IV

INDUSTRY CORNER

INTEGRATED DESIGN FOR FLOOD RISK AND SPATIAL QUALITY—EXAMPLES FROM THE DUTCH DELTA PROGRAMME

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INTRODUCTION

The Netherlands faces a significant flood risk task. In order to remain a safe place to live the Netherlands has to upgrade its extensive flood risk protection system. This results in an elevation and reinforcement task for many of the Netherlands water barriers. When those barriers are positioned in an open landscape, the technical reinforcement is often easy to embed specially. However, many barriers have been built over the years making the reinforcement into a challenging spatial assignment. This article shows different case study examples of a research by design study (performed in the broader context of the Dutch Delta programme) that explores integral design solutions for flood risk and spatial (re)development. The Houston Galveston Bay case study demonstrates the international applicability of the research by design method.

KEYWORDS

research by design, flood risk, integral design, Dutch Delta programme, spatial design, The Hague Rijnmond region (The Netherlands), Houston Galveston Bay (USA).

BACKGROUND

Due to its position on the edge of the Rhine Meuse delta, The Netherlands faces a significant flood risk task. As with many other urbanized deltas worldwide, the favourable position from an economic and trade point of view leads to urban development in areas that require continuous water management efforts (UN-Habitat, 2006). The Netherlands has developed an extensive flood risk protection system consisting of dike rings, barriers and dunes. Nevertheless, unless additional measures are implemented, flood probability and consequences will increase due to climate change, subsidence and the growing economic value and occupation in the areas that are protected. Thus, for The Netherlands to remain a safe and attractive country, its flood risk protection system will have to be updated (Delta Programme, 2008).

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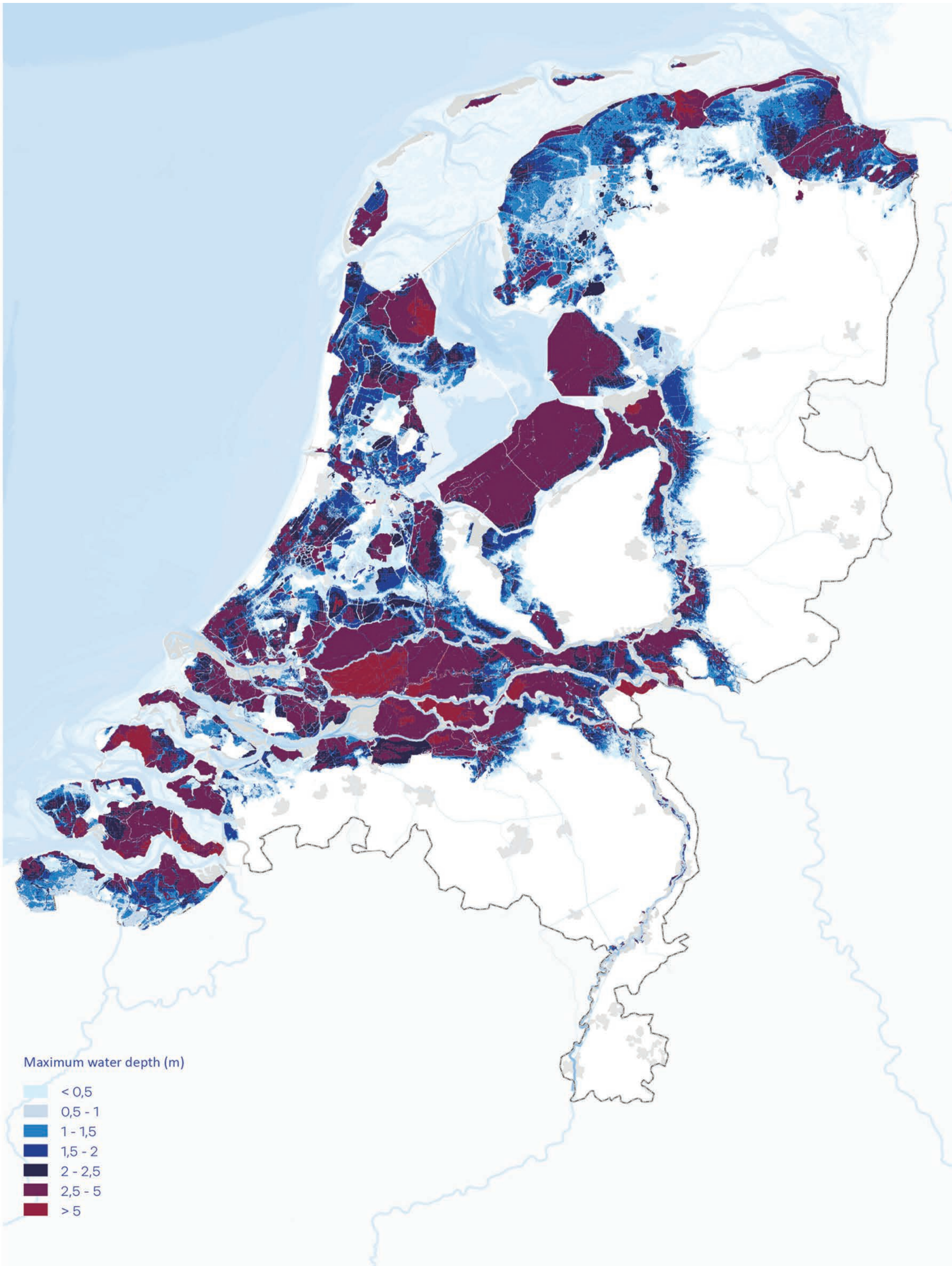
FIGURE 1. Map indicating the 60% of the Netherlands that is liable to flooding from the North Sea, lakes and major rivers. Potential water depths may locally exceed five meters. Source: Kok et al. (2017).



Context

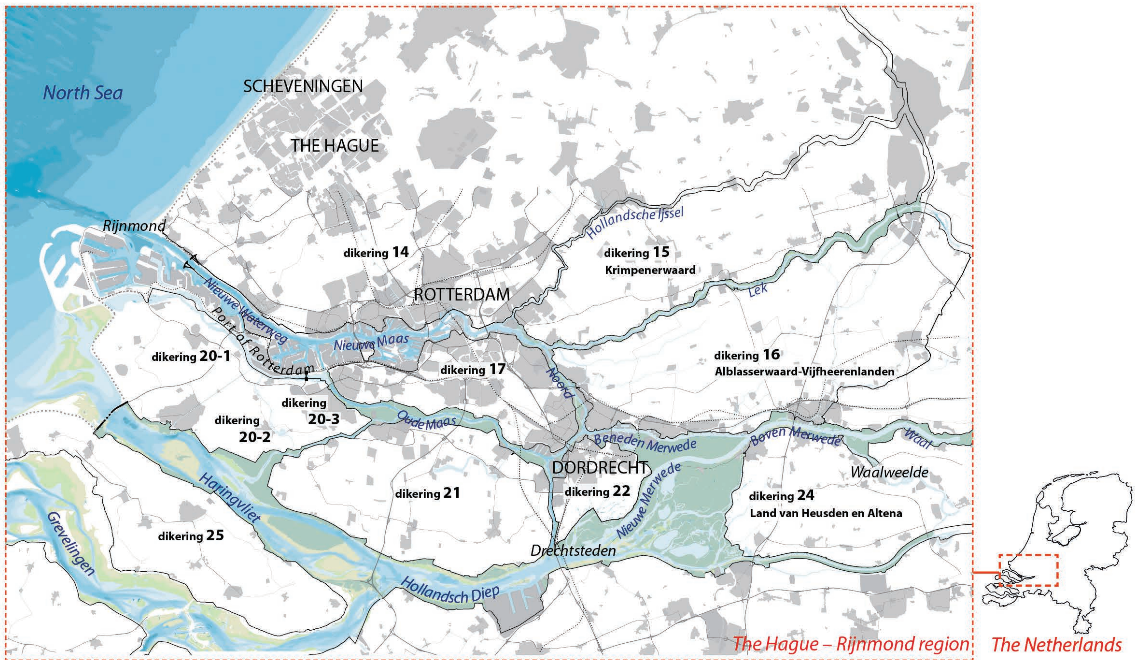
Substantial parts of The Netherlands are below sea level: 60% of the country is subject to (significant) flood risks from the North Sea, lakes and rivers, Figure 1 (Kok et al., 2017). For protection, an extensive system consisting of natural dunes, high grounds, dikes, barriers, locks and dams has been created. Figure 2 shows some typical sections of land-water transitions formed by a) natural sandy dunes, b) polder dikes and c) natural high grounds. Natural high grounds are present primarily in the eastern part of the country, which is elevated above sea level and safe from flooding from the sea or rivers. Natural sandy dunes, originally formed by sedimentation processes, can be found along the coastline. Man-made additions such as dikes and barriers complement the high grounds and dunes, and can be found along the North Sea, estuaries, rivers and lakes. Dikes played an important role in developing the polder system: polders were created by building closed systems of dikes in and around water-rich areas such as lakes and estuaries, and subsequent draining of the enclosed areas using windmills and (steam-)pumping stations. The biggest Dutch infrastructure works related to water-safety are the Delta Works: following the 1953 North Sea flood, which caused major fatalities and inundated large parts of the country, a comprehensive system of fixed and flexible barriers was created that provides protection against storm surges.

The Hague-Rijnmond region

In this article, three integral flood risk and spatial design studies for The Hague-Rijnmond region are described. Figure 3 depicts the region with its flood risk protection system and spatial context. It is home to approximately 2.5 (of in total 17 million) citizens and includes The Hague and Rotterdam, the 2nd and 3rd largest cities in the country. The city of The Hague, positioned along the coast, is the seat of the Dutch national government. Rotterdam, located along the river Meuse and directly connected to the river Rhine, is a major seaport. It serves as a gateway to northwest and central Europe and contributes substantially to Dutch GDP. The dike ring around this high-value urban cluster, dike ring 14, is therefore assigned as the highest available protection norm. The region also includes several rural polder areas among

FIGURE 2. Photo's and diagrams of different elements of the Netherlands flood risk protection system a) natural sandy dunes, b) river dikes and c) natural high grounds. Photo of the natural high grounds of the city of Nijmegen by Rijkswaterstaat, Harry van Reeken.

