local government, the City of Galveston 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 successfully challenged the so-called rolling easement in 2011, a legal tool that allows mandatory public access to the beach following the vegetation line.

Spatial planning

Although greater Houston is internationally known for its absence of zoning (Lerup, 2011), Galveston City does have some of the basic US planning tools (Berke et al., 2006): a comprehensive plan, land use regulations (LDR), and building codes. For an outsider, it's hard to get a proper understanding of how 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 effective or up to date. For example, the disturbing findings from the 2004 Galveston Island Geohazard Map (which put much of Galveston's west end in imminent danger of flooding) were never translated into planning policy. To avoid controversy, new land use regulations for beach house construction and dune restoration in the coastal zone were removed from the 'revamped' regulations accepted by the City Council in February 2015.

While integrating water concerns into spatial plans would seem a logical step, this seems hardly to occur in Galveston Island. In fact, lack of integration of spatial plans (or even conflicts) appears to be a systemic problem in the United States in general, undermining the potential to reduce vulnerability to flooding (Berke et al., 2016). In contrast with the Netherlands, where coordination between different spatial plans is mandatory, in the US vertical integration of plans is often lacking. Thus, at first sight, spatial planning in Galveston does not offer ready-made tools to effectively reduce vulnerability to flooding.

The ownership issue

Unlike the Netherlands, where no real debate on property rights exists (Hobma & Schutte-Postma, 2010), these are key to US planning discourse (Berke et al., 2006) and to political debate in Texas (Brand & Hogendoorn, 2015). As mentioned earlier, the jurisdiction of the State of Texas in the form of a rolling easement on the beach has been successfully challenged in court (McLaughlin, 2013). In theory, the Texas General Land Office owns the so-called 'wet beach', an ownership that automatically relocates along with the vegetation line. Now the vegetation line is no longer commonly recognized as the demarcation between private and public property, the TGLO - the only agency that has safety from flooding among its directives and possesses considerable funding - has discontinued nourishment projects on Galveston's west end, as public funds cannot be used to nourish private land. Thus, the agency in Galveston with the most potential to act for flood risk reduction has been sidelined, both in terms of ownership and in competences. Ultimately, TGLO may use its powers of imminent domain to take property for public use in order to construct a flood defense. However, in a state dominated by traditional classical-liberal political values, this is not a very likely scenario.

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 does the construction of a flood defense. However, during the time the MFFD program was involved in Texas, the Ike Dike gathered increasing support (Houston Press, 2016). While the Gulf Coast Community Protection and Recovery District - a six county entity created by former governor Rick Perry in response to Hurricane Ike - has finalized its three-phased report (GCCPRD, 2016), several trajectories for the Ike Dike have been studied (Van Berchum et al., 2016).

Given the ambiguity of ownership along the Texas coast, one of the trajectories focused on raising the existing public road FM 3005 / SH87 along the Gulf-side of the island. Although many issues remain before this can be done - private properties on the bay side will have their view of the ocean impaired, while properties on the Gulf side will remain unprotected - the ownership issue can be avoided. It is possible that the recent ratification of the Water Infrastructure Improvements for the Nation (WIIN) Act and the election of Donald Trump as 45th president of the US in November 2016 may give the flood defense the priority over spatial planning as a flood risk reduction strategy on Galveston Island.

According to Congressman Randy Weber, the passage of the Water Infrastructure Improvements for the Nation (WIIN) Act

> "... includes two provisions that will greatly benefit Texas Congressional District 14 .... The WIIN Act [also] includes language from H.R. 5225, The COAST Act, legislation that I introduced to address concerns regarding the U.S. Army Corps' timeline to complete the Coastal Texas Protection and Restoration Study. It is critical that we expedite the completion of the Army Corps' study that will generate the coastal storm surge protection projects necessary to protect our state against the next big storm. Among the great news for our district, this bill will also provide a solid foundation for President-Elect Trump when addressing the needs of our ports, waterways, and infrastructure in his first 100 days" (statement issued December 12, 2016).

Let's hope so.

Figure 1.
Evacuation route sign at Galveston Island (Photo courtesy Helena Van Boxtelaere).

Figure 2.
Elevated but still destructed residence at Galveston Island, never repaired after Hurricane Ike (Photo courtesy Helena Van Boxtelaere).

Daniel Hogendoorn

IMPACT OF POLITICAL VALUES ON FLOOD RISK REDUCTION DESIGN SPACE

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(Tentative) dissertation title:
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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 rigorous 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 a flood risk reduction plan can occur at all, how difficult it will be, and even influence the technological aspects of the design? (Brand & Hogendoorn, forthcoming).

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 governance*, this 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 processes mean 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 Netherlands, where the development of Multifunctional 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.

Figure 2. Texas City petrochemical complex and port (Photo courtesy Helena Van Boxtelaere).

However, the social pattern in Greater Houston has become very complex: it is now 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 local landowners to administer their own affairs.

For this case study, we first identified all flood-related policies executed by the numerous governing groups within the boundary of the 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 these 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 contraflow, 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 home-owner 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, where governments and NGOs approach 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 'Red State' 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 shoe-horned 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 not 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 to a large extent what commitments 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.

Matthijs Kok, Nikki Brand

EVERYTHING IS BIGGER IN TEXAS

REFLECTION PROGRAM CASE 'HOUSTON GALVESTON BAY, 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 agreement that the current risk is unacceptable. There is currently no formal direction, 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. Collaborating 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 analyzed how wetlands could contribute to a future flood safety strategy in Texas, comparing it with the case of the Wadden Sea. She concludes that given the large amount of pristine wetlands along Galveston Bay, a spatial strategy that prevents the development of these lands will be very valuable for flood protection. Dupuits investigated the economic optimization of multiple lines of defense, developing an optimization algorithm. He shows that multiple lines of defense can be very cost-effective compared to a single line. However, the Houston case was strongly simplified in his calculations - more research is needed to make the case more realistic. Looking at spatial planning tools from the perspective of territorial governance, Brand concludes that despite the potential and desirability of such a spatial strategy, both the tools and the authority required to achieve to it, are lacking. Galveston's local governance does not favor protection, nor does it favor planning. Applying the CIGAS-approach, Kothuis revealed multiple frames and interests regarding flood risk reduction in the Houston Galveston Bay Region. Application of this approach contributed to a shared problem-analysis and mutual understanding of frames. Next, Hogendoorn explored how well the region's existing patchwork of flood risk reduction strategies align with the predominant political values of Texas (known as a traditional 'Red State' with a *low government – low service* mentality), and found a considerable match. This strengthens the assumption that more abstract societal phenomena like political values do function as boundary conditions for the design of a flood risk reduction strategy. In a separate publication, Brand & Hogendoorn confirmed that existing policy and action in the region is geared towards emergency management and recovery (Brand & Hogendoorn, 2015).

