Environmental Science and Policy 103 (2020) 67–76

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Planning infrastructure replacements: Restructuring and exerting partial control over the environment

Mark Zandvoort[a,b,*], Maarten J. van der Vlist[a,c]

[a] *Wageningen UR, Landscape Architecture Group, the Netherlands*
[b] *Tauw BV, the Netherlands*
[c] *Rijkswaterstaat, the Netherlands*

ARTICLE INFO

Keywords:
Uncertainty
(un)control
Replacement strategies
System transformation
Infrastructure

ABSTRACT

By building infrastructure, planners want to exert control over the environment for the sake of society. Due to uncertainty and complexity, such control is always limited and can become contested. Based on a case study of replacing a pumping station, we show how planners can understand the replacement of infrastructure and what informs adequate replacement strategies amid uncertainty. The paper argues that the concepts *(un)control* and *(re)structuring* help understand replacements in the context of infrastructure planning. Infrastructure replacements are interventions on different levels which restructure existing systems, asset networks, local areas and assets themselves. Necessary information for developing a replacement strategy, exerted control or uncontrol, possible innovations and restructuring effects differ among these levels. We conclude that planners need to be cognizant that infrastructure replacements, no matter how large or small, restructure both environments and social institutions.

1. Introduction

The day-to-day operation of highly organized water systems aims to sustain societal functions, such as flood risk protection or fresh water supply. Water systems depend on the proper functioning of hydraulic structures. These structures deteriorate and will, sooner or later, reach their technical end-of-lifetime. Moreover, societal demands may alter structures' desired functionality, increasing their use beyond what is technically feasible, or rendering required uses or functions difficult. Sustaining their proper functioning is, however, surrounded by uncertainties and complex interdependencies (Giezen, 2018). Nonetheless, planners need to develop strategies for the renovation, replacement or demolishment of structures.

Despite recent work on replacement strategies for infrastructure (e.g., Bernardini et al., 2014; Hertogh and Bakker, 2016; Smet, 2017; van der Vlist et al., 2015; Willems et al., 2016), what constitutes an adequate replacement strategy is understudied. This has partly to do with the just recently growing urgency to replace infrastructure, instead of building new assets. As Willems et al. (2018) signal, there is a shift happening from developing infrastructure-based systems to continuous re-development of such systems. This reconfiguration takes place in already established systems depending on networks of infrastructure (Coutard and Rutherford, 2015).

Replacements of infrastructure can be decisive moments for reordering spatial structures, environments or transforming landscapes. Landscapes are subject to splintering and spatial restructuring (Abbott, 2009; Graham and Marvin, 2001). Moreover, there is a growing insight that planners develop strategies within fragmented governance systems (Allmendinger and Haughton, 2009) and are just one player among many in spatially ordering and transforming our landscapes (Healey, 2007; Innes and Booher, 2010). The development of strategies for infrastructural interventions is situated within this context, and strategies are formed and transformed by the messy world in which contemporary planning happens (Alexander, 2015; Boelens and de Roo, 2016). Connected to the long lead-up time to a replacement and the heavily dependence of society on physical infrastructure makes adaptive planning and decision-making about replacements important. Sunk cost after inadequate investment decisions can be prevented by sufficiently addressing uncertainty and interdependencies between infrastructures.

This paper argues that planning for infrastructure replacement is a balancing act between uncontrollability and control, aimed at harnessing uncertainty and complex interdependencies. Planning of replacements leads to restructuring, transforming and exerting partial control over the environment and landscape structures. To take adequate

---

[*] Corresponding author at: Wageningen UR, Landscape Architecture and Spatial Planning chair group, Droevedaalsesteeg 3, Postbus 47, 6700 AA Wageningen, the Netherlands.