FIGURE 3. Map of The Hague-Rijnmond region, southwestern corner of the Netherlands. The map includes different dike rings in this region.



which, Alblasserwaard-Vijfheerenlanden, is referred to as dike ring 16. This polder is largely positioned on peat soil and mostly used for agriculture (Steenbergen and Reh, 2009). Unbanked areas along the polder are home to hydraulic and shipbuilding companies. Dike ring 16 has a lower economic value and density than dike ring 14 and therefore a lower flood risk protection

FIGURE 4. Characteristic photos of the Rijmond region including Rotterdam (left), The Hague's seaside Scheveningen (centre, source Municipality of the Hague), and Alblasserwaard-Vijfheerenlanden polder area (right).

norm (Brinke and Jonkman, 2009). However, this peat polder is subsiding; in case of flooding, it would be inundated quickly and faced with high water levels (de Vries, 2014). It therefore requires considerable protection as well.

Delta Programme

In order to proactively address future flood risks, the Delta Programme was established and tasked with developing long-term flood risk strategies, with a time horizon until the year 2100 (Delta Programme, 2008). Establishing increased safety norms, to accommodate for the expected increase in flood risks, is part of the programme's strategy. The increased safety norms may subsequently result in the need to reinforce many of the barriers, dunes and dikes in the future. Figure 5 provides an indication of the dike elevation task resulting from climate change and subsidence. The new increased flood risk standards for the The Hague-Rijnmond region will further increase the dike elevation and reinforcement task.

A dike that is constructed from sand and clay, and that is positioned in an open landscape, can be reinforced relatively easily by expanding its height and width. However, many dikes that used to be located in an open landscape have become part of urban areas; there, the implementation of reinforcements is more challenging. Figure 6 shows different options to do so. There are technical options to reinforce a dike with minimal spatial impact using an expensive steel pile sheet or cofferdam construction. As a result of a previous iteration of reinforcing dikes—necessitated by increased flood risk standards following the 1953 North Sea flood—many houses were demolished to provide space for reinforcements (see figure 7). Future dike reinforcements have to be realised in a markedly different political context: both the resistance to demolishing historic buildings and a recognition of the importance of spatial quality of the built environment (and specifically the appreciation for cultural heritage) have grown (Klijn et al., 2013).

FIGURE 5. Dike elevation task for the different dike rings in the The Hague-Rijnmond region, due to climate change and subsidence (based on data by vd Kraan, 2013). Red indicates dikes that require reinforcement, with line thickness indicating height deficiency. The new increased flood risk standards for The Hague-Rijnmond region will further increase the dike elevation and reinforcement task.

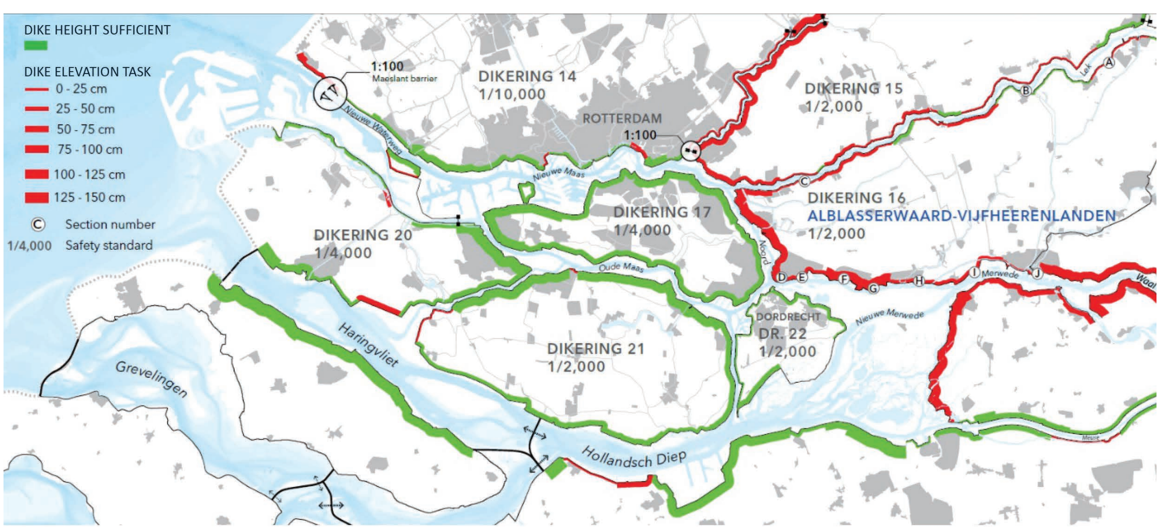


FIGURE 6. Different options for reinforcing a dike, on the left an inner-dike and outer-dike option for enforcing a dike with earth, on the right two construction: the sheet pile and a cofferdam.

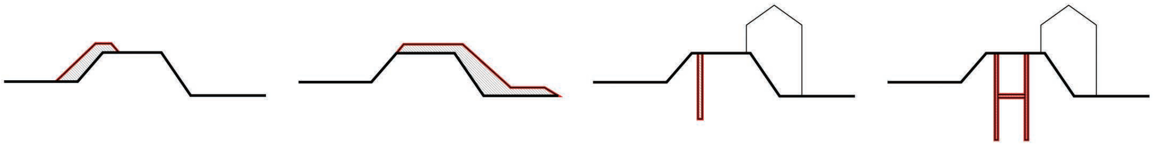
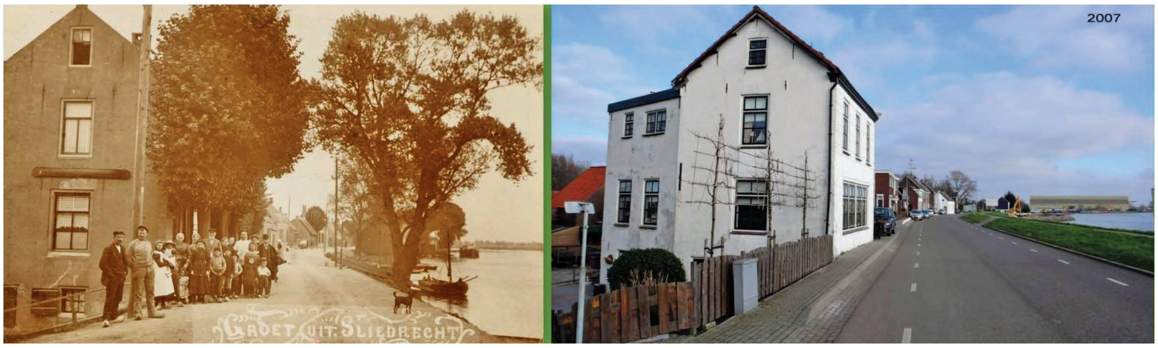


FIGURE 7. On the left a historic photo of the Sliedrecht dike, showing the historic presence of trees and buildings in the unbanked area along the river. The trees were removed to accommodate for dike reinforcements, changing the spatial characteristic of the dike ribbon. The picture on the right shows the current situation. Photos: Sliedrecht historic society (http://www.historie-sliedrecht.nl).



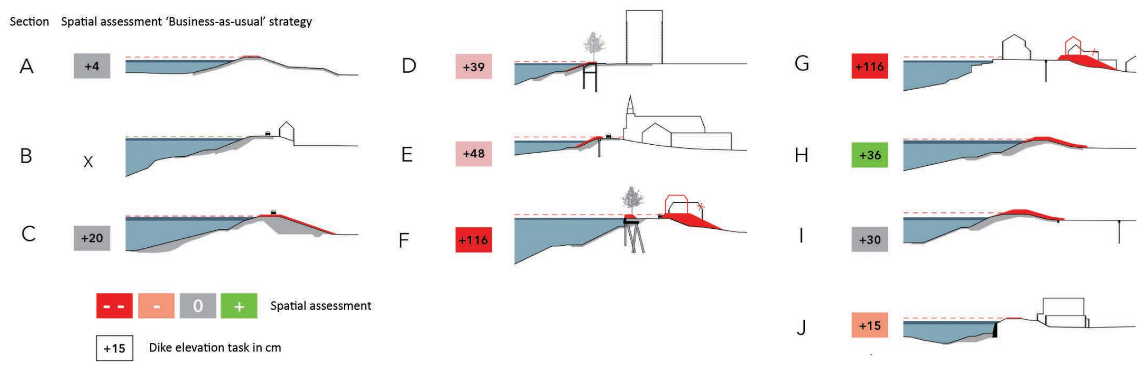
Project

The developments described above together result in an urgency for developing integral strategies and designs in which technical and spatial aspects are combined (Meyer, 2009). Research by design methodologies are used to explore the potential spatial impact and spatial economic opportunities that are associated with the necessary flood risk measures; the application of these methodologies in an early stage has become a key element of the Delta Programme. In this article, utilisation of one such methodology by urban design office Defacto is demonstrated for three locations in the The Hague-Rijnmond region: Sliedrecht, Scheveningen and Kinderdijk.

Case study selection

In The Hague-Rijnmond region, reinforcements will have to be implemented in multiple locations. For some of these locations, embedding these reinforcements in their environment in an acceptable way, from a spatial perspective that is, will be difficult, for instance due to urbanisation or specific landscape characteristics (Delta Programme, 2011). An overview of these locations was created. Figure 8 shows the results of a design study in which the expected impact of a standard 'business as usual' dike elevation on spatial quality is assessed for locations along the Alblasserwaard-Vijfheerenlanden dike ring. In some instances, traditional dike reinforcements would have a considerable negative impact on the spatial quality of the location; in those cases, the implementation of integral designs may possibly mitigate negative effects.

FIGURE 8. Results of a design study in which the impact of the expected 'business as usual' standard dike elevation on spatial quality is assessed. Then numbers represent the expected dike elevation (in centimeters). The sections correspond to the locations indicated in Figure 5. The colours indicate the assessed impact on spatial quality which can be: positive (green), neutral (grey) slightly negative (light red) or very negative (dark red). The sections represent different dike typologies along the Alblasserwaard-Vijfheerenlanden dikering. Section G represents the Rivierdijk in Sliedrecht, based on a very negative assessment for implementing a standard dike reinforcement, for this location a design optimisation study has been performed (see case study1: Sliedrecht).