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 land 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 also has a road on top.

For now, we can conclude that both the first and second track of multilayered 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 Youtube video supporting the construction of set of 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 would not only be a huge step for the Houston Galveston Bay region, but for mankind as well.

Figure 1. Multifunctional use of flood protection structures is not strange to Texas. The Galveston Sea-wall, here depicted on a postcard dating from 1911, was built with a road and hotels on top, as a response to the 1900 Great Hurricane (image courtesy University of Houston Digital Library).

PROGRAM CASE: ROTTERDAM ROOF PARK | DAKPARK

Peter van Veelen, Mark Voorendt, Chris van der Zwet

A CITY PARK ON TOP OF SHOPS AND A DIKE

INTRODUCTION

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The Roof Park ('Dakpark') is an elevated park on a former railway yard in the Delfshaven quarter in Rotterdam. The park is located on top of the roof of a new shopping centre, which includes a parking garage (hence its name, 'dak' means 'roof'). The park is the largest green roof in Rotterdam and one of the largest in the Netherlands. The park offers a playground, communal garden and a Mediterranean garden with an orangery (figure 9). The Roof Park is 1,000 m long and 80 m wide. The park is situated 9 m above street level. There is 25,000 m2 retail spaces under the city park, and the structure includes a car park with space for about 750 cars. The gardens bring more nature to the district, and the project as a whole has provided more employment. The Roof Park is combined with a dike, the 'Delflandse Dijk', that is part of dike ring 14, which protects the urban area of the Randstad.

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 (Siemerink, 2012).

The district authority finally decided to designate 80% of the space that became available for 'green' purposes. The project developer and owner of the area, the Rotterdam Port Authority, intended to develop a commercial and industrial zone, which was conflicting with the residents' ideas. Ultimately a multifunctional structure has been designed that accommodates shops, offices, and a parking garage on the ground floor and first floor and a park with leisure functions on the rooftop (Kennisbank Platform31, 2013). Important issues that had to be solved were the division of the costs, the presence of objects like stair-cases in the flood defence, and the by-law of the Water Authority which contains regulations regards building in the vicinity of the flood defence (Van der Leeuwen, 2008).

The original dike is not integrated into the new structure of the Roof Park building itself (Figure 4). Actually, the shopping/offices/parking complex is situated next to the old dike and the space in between the complex and the dike has been filled out by soil. Meanwhile, the crest height of the dike was raised to make it 'climate-proof', which means that a worst-case scenario has been taken into account for the design lifetime of the flood defence. The complex is situated in the outer zone, the 'influence zone' of the flood defence according to the definition of the Water Authority. This is only allowed under exceptional circumstances, but in this case it is compensated by reinforcement of the park strip. Several agreements, e.g., about foundations in the core zone, and inspectability, ensure the flood protection function in the future (City of Rotterdam, 2008).

This text is an adapted version of part of the chapter 'Design challenges of multifunctional flood defences. A comparative approach to assess spatial and structural integration' published in Flowscapes. (2015). All authors contributed equally to this chapter.

Figure 1 (left). Mediterranean garden plus orangerie on the Roof Park (Photo courtesy Mark Voorendt).

Figure 2 (bottom left). Frontside of the Roof Park (Photo courtesy Mark Voorendt).

Figure 3 (bottom right). Backside of the Roof Park (Photo courtesy Mark Voorendt).

Figure 1 (below). Various examples with different degrees of spatial integration.

Figure 2 (below below). Cross section of Rotterdam Roof Park.
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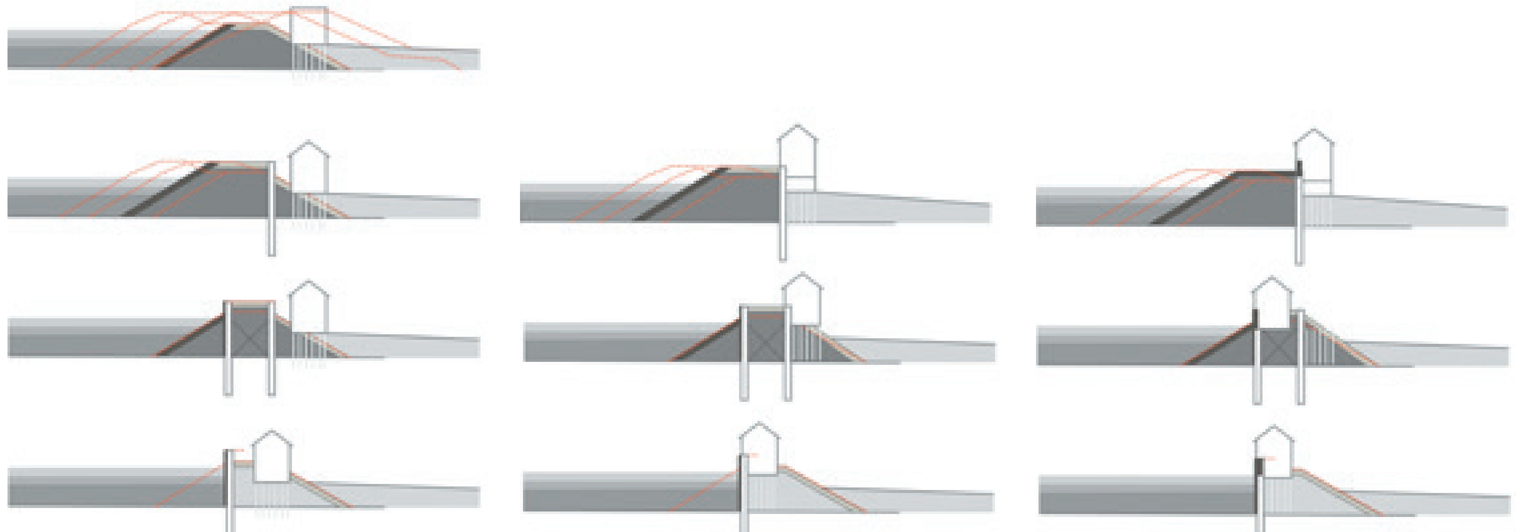