E-mail address: Mark.zandvoort@wur.nl (M. Zandvoort).

https://doi.org/10.1016/j.envsci.2019.10.010
Received 11 March 2019; Received in revised form 14 October 2019; Accepted 14 October 2019

replacement decisions, planners[1] need to make realist *claims* in order to come to one set of technical design requirements for an asset. When doing so, two key issues stand out. The first issue is the position of planners between control versus uncontrollability (Luque-Ayala and Marvin, 2016). Planners want to control the living environment through building or replacing infrastructure. Controlling (and certainty about) all variables interacting on the replacement of a structure is, however, impossible. Second, and related to the first issue, is that (interrelations between) choices in developing adequate replacement strategies for assets within highly organized systems are unknown (cf. Zandvoort et al., 2019).

Our aim is to study how interdependencies between functions and water system components on different scales come together in the replacement of a particular asset. Thereby we develop the argument that through replacements existing systems and landscapes are restructured and control is exerted on particular phenomena, while other variables are left uncontrolled. We further develop the argument that particular information is needed to develop an adequate replacement strategy in light of restructuring landscapes and transforming systems (Belanger, 2013).

2. Theoretical framework

Our theoretical framework is build up along the following reasoning. Infrastructure replacements (2.1) have distinct characteristics which planners and policy-makers need to understand before making infrastructure investments. This links to the restructuring effects of infrastructure replacements, which are directed at exerting more or less control over the environment (2.2). Thus, planners need to think about replacements as establishing a dialectic relationship between the real and perceived (2.3). Studying this brings insight in mechanisms of (un) control and restructuring through infrastructure replacements (2.4).

2.1. Infrastructure replacements

In this paper we focus on infrastructure replacements because these are the moments at which system renewal is a prominent possibility for planners (Willems et al., 2018). The replacement of an infrastructure has several different characteristics compared to a newly proposed asset or infrastructure. The replacement needs to be considered and executed at the place where an infrastructure is currently located. Second, over time the risk of failure or outages grows, putting a time-based strain on decision-making (Smet, 2017). Third, a replacement is a window-of-opportunity to renew or alter the dependent network or system including capitalizing on system-synergies. A piece of infrastructure always contributes to a larger whole, which should not be undermined due to the replacement (Brown, 2014).

These differences support the claim to pay more attention to infrastructure replacements in general and the replacement of hydraulic structures in particular. We would argue that hydraulic structures are distinct from, for example, road or telecom infrastructure replacement because of their stronger interaction with the environment: through surface water and groundwater there is an inseparable link and, thus, influence of hydraulic structures with their surroundings. Said otherwise: the externalities of a hydraulic structure are more strongly tied to the asset compared to a road or a Wi-Fi router. This raises the question how to perceive an asset and its environment. In this paper, we define an asset as a physical structure such as a pumping station, sluice, weir or bridge (or a viaduct, railway station, harbour, etc.). Through the water system these assets always interact in a network of different assets. Both functional (how they influence components of the water system) and operational (a network of assets is often managed in interaction by one operator). We see the environment as the surroundings in a broad sense. So both the effect on the area near the location of an infrastructure and the wider environment of the managed network or system.

2.2. Planning on the fringe of (un)control

To understand the planning of infrastructure replacements and to inform adequate strategies accounting for uncertainty and uncontrollability, we develop our argument based on the control exerted through infrastructure and uncontrol due to irreducible uncertainty, complex interdependencies and contestations of reality (Brugnach et al., 2008; Zandvoort et al., 2018a). We argue that adaptiveness and flexibility are control-enhancing mechanisms.

We start from the premise that planning and planners act in complex situations, in which adaptive behaviour, emerging self-organisation and non-linear change are the main characteristics of the socio-physical system at which spatial interventions are aimed (de Roo and Silva, 2010; Folke et al., 2005). As Boelens and de Roo (2014) claim: uncertainty prevails. We argue that an epistemology based on complexity necessarily requires the establishment of a connection between a material disposition on the one hand, and a disposition based on heterogeneity, poly-rationality and communicative rationality on the other (Allmendinger, 2002; Davy, 2008; DeLanda, 2006; de Roo and Silva, 2010; Folke et al., 2005; Healey, 2007).