In addition to selecting locations where dike reinforcements would be difficult to embed spatially, the programme also looked for possible synergies between spatial and technical assignments. Such synergies might for instance result from integrating flood risk interventions with urban (re)development projects.

In order to obtain an overview of developments that can possibly be linked to dike reinforcements, a so called spatial economic 'opportunity map' was made. In those maps, different spatial assignments and projects are inventoried (by means of desk study and interviews) and shown in combination with the expected dike reinforcement task (Bos, 2016).

Figure 9 shows part of the opportunity-map for Alblasserwaard-Vijfheerenlanden (dike ring 16). Spatial assignments for this area include aspects such as preservation of cultural heritage, improved mobility and traffic safety, building and redevelopment projects, improvement of recreational routes and ecology, strengthening the (visual) relation with the Merwede river and improving the associated shipping channel.

Each of the three case studies selected for this article represents a different relation between flood-risk and spatial assignment (as can be seen in figure 10). In the first case study, which concerns the town Sliedrecht, the assignment is focused on embedding the flood risk interventions so as to preserve characteristics of the existing historic dike ribbon. In the second case study, regarding the seaside section of the city of The Hague, the flood risk task coincides with the ambition for urban redevelopment and extension. The third case study concerns Kinderdijk, a UNESCO world heritage site. There, dike reinforcements are easy to embed; still, synergies can be achieved if dike reinforcements are used as a catalyst for integral development.

Often, it is questioned whether the approaches described in these case studies are applicable beyond The Netherlands. Therefore, the Houston/Galveston Bay area is included, to demonstrate applicability of research by design in a non-Dutch, international context.

FIGURE 9. 'Opportunity map' showing both the indicative dike reinforcement task as well as different spatial assignments and projects. This map is a cut-out of a larger map and shows the southern dike of the Alblasserwaard-Vijfheerenlanden, along the Merwede river.

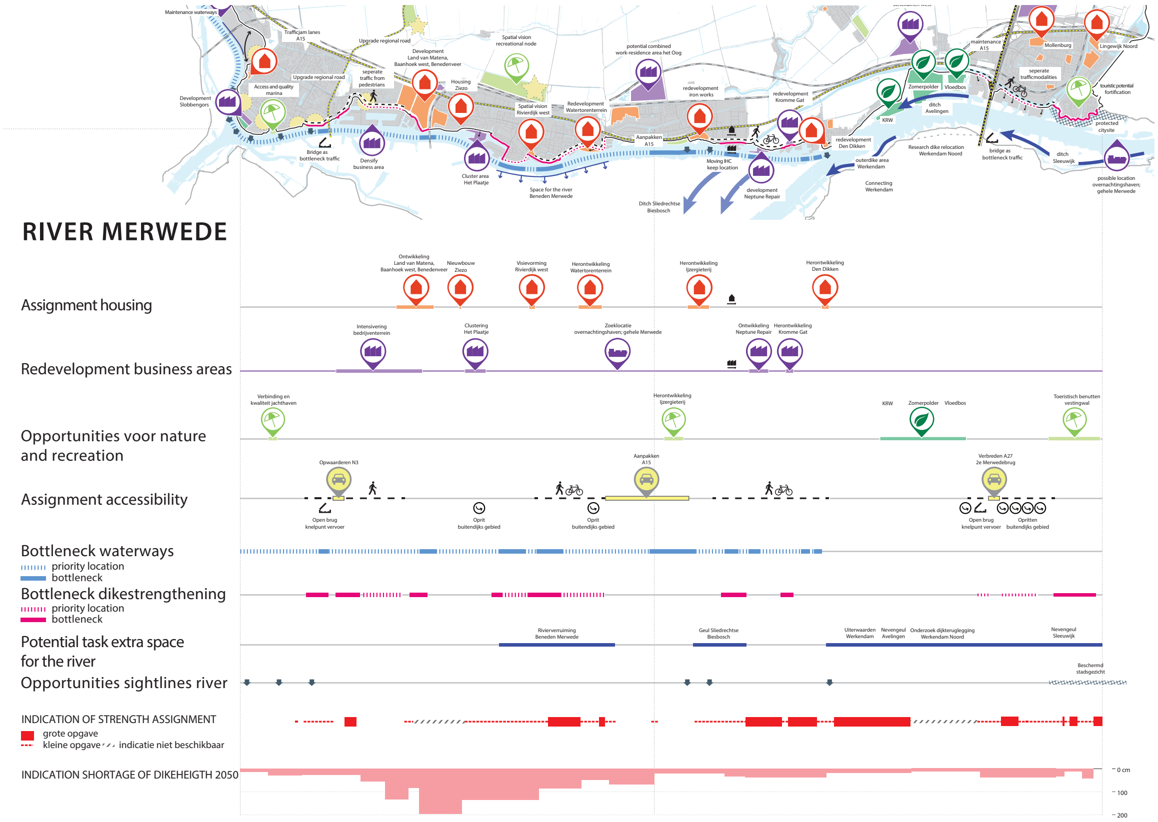


FIGURE 10. Overview of different case study locations, selected because dike reinforcements are spatially difficult to embed and/or offer opportunities for synergy with spatial (re)development.

Case study locations	Dike reinforcement spatially difficult to embed	Opportunity for synergy with urban (re)development
1 Sliedrecht	**V**	x
2 Scheveningen	**V**	**V**
3 Kinderdijk	x	**V**
4 Galveston (USA)	**V**	x

Research by design methodology

In all case studies research by design is employed to explore possibilities for combining flood risk and spatial design. The term research by design is widely used and many different definitions exist (Geldof and Janssens, 2013). In the research by design methodology used in the cases studies, multiple different 'technical' variants are tested for each location and then assessed for their spatial potential. In order to do so, teams were formed that included technical experts, local experts and spatial designers.

Although the focus of the research by design studies varies, in all case studies the following research by design steps have been applied to a greater or lesser extent:

1. Creation of an inventory of the spatial-economic ambitions and challenges of the location
2. Creation of an overview of possible (and viable) technical options for dike reinforcements
3. Performing a design study for the spatial implementation of each intervention
4. Reflecting on the pros and cons of the applications

The research by design studies resulted in a range of viable design variations, each with its own characteristics. It is not necessarily the objective to choose a favourable solution; rather, the aim is to identify a range of possibilities. The outcome provides insight to local municipalities with regard to the impact and opportunities related to future dike reinforcements. This allows municipalities to be activated: they can prepare budgets and seek timely cooperation with waterboards in order to reach agreement on integrated design solutions (waterboards are independent governmental bodies responsible for a range of water-management and water-safety tasks) (Kok et al., 2016, p.25). This approach provides the opportunity to realise dike reinforcements with a positive impact on the built environment.

Case study 1: Sliedrecht

Sliedrecht is a town along the river Merwede with approximately 25.000 inhabitants. Its shipbuilding, hydraulic engineering and dredging companies are closely linked to the country's aquatic history and economic development. The town originated as a built dike ribbon and subsequently expanded into the polder as well as the riverbed. Historically, in Sliedrecht as well as elsewhere, houses and other structures were constructed along both sides of a dike ribbon—in the remainder of this article referred to as double sided built dikes. During previous rounds of dike reinforcements, this often left little room for expansion; dikes had to be altered or completely reconstructed, with structures being demolished on at least one side. Some stretches of double sided built dikes still exist; the longest such stretch is the 'Rivierdijk'. It is a narrow

FIGURE 11. Aerial photo of the Rivierdijk in Sliedrecht (source PDOK). On the right a photo of the build dike from the road (centre of the dike) and from the river.

dike with separate houses on both sides along a staggered building line. It dates from the 19th century; some of the buildings are considered protected monumental heritage (Province of South Holland).

Spatial ambitions and assignment

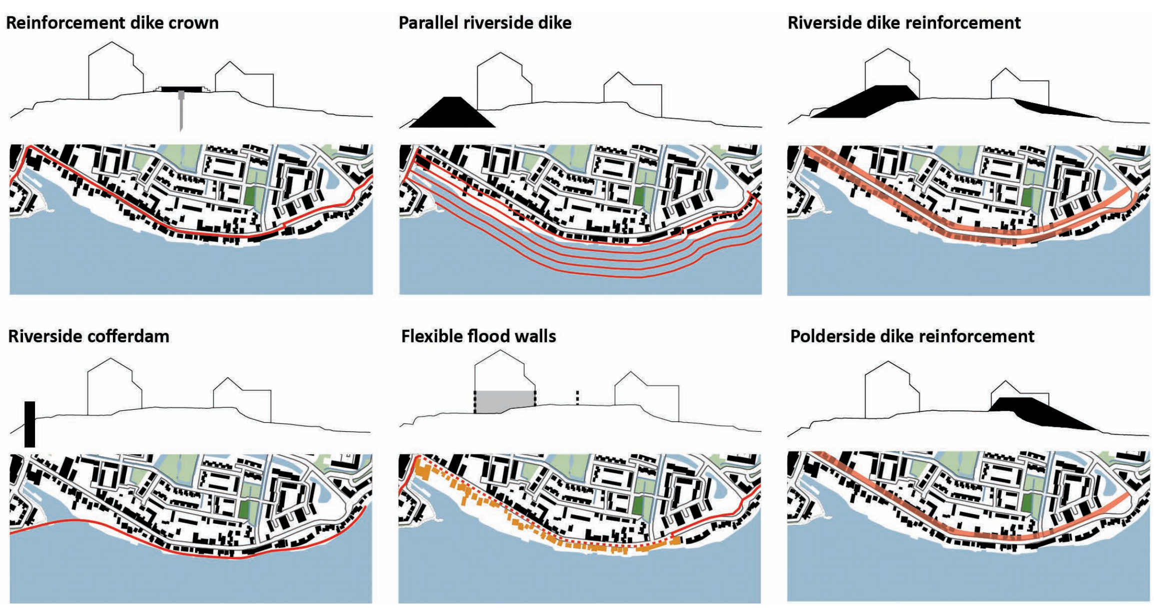
Spatial assignments mentioned for this area are the preservation of the historic dike ribbon, the improvement of traffic safety on the narrow dike road, strengthening the visual relation with the river and widening the shipping channel. For this location, the primary objective was to identify integrated solutions that would respect and, if possible, preserve the cultural value of the dike ribbon.