Spatial optimization

Dike improvements in the urban context

Multi-functional zone

Structural integration

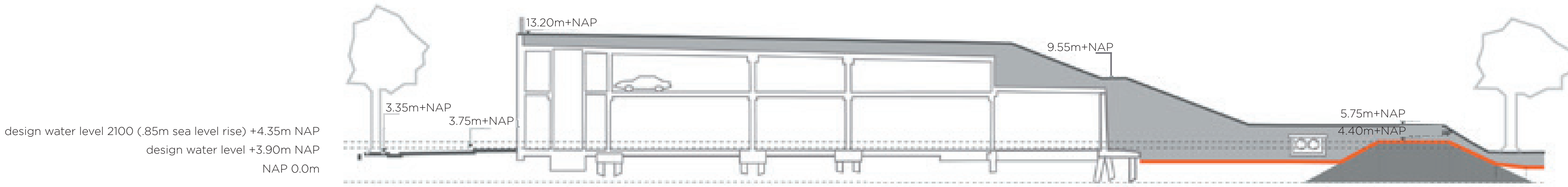
Building is part of the supportive structure of the flood defense

Bi-structural or multi-structural

Functional integration

Building is part of the water retaining structure of the flood defense

Multi-structural water retaining



Peter van Veelen, Mark Voorendt, Chris van der Zwet

ROTTERDAM ROOF PARK: A MULTIFUNCTIONAL STRUCTURE OF SHARED USE

DEFINING FOUR SPATIAL DIMENSIONS OF MULTIFUNCTIONALITY

In the context of urban planning, concepts of multiple land-use refer to situations were the existing space is more intensively used (Habiforum, 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 3):

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, in 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 optimization'.
- If the object, or part of it, fulfils a structuralrole 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 Roof 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 dike profile has not been adapted to make space for other functions. The Roof Park therefore is classified as 'shared use'.

This text is an adapted version of part of the chapter 'Design challenges of multifunctional flood defences. A comparative approach to assess spatial and structural integration' published in Flowscapes (2008). All authors contributed equally to this chapter.

Figure 1 (right). Constructing a joint visual language by building a scale model (Source: Masterplan "het Darkpark", Ontwikkelingsbedrijf Rotterdam, 2003)

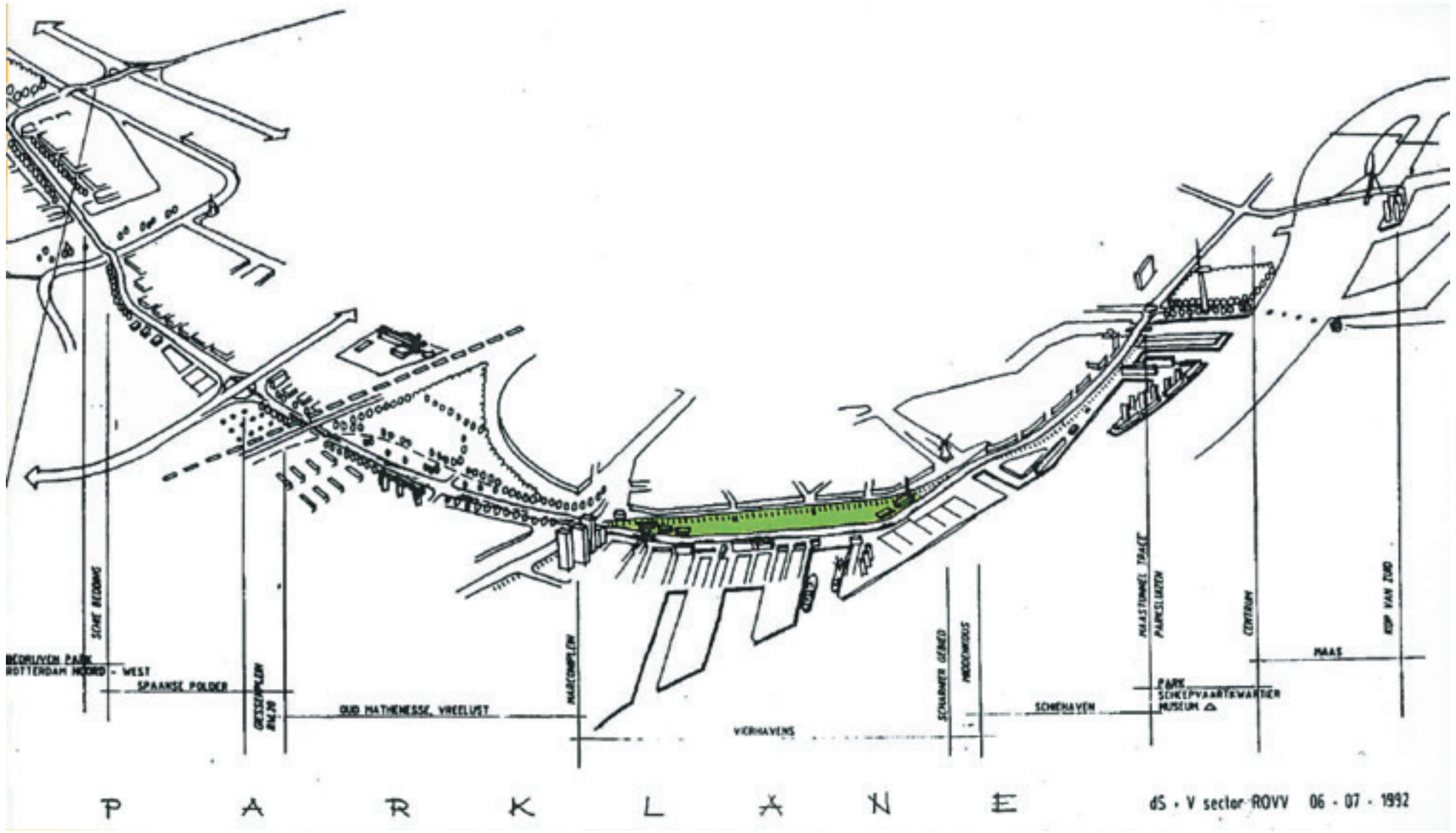


Figure 2 (below). Bird's eye view sketch of the 'parklane' concept (Source: Masterplan'Het Darkpark', Ontwikkelingsbedrijf Rotterdam, 2003)

Kevin Raaphorst

'DECONSTRUCTING' THE ROTTERDAM ROOF PARK

MULTIPLICITY OF DESIGN REPRESENTATIONS

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

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Visual representations of landscape designs tell a lot about a project, the design process, and about the politics involved. The visual content of these representations reflects a myriad of choices, not only in what they show or do not show, but also what visual techniques and styles are used. A visual analytic framework enables the researcher to 'read' design representations by relating the images to their makers, the interests of those makers, as well as to the socio-political context within which those images were created. This can be illustrated using the case of the Rotterdam Roof Park.