Possible (and viable) technical options

Reinforcement of the dike ribbon is likely to be needed as a result of increasing river discharges, sea-level rise and increased risk norms. A range of potential reinforcement options have been inventoried and assessed on their technical applicability (see Figure 12), amongst which: the reinforcement of the dike crown (by use of a cofferdam or pile sheet), flexible flood walls (for instance with sand bags), reinforcement of the inner slope, reinforcement of the outer slope, the construction of a parallel dike either the riverside, or a cofferdam in the river.

During the technical applicability assessment, temporary flood walls with sand bags were dismissed because these cannot meet the protection standard; reinforcement of the outer dike slope would require reinforcement of the inner dike slope, thus not offering a viable alternative for reinforcing the inner dike slope. The inland parallel dike would result in a large new dike in another built and low-lying area, which was not perceived to be a viable alternative option either. Implementation of the remaining options was subsequently analysed in design studies.

FIGURE 12. Overview potential reinforcement options have been inventoried (this is a selection from the complete overview).



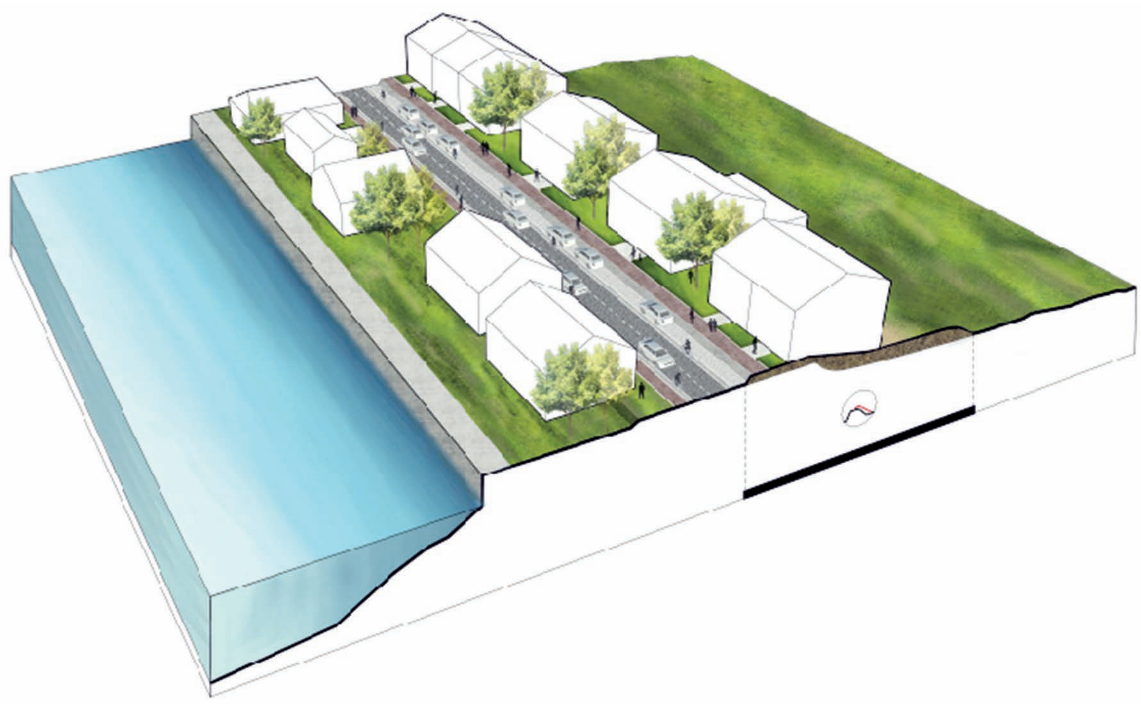
Design study: Reinforcing the inner slope of the dike

Reinforcement of the inner slope can be considered as the 'business as usual' solution for dike reinforcement of double sided built dikes. This does not necessarily imply that all houses on the inner slope need to be demolished. In previous dike reinforcement projects, this solution was implemented leading to an adverse impact on spatial quality of the dike ribbon. Despite the intention to create a more liveable, modern street profile, the historic characteristics of the dike ribbon disappeared. Not only does newer larger scale housing not match the remaining small-scale houses, the widened road with separate lanes for pedestrians, bikes and cars is not in proportion to the scale of the remaining original houses. Therefore, using the same solution for the new iteration of dike reinforcement would require careful redevelopment that respects original characteristics such as: the individually built small scale houses, the narrow road, matching low facades and the staggered plot lines.

Design study: Parallel dike in the river

Construction of a parallel dike in the river allows preservation of the original built dike ribbon. However, the visual relationship between the houses along the outer dike slope and the river would change dramatically. This solution was applied along other parts of the dike and therefore perceived by local stakeholders as a viable and promising option. By including a footpath along

FIGURE 13. Visualization of the reinforcement of the inner slope. When reinforcing the inner slope, buildings either need to be jacked up or replaced. This option is considered a 'business as usual' option since in previous dike reinforcement iterations, this concept was commonly practiced. It is challenging, but possible to preserve existing characteristics of the double sided built dike ribbon. The most challenging part of the redesign is to balance dimensions since the width of the street profile will increase and be elevated, while the small-scale houses on the outer slope remain.



the water, the new dike can provide a new, safe route for pedestrians with spatial proximity to the water. At the same time, a parallel dike further narrows the shipping channel, making it impossible to pursue this alternative without additional compensating measures. In this location, the compensating measure would be to widen the river on the opposite side. Given that the opposite side is part of a different municipality and, especially, of a protected natural reserve, this means that the parallel dike would require politically challenging compromises.

Design study: Parallel cofferdam

A derivative from the parallel dike is the parallel cofferdam. It requires less space and therefore does not compromise the shipping channel. This option results in an inspiring typology that is so far uncommon in the Netherlands. The cofferdam could include a footpath parallel to the main road that creates a safe walking route and allows pedestrians to stroll along the riverbank. The path could create a staged route with different sequences of views and proximity towards the river. Although the view from houses along the dike towards the river is obstructed in a similar fashion as with the parallel dike, all buildings can be preserved. As an additional advantage, this could be an interesting pilot and showcase for the local hydraulic engineering companies.

Design study: Reinforced dike crown

Despite space limitations, it is possible to heighten the existing dike crown. This method was originally applied in the area to preserve existing building rows. By again reinforcing and elevating only the centre section of the dike, houses can be preserved. They can then be accessed through narrow walkways alongside the dike. This solution fits the characteristic of the area,

FIGURE 14. Visualisation of the parallel dike in the river. The footpath along the dike is positioned at a lower level. This allows for a stronger relation with the river and preservation of privacy for the adjacent gardens.

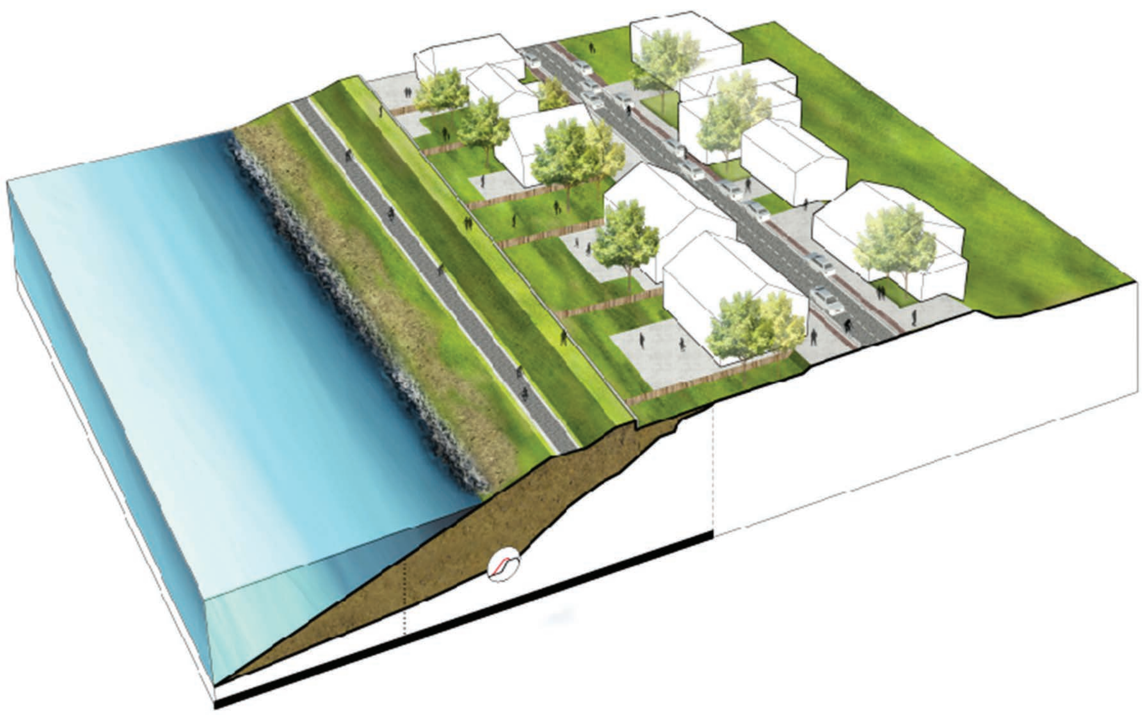


FIGURE 15. Visualisation of the parallel cofferdam. The coffer dam has the potential to function as a recreational pedestrian route with close proximity to the river.

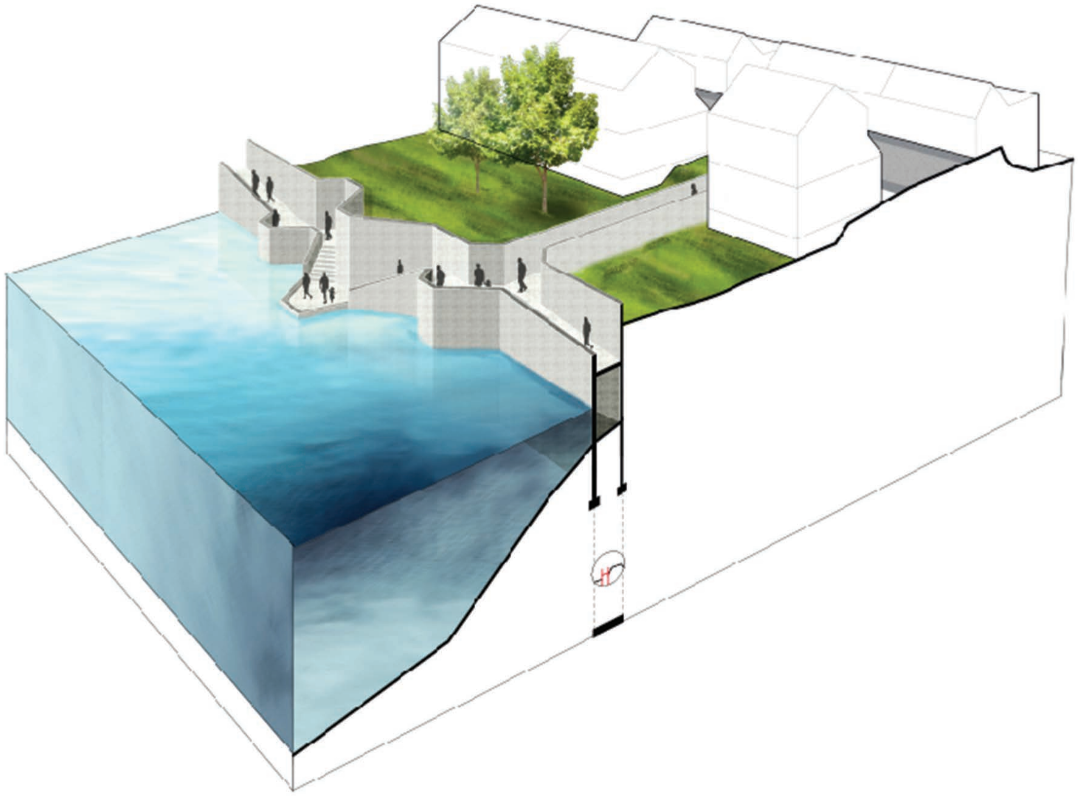
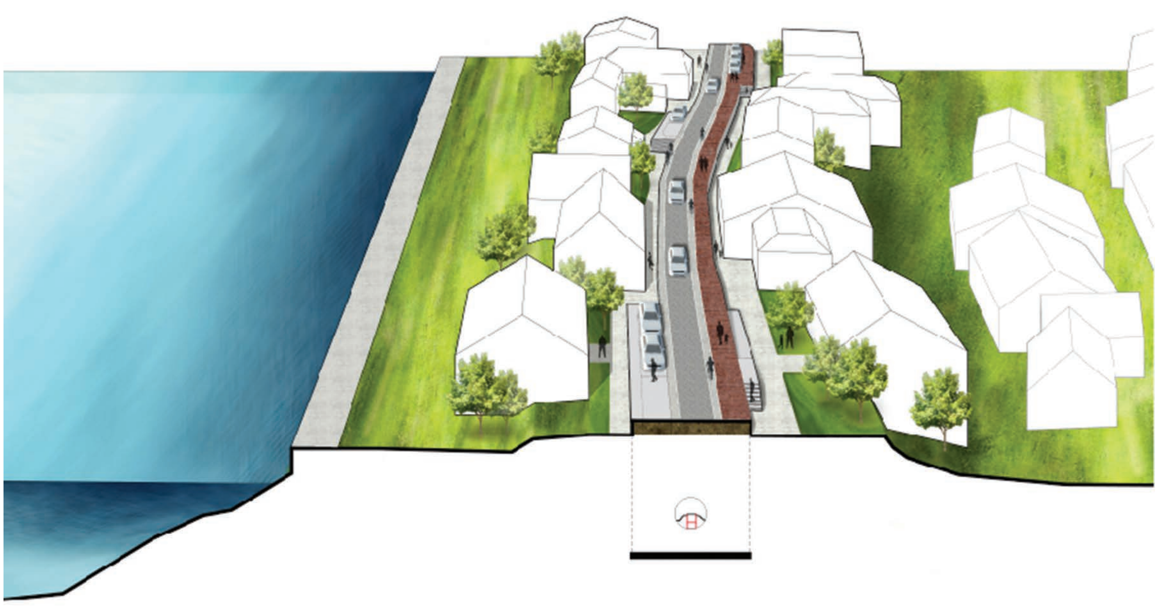


FIGURE 16. Visualization of the reinforced dike crown, by creating a one-way car road (instead of the current 2 car lanes) there is sufficient space for a continuous pedestrian path.



where the houses have slowly been disappearing behind the dike. The road would narrow resulting in insufficient space for a two-lane road, transferring the road into a one-way car road (and two-way bike road) could according to the experts resolve this while also improving the traffic safety. A big advantage of this solution would be that the original relation between the dike houses and the river would remain.

Case study 2: Scheveningen

Scheveningen used to be an independent fisherman's village on the coast. It has gradually become a neighbourhood of the city of The Hague. Tourism started in the early 19th century. Nowadays, this seaside borough is known as a recreational resort with a nationwide reputation. The monumental 19th century Kurhaus and Pier are reminders of the long history of tourism and recreation.

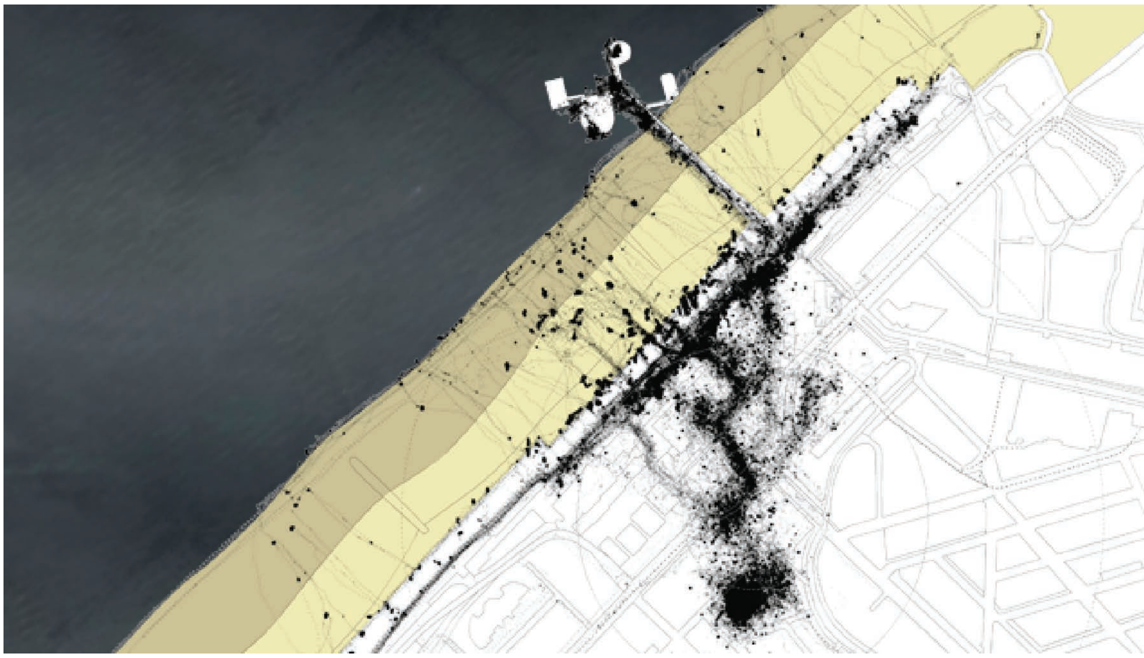
Spatial ambitions and assignment

The close proximity of a city to the sea is rare in the Netherlands and results in a unique identity that the municipality of The Hague would like to strengthen further. Scheveningen currently however faces socio-economic and spatial challenges (Municipality of The Hague, 2009) with regard to the vitality, identity, accessibility and spatial quality of the area. For the harbour area an urban transformation is envisioned in which the current fishing harbour has the potential to partly transform into a housing or business district.

An important ambition is the improvement of the spatial quality of the shore area (Municipality of The Hague, 2009). Also, the accessibility of the shoreline is an important theme. Not only is the shore difficult to access by public transport or car: the urban tissue between the main traffic road and the shoreline is difficult to permeate for pedestrians. Figure 18 shows the results of a GPS user study performed by the Delft University of Technology. It shows that the build tissue along the coast is mainly penetrated by pedestrians on one of the main entrance points of the boulevard. This might also relate to the fact that it's difficult to orientate: it is unclear which direction to follow towards the shoreline since there is no visual connection.

FIGURE 17. Aerial photo of the Scheveningen seaside (source PDOK). On the right an aerial photo of the Kurhaus and Pier area (source Municipality of The Hague), and below a photo from the Kurhaus taken from the seaside boulevard.