The visual rhetoric of the Roof Park
A city planner from the municipality of Rotterdam allegedly drew a sketch on a paper napkin. This sketch presented an elevated park situated above an industrial train yard located beside a river dike. This idea sparked interest among inhabitants of the neighborhood and, thanks to a participatory design process, gained public support for what became the multifunctional flood defense *Rotterdam Dakpark* ('Rotterdam Roof Park').

Originally conceived as a gentrification project, the park area was intended to improve social cohesion in the adjacent neighborhood. The concept of an elevated park was born out of necessity due to the need to preserve the industrial railroad tracks, while at the same time offering space for harbor-related activities at the ground level. However, the railway stakeholders withdrew halfway through the design process. Consequently, the railroad tracks no longer needed to be preserved, and thus the rationale for an elevated park evaporated: a simple ground-level park could now suffice. However, the most powerful stakeholders involved continued to push the idea of an elevated park through the remainder of the design process: the municipality, who desired an iconic design; and the project developer, who saw the potential value of ground-level commercial real estate. The desirability of high-profile competition for local shops in the neighborhood was questioned severely, but the pivotal role of the project developer and their resources proved decisive.

A design workshop was organized at the beginning of the project to gain insight into the concrete ideas and desires of the local community. Stock photos and on-the-fly photo montages created a preliminary composition of the park's architecture and a 'top 10 list' of desired functions. Additionally, this group of inhabitants developed a visual language together with a landscape architect and community organizer by constructing a scale model (Figure 1). One could say this approach was successful: the local community could express their wishes and concerns, and arrived at a design concept they were satisfied with.

Parallel to the participatory design process, the municipality was pursuing a more iconic design: they presented the Roof Park as part of the 'Parklane', a park interwoven with the city's infrastructure, through a bird's eye drawing (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.

The visuals used by the municipality and designers up to this point reflect these interests. The drawings and maps are from the perspective of the neighborhood (northeast ñ southwest), emphasizing the connectivity with the local community and the neighborhood role of the Roof Park. The 'Parklane' is clearly present in the perspective drawing, 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 cartographical material, as well as the bird's eye views, was now oriented towards the park 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, which was previously invisible. The layering of functions is still shown by using small iconic drawings to maintain visual consistency, be it with different functions.

Figure 3.
Layering of iconic drawings shows the multifunctionality of the Roof Park plan (Source: Gemeente Rotterdam).

Figure 4.
Top view map of final Roof Park plan (southwest–north-east) (Source: Gemeente Rotterdam)

Figure 5.
3D artist impression at ground level of Bigshops Boulevard (Source: Buro Sant en Co).

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 Bigshops 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 these images that become the focus of public discussion.

Figure 6. 3D bird's eye visualization of the Roof Park (southwest – north-east) (Source: Buro Sant en Co)

Figure 1.
Timeline of project events (Matos-Castaño et al., 2015).

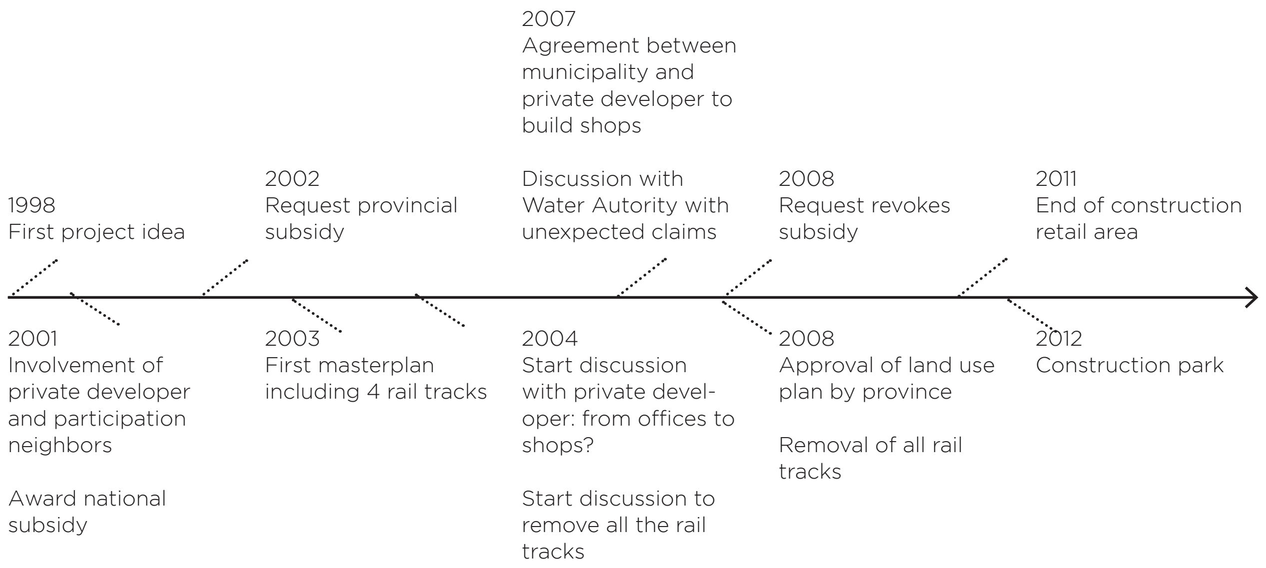
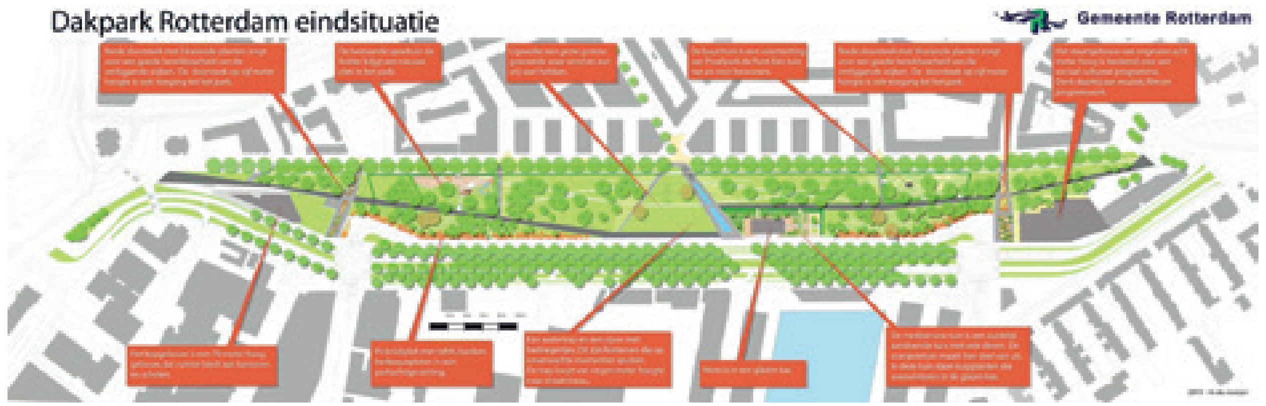
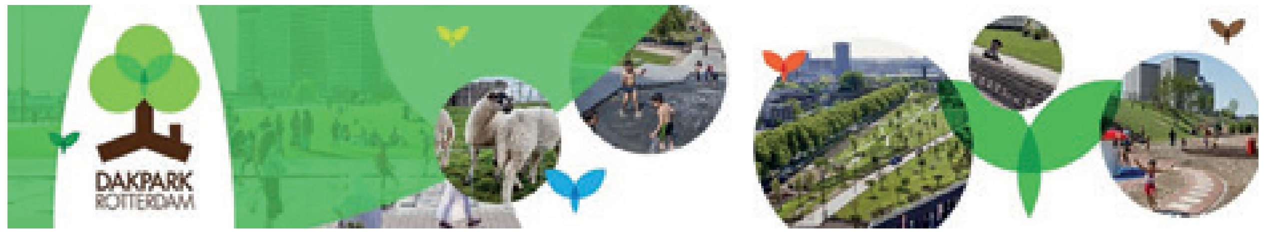


*Figure 2 and 3.
Multiple functions of Roof Park mentioned on website 'Friends of the Dakpark'. Map of final situation and banner (Source: vriendenvanhetdakpark.blogspot.nl)*





Julieta Matos Castaño

DECISION-MAKING FOR ROTTERDAM ROOF PARK

HOW PREDOMINANT FRAMES DETERMINE SELECTION OF FUNCTION COMBINATIONS

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*This is an Author's Accepted Manuscript of an article published in the Engineering Project Organization Journal, Vol. 5, No. 1 (2015), pp. 36-48, [copyright Taylor & Francis], available online at: www.tandfonline.com/doi/abs/10.1080/21573727.2014.997712.
Full citation: Matos Castaño, J., Hartmann, T., Dewulf, G. P., & van Huffelen-de Kort, I. A. (2015). 'What is going on and what should we do? Divergent frames in multifunctional projects.' Engineering project organization journal, 5(1), 36-48.*

Multifunctional projects offer advantages because they enable synergetic effects among functions. However, realizing these plans is more challenging than mono-functional 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 actors involved, their frames, the emergence of a predominant frame, the mobilization of other actors, and the final decision.

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 solutions in situations that require several actors to make a decision. Similar to Kaplan (2008) we have focused on the link between what actors perceive, and construct together in the decision-making process. Our data shows that actors do not follow a linear path in which they identify a problem and match a solution. On the contrary, actors perceive different problems; thereby solutions are not always evident. Successful framing practices produce a predominant frame, used for diagnosing and forecasting the future. This frame shapes the definitions of problems, solutions, and decisions. Consequently, predominant frames are decisive to reach collective action..

In our study, the episodes of the integration of the dike 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.

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 provide a subsidy, the municipality and the district authority considered that this frame did not guarantee the achievement of their interest of developing a park. Consequently, the private developer's frame became predominant instead of the province's frame. However, the province used their authority and delayed the approval of the land use plan and refused to give the provincial subsidy for business restructuring. It could

Table 1. Decision-making process and actors' frames for each decision situation (Matos-Castaño et al., 2015: 6).

Decision event	Decision situation	Main involved actors	Diagnostic frame	Prognostic frame	Emergence predominant frame of:	Mobilization of actors	Decision
1. Flood protection requirements	Existence of a dike in the project area	Municipally	Financial	Design integration	Water board using authority	Water board uses its authority to satisfy their interests	Multifunctional design respecting the boundaries of the dike
		Private developer	Financial	Design integration			
		Water board	Flood risk	No interference			
2. Flood protection requirements/ requests Water board	Responsibilities associated to a future dike reinforcement	Municipally	Financial	Feasibility	Water board using authority	Water board uses its authority to satisfy their interests	Municipaly takes the risk of demolishing the building in case the dike has be reinforced
		Private developer	Financial	Business focus			
		Water board	Flood protection	Legal			
3. Selection of the function under the park	Selection of the function under the park	Municipally	Financial	Feasibility	Private developer	Actors mobilize around the need of private developer's capacities	Development of a commercial area under the park despite the revocation of provincial subsidy
		Private developer	Financial	Retail			
		Province	Regional interest	Business			
		District autority	Social	Pro-green			
4. Removal of rail tracks	Existence of rail tracks in the project area	Municipality	Obsolescene	Removal	Private developer	Need for in-between solution including four rail tracks	Users expropriated by the municipalty
		Port authority	Obsolescene	Removal			
		Rail company	Political			Incorporation of the private developer supporting the removal of the rail tracks	Removal of the rail tracks by rail company
			Transport service				
			Obsolescence				
		Private developer	Financial	Removal			

also be argued that actors had a preference for the short-term locally oriented decision to develop retail instead of office space, above the longer-term regionally oriented decision to develop office space and fulfill the provincial conditions. The future consequences of mobilizing around the private developer's frame instead of the province's one are still disputed.

Moreover, the case of the integration of the dike and the multifunctional project showed how the water board used their legal authority to make their own frame predominant. Although this predominant frame did not contribute to satisfy 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: without the permit of the water board it was not possible to develop the project hence actors decided to mobilize around this frame and look for strategies that avoided an impasse in the decision-making process.