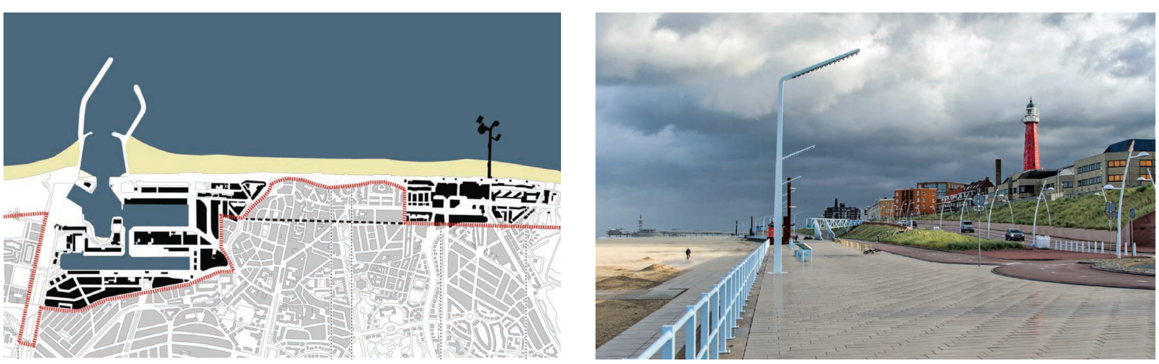
FIGURE 18. Results of a GPS tracking study by Delft University of Technology. Data shows people's trajectories starting from a GPS distribution point, lower-central part of the map. A lot of people visit the beach and boulevard; most of them use the main entrance route towards the beach, as the built tissue along the beach has low permeability.



Possible (and viable) technical options

The water defence line of the flood risk protection barrier, best characterized as a dune, runs though the touristic heart of Scheveningen. Reinforcing the barrier in this highly densified area is challenging. Formerly a weak spot urgently in need of improvements, the sea defence line was recently upgraded. It was moved seaward as there was sufficient space to reinforce the dunes along the beach. The reinforcement was used as a catalyst to upgrade and improve the design of the boulevard.

FIGURE 19. (left) The water defence line that runs through the urbanized seafront of Scheveningen. In the middle part the water defence line has already been brought seaward, during a recent reinforcement. The landscape design was created by De Solà-Morales (photo on the right: Rijkswaterstaat, Harry van Reeken).



In the current design study, three viable different technical options are explored: a seaward quay, a seaward dune extension and a perpendicular dam. The exploration focusses on long-term development options, beyond the year 2050. Different technical starting points lead to multiple design concepts that are described below. In each of them, the main roads coming from the city centre of The Hague are emphasized and extended towards the coast.

Design study 'hard seaward' extension: City by the sea
In this option, the existing boulevard area is extended at a level of + 14 meters NAP (see white extension, Figure 20). Compared to the current situation, the water defence line is moved further seaward, thus creating space for a housing and business district adjacent to the sea. The new platform provides sufficient parking space. In front of the new district, a lower platform positioned at +7 meter NAP forms a zone closer to the sea with ample room for recreational functions such as a tidal pool, bars, restaurants and surf schools. Along the shoreline, a wooden walkway provides access to the sea for swimming; it will flood during high tide.

From the endpoints of the roads coming from The Hague, there is an open view towards the sea at the higher +14 meters platform. The tidal swimming pool (middle left), a dune park (right middle) and a seaside square (on the right) can all be seen from there. The latter restores the connection between the historic Kurhaus and the sea.

This design option emphasizes the character of the high density urban area close to the sea and strengthens the identity of Scheveningen and The Hague as 'city by the sea'.

Design study seaward dune extension: City behind the dunes
In this option the existing natural dunes are extended in seaward direction (see figure 21). The water defence line also moves seaward and allows new development, but in a different fashion compared to the 'hard seawall'. A sandy dune is at risk of erosion during storms. The outermost part of a dune, closest to the water, is therefore unsuitable for permanent structures. Although

FIGURE 20. Conceptual ground plan of the city at the sea proposal (with the 'hard seaward' quay extension).

FIGURE 21. Conceptual ground plan of the city behind the dunes proposal (with the seaward dune extension).

this limits somewhat the possibilities for development, it creates a unique natural end recreational dune landscape that connects existing natural dunes on both the southern and northern edges of Scheveningen. The resulting beach can host seasonal pavilions used for recreation during summer. Along the harbour a unique living environment can be created with high rise residential rowers positioned in the dune landscape.

Design study perpendicular dam; a city in the sea

The third design study option (see figure 22) derived from the assessment of the previous seaward extensions; it became apparent that both seaward extensions would require significant maintenance. Sand would have to be supplemented periodically to ensure the seaward extension would not erode. The perpendicular dam was proposed to address this issue. Based on a rule of thumb, a perpendicular dam causes sedimentation along a coastal stretch of 1,5 x the length of the dam and additional erosion beyond that stretch. This information was key to positioning the dam, given the wish to protect the urban core of Scheveningen, while the adjacent natural dune park area might benefit ecologically from erosion.

The dam makes it possible to extend the city into the sea and offers the great opportunity to extend the tramline to the end of the dam. The dam is positioned in such a way that the historic village centre and Kurhaus alongside the dam keep their direct relation with the sea. Such a city in the sea is an uncommon typology it the Netherlands. It brings to mind built, rocky shores along the Mediterranean coast.

Results

In this case study, joint expert sessions and design sessions with both engineers and designers proved invaluable in making integrated visions. Based on intuition, designers for example had incorrect assumptions about the dimensions of varied types of sea defences: some of them

FIGURE 22. Conceptual ground plan of the city in the sea proposal (with the perpendicular dam).

assumed the new seaward dunes might be so high that they would form a visual barrier between the built edge of Scheveningen and the sea; they therefore favoured the 'hard seawall', which they thought to be lower (Arcadis and Alkyon, 2005). However, because the sandy dunes absorb more wave energy, they can be dimensioned somewhat lower (at +12 meters NAP) than a hard boulevard (at +14 meters).

This case study did not have the objective of selecting a preferred strategy. Rather, the options are meant to support the debate on the value of an integrated approach for the long-term development of Scheveningen. The study and associated workshops made clear that any discussion on the type of flood risk protection cannot be seen isolated from the future development vision for the area; an integrated approach is a must.

Case study 3: Kinderdijk

Kinderdijk is a world-renowned UNESCO heritage site. Located in the north western, low-lying corner of the Alblasserwaard polder, water from the entire polder is gathered here and discharged into the river Lek. In the past, the excess water was pumped into a discharge basin using windmills and subsequently discharged into the river during low tide. Nowadays, the windmills, from the early 18th century, serve as a tourist attraction. Electric pumping stations have taken over their original use.

Spatial ambitions and assignment

Currently, about 400.000 tourists visit Kinderdijk each year. This number is growing. Access to the site is provided by the original dike road that is not well equipped to handle this. To improve the liveability of the old village centre adjacent to the world heritage site, a visitor management strategy is being developed that encourages tourists to visit by boat. The river cruises and water-bus that provide service to Kinderdijk currently dock at jetties along the dike of the river Lek.

FIGURE 23. Aerial photo of the Kinderdijk world heritage site (source PDOK). On the right a photo of the historic 'waterboard' residence and the famous windmills.

Possible (and viable) technical options

Reinforcement of this dike is relatively simple since it is freely positioned in the landscape and there are hardly any buildings. Though there is no urgency from a spatial perspective to develop an integral design vision for this area, it was found that the dike reinforcement could be an interesting inducement for improving the transport infrastructure, especially for tourists arriving by boat.

Design study arrival deck

In a design workshop, options are explored to improve the arrival route of tourists accessing the area from the jetties. They currently set food on the ground at a priority bike path that, unknown to most foreigners, functions as a cycling highway for bikes. This results in dangerous situations and annoyances. In the design vision, a public arrival deck is positioned on the riverbank (see figure 24). Visitors can first arrive, gather and orientate before they cross the public road. A local interest group is now pushing for a tunnel through the dike, to connect the deck to the heritage site without the necessity to cross the road. Establishing a tunnel in a primary water defence seems contradictory to most experts, but the interest group feels confident that local hydraulic engineering companies have the inventiveness to design and realise such an extraordinary construction safely.

What is interesting in this case, is that instead of the usual hope that a local dike does not have to be reinforced, here is a situation where reinforcements are welcomed, in order to serve as a catalyst for redevelopment of the area.

Application abroad: Houston-Galveston Bay

Houston is positioned along the Galveston Bay, which is separated from the Gulf of Mexico by Galveston Island and the Bolivar peninsula. The area is prone to flood risks caused by hurricanes, resulting in storm surges and extreme storm water conditions. In 2008, Hurricane Ike flooded the peninsula and nearly missed Houston's city-centre and petrochemical industry. In 2017, hurricane Harvey caused up to $180 billion in damage, primarily through extreme storm water conditions (Reuters, 2017). These recent events emphasize the need for an integral flood

FIGURE 24. Proposal for a tourist arrival platform along the dike near the UNESCO world heritage site Kinderdijk. The three jetties already exist and currently land directly on the main road. Behind the dike are two pathways leading to the famous windmills.

risk management strategy for the larger Houston metropolitan region. Given the high level of urbanisation in the area, this strategy should be integral in that it both includes different technical aspects (storm surge protection and storm water management) and different disciplines (for example urban planning and ecology).

Over the past years, several studies explored different aspects for protection of the Houston Galveston Bay area. One of the potential building blocks for a regional flood risk protection strategy is the creation of a coastal sea barrier along the low-lying peninsulas (SSPEED centre, 2015). Such a spine can limit the amount of storm water that enters the bay; it allows, for example, maintaining a lower water level in the bay in anticipation of hurricanes and other severe weather events. This increases the storage capacity for storm water that is discharged towards the bay and reduces the risk that bay water will flood Houston's city centre and port. This design study preceded Harvey; it was performed in 2016 in close cooperation with Texas A&M and Rice University SSPEED centre.

Galveston island

Galveston island is approximately 44 km long and mostly natural; the city of Galveston is located on the eastern end. Galveston was an important city and port in the 19th century until a major flood occurred in 1900 (Blake and Gibney, 2011). Although much of the city was rebuilt, the economic centre of the area moved north towards Houston. Along the Galveston seawall, some of the hotels are reminders of 19th century grandeur. Except the urban core of Galveston, most structures on the island are low density recreational residences, located in the open Galveston march and beach landscape. Despite some of them being constructed on poles,

FIGURE 25. Map of the Houston Galveston Bay area (source Delft University of Technology.) On the right photos of the Galveston sea wall and one of the holiday home neighbourhoods.

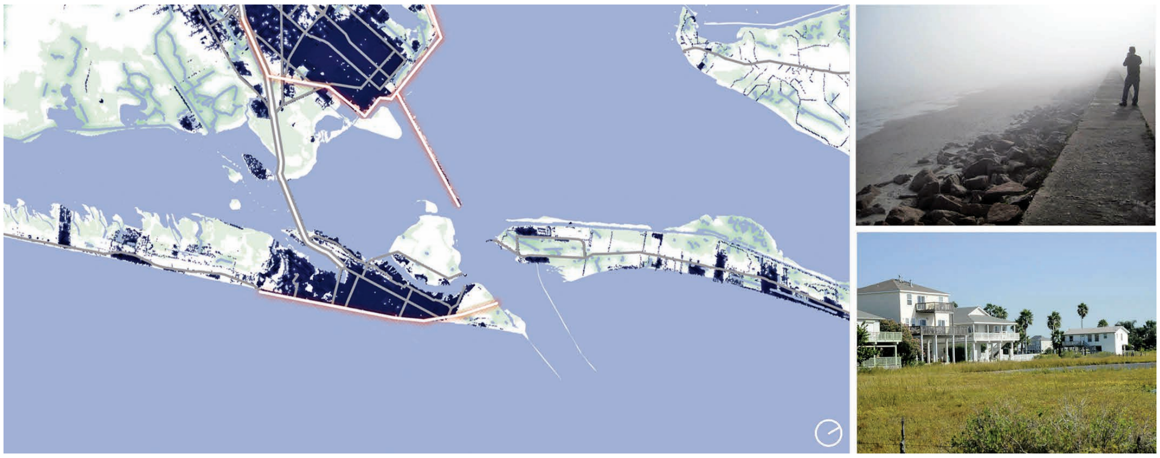
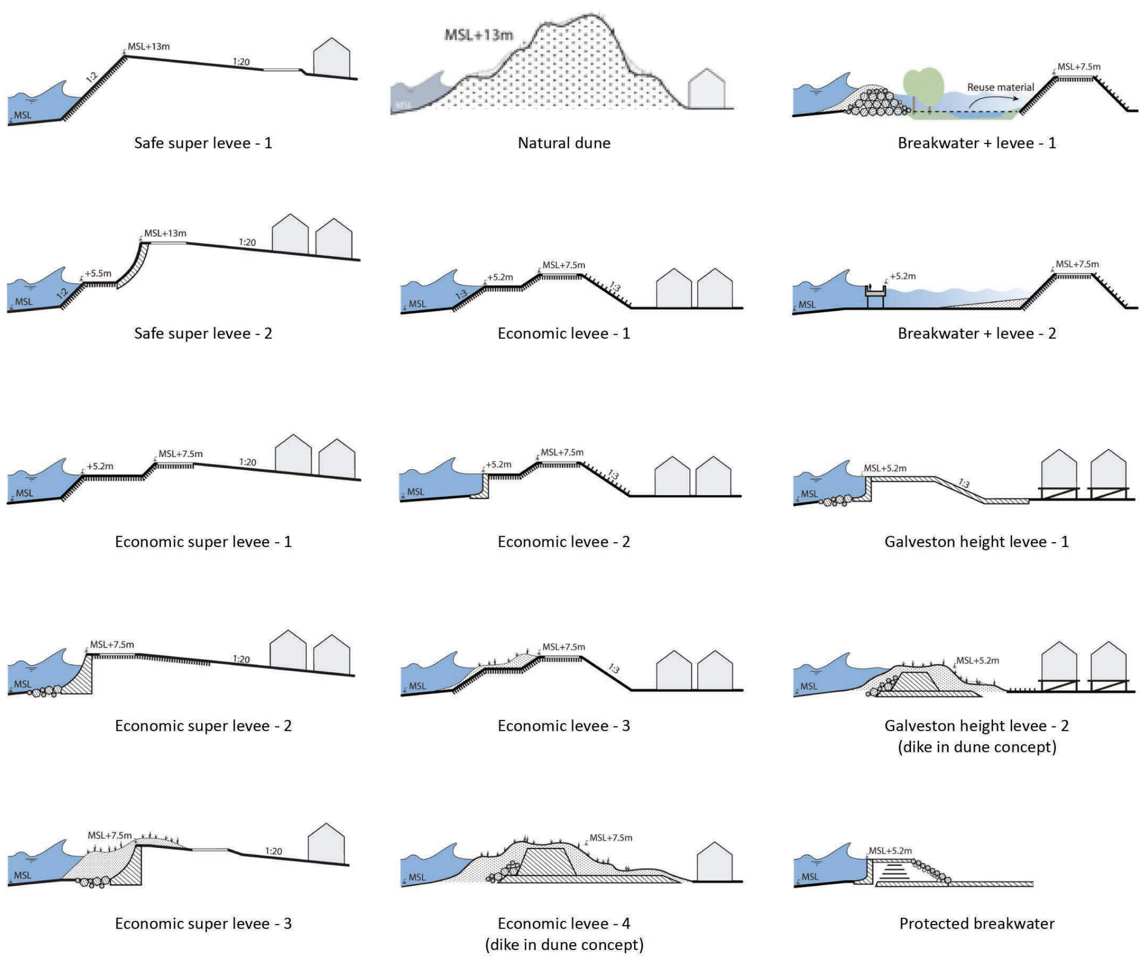


FIGURE 26. Overview of different technical opportunities (in section) for constructing the coastal barrier.



many buildings suffered from flood damage. Hurricane Ike required significant rebuilding efforts, Hurricane Harvey may require so as well.

Spatial ambitions and assignment

The main spatial ambition was preservation of the spatial and ecological qualities of the island. Preserving the view towards the ocean from both residences as well as the road along the shoreline was an important spatial requirement.

Possible (and viable) technical options

Together with engineers, an overview was made of the different possibilities for constructing a sea barrier (van Berchem et al., 2016). This broad inventory showed a wide range of options including dikes, sandy dunes, breakwaters and quay walls. For Galveston city, the current seawall was deemed sufficient. The study therefore focused on stretches of the island west and east of the city centre (see figure 28).

The wide range of possible alternatives were assessed, resulting in 3 conceptual options that were studied:

1. The extension of the existing Galveston seawall
2. A barrier with natural appearance (a dike with a clay core covered with a natural dune layer)
3. Creating a seaward breakwater combined with a levee

Design study: dike in dune

In the first selection of possible barriers, there was a strong preference for a natural appearance of the barrier, which would suggest a sandy dune solution. The disadvantage of such a solution at this location was the height that was needed to provide sufficient strength (13 meters) and the cost related to constructions that use sand (in contradiction to the Netherlands, sand is not easily available in Galveston).

Therefore, a 'dike in dune' option was proposed, in which a dune is constructed as a rigid clay core covered with a layer of sand. The height of such a dune could be limited to around 7–8 meter, whilst preserving a natural appearance. For different areas along the island it was studied how this barrier could be best positioned. Taking into consideration land ownership and the requirement to preserve the seaside view towards the ocean, it was decided that the

FIGURE 27. The three selected viable options for a barrier, being the extension of the Galveston seawall (left), an natural appearing dike in dune concept (centre) and a seaward breakwater combined with a levee (right).

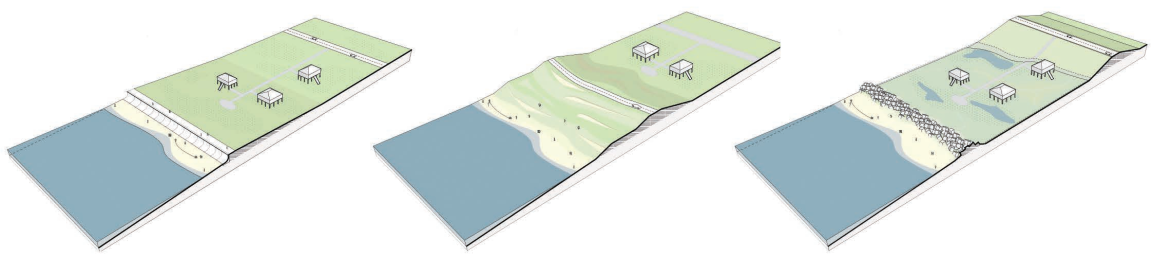
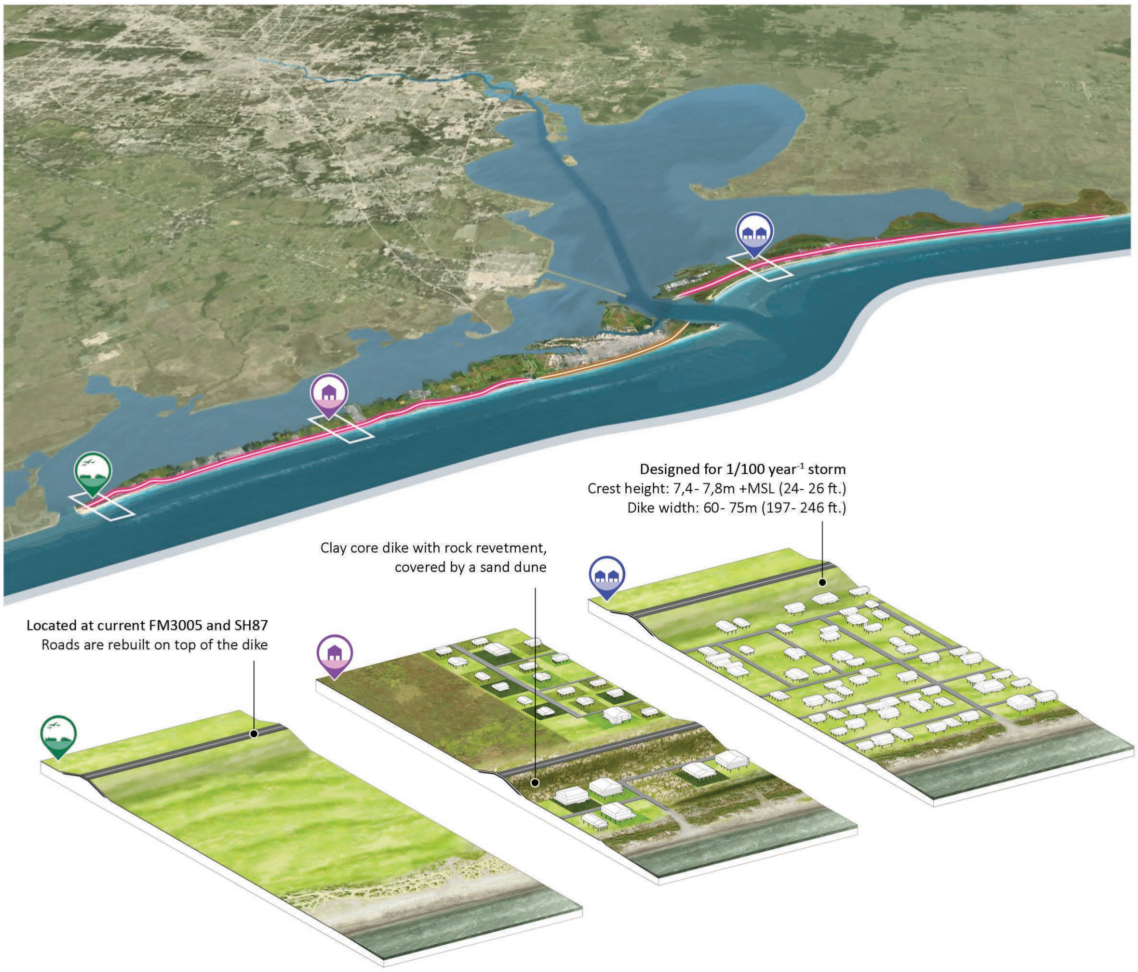