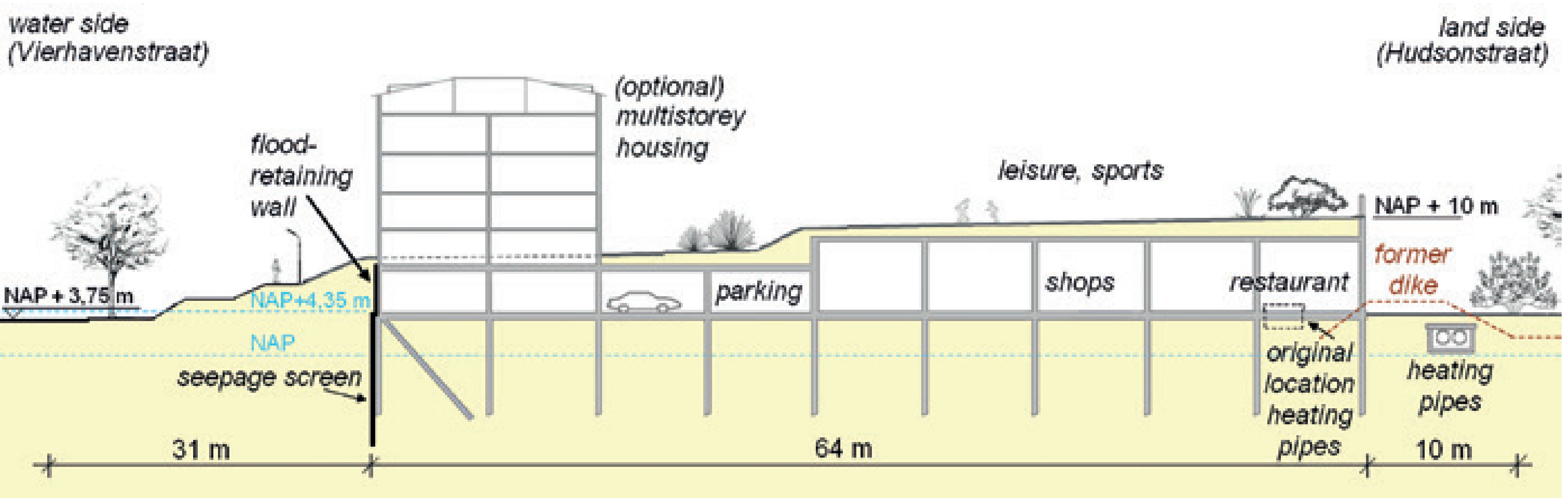
Our research results show that the emergence of a predominant frame proved to be important not only for collective actions but also for individual ones. Indeed, in our case we observed how actors held multiple, and sometimes contradicting frames, not only among different organizations, but even within 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 between two potential strategies: (1) to satisfy political interests or (2) to facilitate the process of implementing the new project by removing the rail tracks. The high maintenance costs and the decreasing activities in the harbor were two of the influences on the rail company to have a preference for removing the rail tracks. However, the emergence of the predominant frame of the private developer to develop shops instead of office space was a determining factor to remove the rail tracks. The pressure and mobilization of the municipality encouraged the rail company to resolve the ambiguity they were struggling with. This case shows the influence of a predominant frame across different decision arenas, helping to resolve the indecisiveness resulting from the existence of multiple divergent frames within the same organization.

In summary, our results show that frame divergences are often resolved by 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 particular course of action. Mobilizing around a predominant frame involves decision tradeoffs. Although tradeoffs are unavoidable in decision contexts, we consider it important to bring frames to the surface to create awareness about the consequences of stakeholders' choices. In light of our results, we consider that understanding how predominant frames emerge and how other actors mobilize around them helps to anticipate strategies to support the predominance of frames that will support the achievement of mutual gains instead of individual interests. Making frames more explicit helps to add interpretations to decision making-processes helping to open up the option space so new and overlooked options might emerge (de Boer et al, 2010).

Implications for multifunctional projects
In multifunctional projects, integrating purposes in the same area and sharing costs and benefits increase the level of interdependencies of these projects compared to mono- functional ones. Our research results show how the interdependencies among functions have an influence on the frames that become predominant as we observed in the episode of the selection for the function under the park. Predominant frames influenced the design and conditions for the project, leading to changes throughout the process. Furthermore, the interdependencies among resources and organizations in multifunctional projects require the consideration of the project as a whole, as a common pool of resources that actors combine to achieve synergy. Actors might use their power or 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. Under these circumstances, there could be a similar problem to the one presented in the tragedy of the commons (Hardin, 1968) where actors attempt to maximize their own self-interest without considering the public good and leading to a situation undesirable for all involved actors. It is therefore important to stimulate strategies that help to identify combinations of functions that minimize the occurrence of this problem.

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 consider highly relevant to search for strategies to stimulate the emergence of predominant frames that help to achieve mutual benefits. Finding these strategies seems highly relevant for multifunctional projects, where different interdependent actors have unique expertise, or resources necessary to implement the project. Organizing open processes that allow for the inclusion of a range of divergent frames might help to create awareness and deal with frame differences (Dewulf et al., 2007). Differences in how actors frame the scope of the context, the selection and definition of options are crucial elements that could be considered as explicit inputs in decision-making processes. Treating key framing assumptions as explicit inputs offers a means to bring to the surface stakeholders' interpretations and how different courses of action would be preferable under different frames, and show how these dependencies relate to stakeholder interests (Stirling, 2006). Furthermore, we encourage the use of deliberative practices to explore the potential of showing existing frame divergences in decision-making processes, helping to make actors aware of the options and potential actions under different interpretations (Renn, 2006) and facilitating the emergence of potential predominant frames that allow for the achievement of synergy and mutual benefits.

Figure 1. Alternative concept for the Dakpark, Rotterdam (Voorendt 2017)



Mark Voorendt

WHAT WOULD AN INTEGRATED DESIGN OF THE ROTTERDAM ROOF PARK LOOK LIKE?

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Dissertation title:
'Design principles of multifunctional flood defences.'

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Ref: M.Z. Voorendt (2017). 'Design principles of multifunctional flood defences.' PhD dissertation, Delft University of Technology.

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 provisionary 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 waterside. 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 multistory 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.

A STEP TOWARDS FUNCTIONAL INTEGRATION

Matthijs Kok

REFLECTION PROGRAM CASE 'ROTTERDAM ROOF PARK'

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 Veelen, Voorendt and Van der Zwet 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 visualization is that there are many possible images of the same alternative, and then the question arises how to visualize the alternatives, and which perspectives to choose. Raaphorst answers that "… 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". 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 Castaño 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 Castaño 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, because the final result 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 Castaño 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.

Figure 1. Rotterdam Roof Park eastern edge, connection of park area to residential area along Hudsonstraat (Image courtesy Mark Voorendt).

Figure 1 (below). Dike along Western Scheldt at Ellewoutsdijk with green foreshore accomodating wave attenuating and recreational functions (Image courtesy Rijkswaterstaat beeldbank, Joop van Houdt).

Figure 2 (page 186). Multifunctional dike-in-boulevard at Scheveningen under construction in 2014 (Image courtesy Rijkswaterstaat beeldbank, Harry van Reeken).