FIGURE 28. The preferred design option for a dike in dune concept positioned under the existing road. The proximity of the road varies along the island, therefore the technical section will vary accordingly.



barrier would have to be positioned underneath the existing coastal road. As an extra benefit, the coastal road will thus gain ocean views.

CONCLUSION

Two aspects of the research by the design approach described in this article that were deemed particularly valuable are the application of research by design in the early design stages and the integral (technical and spatial) work forms.

Research by design in an early project stage

The research by design in the early stage of formulating new flood risk standards, rather than in a later stage when implementing the reinforcements, is perceived to be very valuable. The design period with regard to implementing reinforcements is generally limited to a four year period. This has often proved to be insufficient time to set up a successful working relation between municipalities and waterboard (which implements the reinforcements), to explore potentials for synergy or optimal embedment, and to establish funds for co-investment in integral design solutions.

By performing a research by design study in an early stage, stakeholders are activated early on, allowing them to start the time consuming integral planning and vision development in an earlier stage and to be an active partner in the integral development. In the Kinderdijk case study, the municipalities are now eager to accelerate some of the reinforcements so that they can be combined with short term spatial developments.

Results from the Sliedrecht case study have been shared with inhabitants. Not to inform them on a future development or vision itself, but rather to explain to them that qualitative alternatives may be possible where houses can be preserved. This eases some of the agitation that was caused by the fear that dike reinforcements would inevitably lead to the demolition of houses.

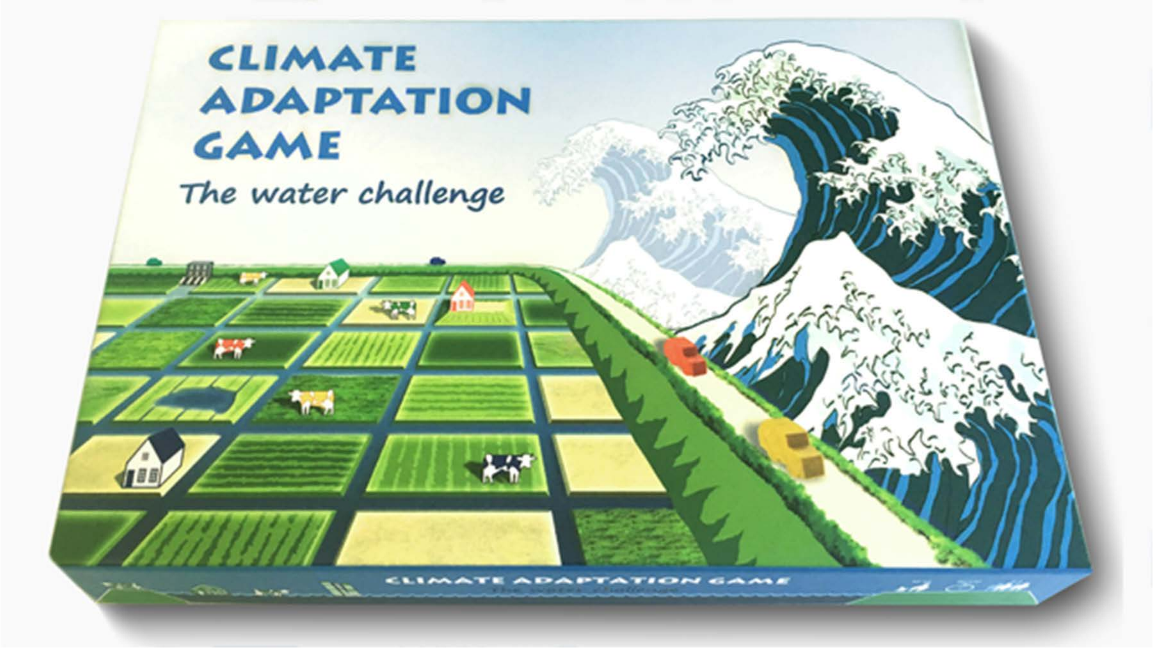
The Alblasserwaard-Vijfheerenlanden opportunity map, which provides an overview of different assignments and projects, was considered a valuable tool. The integrated information allows stakeholders from different organizations to find opportunities for synergies. The opportunity map concept has since then been used in many follow-up projects.

Integrated design workshops

The integral design process helped to combine technical and spatial assignments and to achieve integrated design visions. One of the aspects that seemed essential in the interdisciplinary collaboration is that designers, with the help of engineers, understand the basic principles of water management and flood risk design. Understanding those principles ultimately leads to an increased number of valid technical alternatives and hence to an increased chance that

FIGURE 29. Photo of the scale model with projections and the Climate Adaptation board game (photo by Frank Auperlé).

FIGURE 30. The Climate Adaptation board game.



one of those alternatives can be combined with other projects or assignments in order to achieve synergies.

For a designer, it is valuable to be involved in the early stage of the project in which the options for the type of technical solution can still be decided on. This allows the spatial implementation, which the designer can advise on, to become a selection criterion. This leads to better results compared to an approach where disciplines operate separately, the technical design is made by engineers, and urban or landscape designers are tasked to implement this to the best of their abilities (the proverbial 'putting the lipstick on the pig'). The interactive expert and design workshop was considered a very successful work form to create interaction, allow joint fact-finding and facilitate integrated concept and vision development.

In order to better inform designers and stakeholders on technical principles related to water management, two special capability building tools were developed. An educational model was built in cooperation with the Delft University of Technology (figure 29); this scale model projects data, system knowledge, climate change scenarios, projects and innovations on a physical model of the The Hague-Rijnmond area. The second is the climate adaptation game: in a playful way, this board game provides insights in complex relations between flood risks caused by storm surges from sea, the discharge of rivers and storm water (figure 30).

SOURCES

van Berchum, E., de Vries, P. A. L., & de Kort, R. P. J. (2016). Galveston Bay Area: Land Barrier preliminary design. Delft University of Technology.

Blake, E. & E.J. Gibney (2011). The Deadliest, Costliest, and Most Intense United States Tropical Cyclones from 1851–2010 (and other frequently asked hurricane facts). NOAA Technical Memorandum NWS NHC-6, Miami, Florida.

M. Bos (2016) Het 'Eindrapport MIRT-onderzoek A5H' is tot stand gekomen als onderdeel van het MIRTonderzoek Alblasserwaard-Vijfheerenlanden. www.A5H.nl [accessed: 10 January 2018]

Deltacommissie (2008) Working Together with Water, A Living Land Builds for its Future: Findings of the Deltacommissie 2008. Deltacommissie (Deltacommittee), The Hague, The Netherlands (in Dutch).

Delta Programme (2011) *Rhine Meuse Delta: Opportunities for the current flood risk management strategy in 2100*

Geldof, C. & N. Janssens (2013) Van ontwerpmatig denken naar onderzoek. Retrieved from: http://www.google.

Meyer, H. (2009), 'The Dutch Delta: Looking for a new fusion of urbanism and hydraulic engineering', in Feyen, J., Shannon, K., and Neville, M. (eds.) (2009), *Water & Urban Development Paradigms* (Leiden: Taylor and Francis).

Municipality of The Hague (2009) Masterplan Scheveningen Kust

Province of South Holland, Cultuurhistorische atlas Zuid-Holland, http://pzh.b3p.nl/viewer/app/Cultuur_historische_atlas [visited 15 January 2018]

F. Klijn, et al. (2013) Design quality of Room-for-the-River measures in the Netherlands: role and assessment of the Quality Team (Q-team) *International Journal of River Basin Management DOI: 10.1080/15715124.2013.811418*.

M. Kok, R. Jonjan, M. Nieuwjaar, I. Tanczos (2016) Gondslagen voor hoogwaterbescherming, Ministerie van Infrastructuur en Milieu en het Expertise Netwerk Waterveiligheid.

Reuters (2017) https://www.reuters.com/article/us-storm-harvey/funding-battle-looms-as-texas-sees-harvey-damage-at-up-to-180-billion-idUSKCN1BE0TL [accessed 10 January 2018]

Steenbergen CM, Reh W (2009) De Polderatlas van Nederland. THOTH, Bussum.

SSPEED Center (2015) 2015 Annual Report, H-Gaps, Houston-Galveston Area Protection System., SSPEED center, Rice University.

UN Habitat (2008) State of the World's Cities 2008/2009:Harmonious Cities. UN Habitat, Nairobi, Kenya.

L. de Vries (2014), Gebiedsrapport Alblasserwaard en Vijfheerenlanden, Deltaprogramma Rijnmond Drechtsteden.