Nikki Brand, Matthijs Kok

A MULTIFUNCTIONAL ANSWER TO MULTIPLE QUESTIONS

EPILOGUE

When the MFFD program took off in 2012, its general goal was to gain a deeper understanding of multifunctional flood defenses, in order to provide a solid foundation for their design, assessment and management. As a point of departure, it assumed that a new generation of explicitly multifunctional flood defenses was the product of a need to accommodate competing spatial claims, and, perhaps, contribute financial savings by combining functions. Flagship projects like the Scheveningen 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 integration'). 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 on and within flood defenses (based on experiments in a hydraulic lab), while Voorendt developed a generic method to evaluate the reliability of multifunctional flood defenses. Both provide stepping-stones towards reliability analysis. Roscoe also investigated the reliability of flood defenses by applying Bayesian network techniques, which have the advantage of clear visual in graphics to communicate with users.

Voorendt also demonstrated that an integral design of a parking garage and a flood defense is in fact cheaper than two separate designs; however, the true bottleneck is that an integral design also requires integral maintenance. Aguilar Lopez showed that embedded structures have a significant effect on safety during storm events, both positive and negative. Hölscher focused on selected risks associated with wind turbines on dikes. Dupuits investigated the multiple-lines-of-defense strategy from an economic point of view, and developed new methods to optimize the combination of defenses and functions. Nonetheless, an overall perspective on the safety of multifunctional flood defenses remains beyond the scope of this book: in practice, multifunctionality 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.

In the *planning & design* section, virtually all contributions focus on the decision-making process in which a flood risk reduction strategy takes shape: how different aspects of this process structure the outcome, like boundary conditions, tools, steps and knowledge regarding future outcomes. Researchers from different academic backgrounds reflected different understandings of 'planning' and 'design'. For example, Voorendt emphasized the technical components of design, while Raaphorst focused on the visual. Both stress the collective action of design work, at least during the exploratory phases of the decision-making process. Design calculations should still be conducted by a specialist, although it should be noted that there is a difference between just doing calculations and making a design: in a design, all perspectives need to be integrated. Additionally, Van Loon made a plea to include salt marshes along the coast 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 Veelen and Islam, on the other hand, addressed temporal aspects of planning, using simulations to study the long-term workings of alternatives, to reduce the probability of possible future lock-ins.

The section on *governance & knowledge transfer* emphasizes the many obstacles different actors face when trying to collaborate, as well as the importance of perceptions (frames), and awareness of these, as a way to smooth decision-making regarding multifunctional flood defenses (Heems, Matos Castano). Hogendoorn and Matos Castaño argue that MFFDs are a means to address diverse interests, and also a way to overcome restraints in the decision-making process regarding flood safety. Tromp provides links to Brand and Van Veelen's contributions in the previous section, addressing the issue of coupling flood risk

management and spatial planning, and the opportunities this offers for synchronizing 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, where the design and decision-making process could be reconstructed and analyzed. The Texas case dealt with international knowledge transfer on a regional-scale project, which is still in the planning stages; the advantage of this was that the decision-making and design process for multifunctional flood defenses could be studied as it evolved. 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, structural and frames analysis. This confirmed the role of several interdependent actors, which resulted in a construction where the shopping mall and the flood defense were ultimately structurally separated for management reasons.

For the Houston Galveston Bay Region, contributions analyzed the role of political values in decision making, considered stakeholder-inclusive design and how governance and planning affect flood defenses and spatial adaptation, and investigated how wetlands can contribute in the design of a future strategy. Dupuits made a simplified analysis of the complex region's flood risk issues; the other authors analyzed boundary conditions for the design of a future strategy. Strikingly, while Van Loon concludes that a strategy based on spatial planning could be rewarding given the large amount of pristine wetlands, Brand concludes that the region lacks the proper tools and the political support for such an approach. The Texas case demonstrates not only how challenging the design of a flood defense strategy is, but also how conflicting interests and lack of instruments can obstruct solutions that would otherwise be feasible.

The experience of the MFFD project, as a multidisciplinary program, confirms some of the obstacles and benefits associated with multidisciplinary research. For example, it was a challenge to find a shared definition for multifunctional flood defense as a concept, as Kothuis demonstrated in her contribution on knowledge transfer. On the other hand, Van Veelen, Voorendt and Van der Zwet managed to create a shared classification of multifunctional flood defenses, based on the degree to which functions are integrated. The example of the Rotterdam Roofpark was classified at the lowest level of 'shared use'. In a separate contribution using a 'single' structural perspective, Voorendt even concludes that it would have been desirable to actually integrate the shopping mall with the flood defense. Management reasons led to the separation of functions; it did not benefit the structure's integrity, nor did it deliver the most efficient design in terms of materials and resources. Another reward of multidisciplinary research is when different approaches confirm the same findings. For example, the role-play between stakeholders in the design of the Roofpark was confirmed by Raaphorst's visual rhetoric analysis.

Still, the number of multidisciplinary peer-reviewed studies published in 2017 is disappointingly small, which demonstrates the challenging nature of multidisciplinary research as Kothuis discusses in connection to the Program Cases. For future research efforts, we recommend an independent management budget, shared workspace, and more time for experienced researchers to integrate their findings at the end of the programs' life. PhD candidates can then broaden their perspective by working with users and exchanging ideas about their individual projects on a voluntary basis with other researchers. Multidisciplinary programs demand more in terms of management than their single-discipline counterparts, in the first case, just to establish trust between participants from different backgrounds. Therefore, a key to successful multidisciplinary research is that researchers be allocated independent time-budgets to organize and integrate their work.

To conclude, the MFFD-program yielded practical recommendations for the design of multifunctional flood defenses and –strategies from a variety of disciplines. Voorendt suggests starting with an early collective design round, after which a specialist can make detailed calculations Additionally, Tromp recommends that water authorities should share their long-term spatial plans in order to allow other interested parties to synchronize their plans. This will make it easier for other functions to 'hitch a ride' with long-term flood safety plans. Van Veelen also warns that the possibility of shifting from one alternative to another in urban waterfronts is limited (for example, moving from incremental adaptation of existing non-flood retaining structures to district-wide protection in the form of flood defenses). Once a path of investment has been chosen it is not easy to switch to another.

As befits the complex nature of multifunctional flood defenses, many questions remain to be studied. Is the multifunctional flood defense a 'no-regrets' approach in all contexts? Are there long-term management risks that need to be considered? What is the best way to organize management and maintenance, and could an owners' association approach (as used in apartment buildings) be an efficient solution? Can implementing multifunctional flood defenses contributed to overcoming decision-making obstacles? For example, by reducing resistance towards flood defenses in areas lacking a long-standing flood safety tradition, and by building alliances that can construct and manage these? And who is best equipped to communicate with policy makers about multifunctional flood defenses? For example, hydraulic experts who focus on the structure itself, or specialists in public administration who focus on the process?

One thing, however, seems certain: multifunctional flood defenses serve a real demand, both in the Netherlands and abroad. We have clearly seen this in Texas, where the rhetoric of multifunctionality and co-benefits has entered the popular debate. With the anticipated rise in sea levels and the increased concentration of population in flood prone cities, we expect to see many more multifunctional flood defenses in the future.

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..

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Reflection 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 Groningen, discussing historical flood levels and multifunctional flood defense at Delfzijl waterfront.

- MFFD-team cooking it up in Amsterdam (image by Tycho Muller, courtesy Rijswaterstaat).

-Scheveningen Dike-in-Boulevard, discussing multi-functionality with local experts.

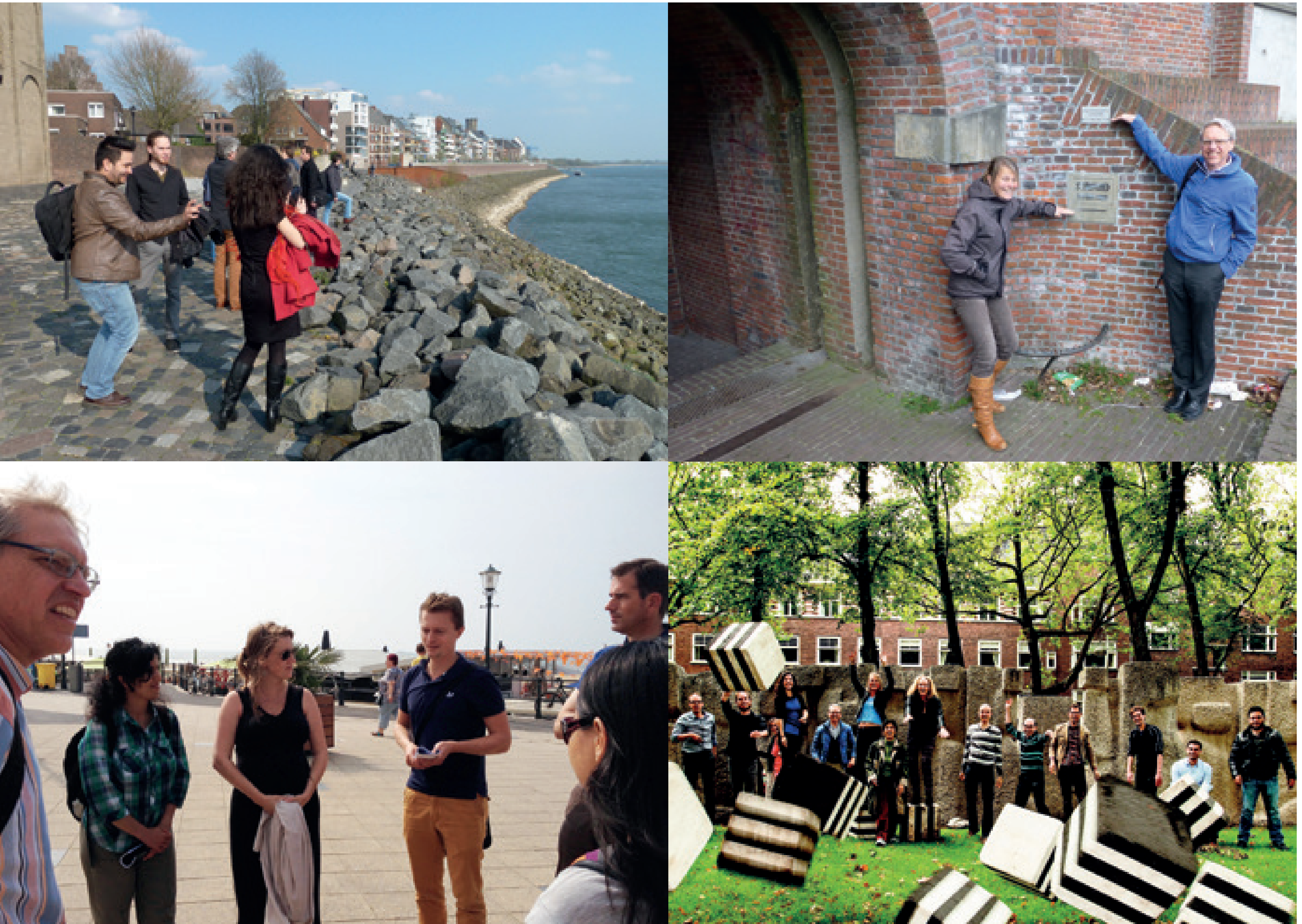

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Image page 194: Vlissingen's multi-functional flood defense system along the Western Scheldt: a seawall, boulevard with buildings with adaptive capacity, and dike-in-dune (Image courtesy Rijkswaterstaat Beeldbank, Yourcaptain Luchtfotografie).

Image page 196: The Sand Engine ('Zandmotor') at Kijkduin; a multi-functional flood defense along the North Sea, accomodating dune formation, new flora and fauna, and recreation of multiple sorts (Image courtesy Rijkswaterstaat beeldbank).

Image page 198: Traditional multifunctional use of primary levee along the river Lek. Reinforcement of a 5,7 km stretch of river dike between Bergambacht-Ammerstol- Schoonhoven (BAS) is part of the HWBP-2 program (Image courtesy Rijkswaterstaat Beeldbank Yourcaptain Luchtfotografie).

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COLOPHON

INTEGRAL DESIGN OF MULTIFUNCTIONAL FLOOD DEFENSES
Multidisciplinary approaches and examples

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Production team B Business Energy, Amsterdam & Urban Integrity, Naarden
Graphic design & cover design steef liefting
English language advice Sören Johnson
Cartography Studio WUFT

Publisher Delft University Publishers, Delft University Library
Printing Quantes Printers, Delft

Publication of this book has been funded by STW National Technology Foundation (currently TTW - Applied and Engineering Sciences Foundation) as part of the *Perspectief Program - Multifunctional Flood Defenses (MFFD).*

Image backcover:
Courtesy OKRA landschapsarchitecten
Image frontcover:
Luuk Kramer, courtesy Gemeente Katwijk
Image page 168:
Siebe Swart

When quoting this publication, please refer to:

Kothuis, B.L.M. & Kok, M. (eds.) (2017). *Integral Design of Multifunctional Flood Defenses. Multidisciplinary Approaches & Examples.* TU Delft Library: Delft University Publishers

ISBN ISBN 978-94-6186-808-4
NUR 950