Instead of leaving planning and policy-making fully open to ‘becoming’ (Cf. Boelens and de Roo, 2014), we assume that planners need to make realist *claims* about the functioning of socio-physical systems. Different, unequivocal ontologies exist due to multiple perspectives and mutually exclusive reality-based claims (Zandvoort et al., 2018a). When planners decide about infrastructure investments, this can result in a paradoxical tension. An example of this tension is that increasing the height of a dyke does not offer a solution for ambiguity due to actors having a different perception of a dyke. Neither will seeking consensus help avoid adverse impacts if a dyke is too weak for river discharges of which the probability of occurrence is uncertain. When in need of a replacement strategy this tension becomes important. An object, such as a dyke, is located at a particular location and will have a specific set of technical design requirements: there is just one final, definitive dyke configuration. Each asset has its particular design and engineered features.

Planners need to assess if the information they have is sufficient to consider the restructuring effects of an asset on the system and asset network for often decades and sometimes even centuries ahead (Belanger, 2013; Wilson, 2015). This also links to planning over the course of different lifecycles of assets and the continual adjustments and restructuring within a larger system (van der Vlist et al., 2015; Zandvoort et al., 2019). Each replacement can be seen as a window of opportunity which enables a longer and broader view on a system’s renewal (Willems et al., 2018)

2.3. Control/Uncontrol

To sustain societal values, some control over the physical environment is necessary as is preparing for unknown change. Moreover, each infrastructural intervention does exert more or less control. Even though the continuous critique on instrumental rationality since Lindblom (1959) his work, the recently developed approaches based on flexibility (Smet, 2017), robustness (Mens, 2015) and adaptiveness (Kato and Ahern, 2008; Lessard, 1998) show a revival of instrumental rationality, albeit with some new characteristics. In addition to thinking in options and accepting inherent uncertainty underlying planning approaches, the main character trait is the provision of control in an

---

[1] We simplify the complex decision-making process at asset management organisations here with the actor 'planner'. Of course there are a lot of complexities, persons and roles involved with policy- and decision-making, but for our aim of understanding the interplay between infrastructure, replacement and the environment we chose in our paper for this 'single actor'.

uncontrollable situation. While the approaches do recognize the persistent difficulty with irreducible uncertainty as underlying component of the wickedness and complexity of problems (Hartmann, 2012; Rittel and Webber, 1973), they do aim to offer some control for planners through the concepts of robustness, flexibility or adaptiveness for infrastructural interventions (Mens, 2015; Rauws, 2017; Smet, 2017; Zandvoort et al., 2018b).

We here argue that the claim underlying these concepts is that planners need to let go of a logic of control, while simultaneously trying to offer enough certainty and direction to control specific situations (Fingland, 2011), for example based on creating particular conditions instead of overarching goals (Rauws and De Roo, 2016). This leads to rethinking the control exerted over systems through infrastructure and to make deliberate choices about the restructuring and controlling effects of assets.

2.4. *Navigating between certainty and uncontrollability: three premises*

What planners need for adequate replacement strategies in an abstract sense is a vehicle to rationalise planning, while acknowledging that conditions change due to natural developments and changing interests at play, now and in the future. As such, planners will always navigate situations that will never be fully controlled, nor be totally out of control (Savini et al., 2015). This balance between leaving some areas of landscapes, environments and future change open to uncontrollability, while deliberately offering control and certainty if necessary, leads to an ontology into which both the real and the perceived are in a continuous dialectic relationship. This is a relationship where they cannot be untangled without having detrimental effects for infrastructure replacement decisions. We therefore suggest three premises to start from.

The first premise is that planners need to acknowledge a limited predictive capacity, although the handling of uncertain change can be enabled if there is a clear portfolio of options and the spectrum of possible outcomes is at least conceivable in light of future conditions. This can inform the adequacy of robust, flexible or adaptive options and innovation of both systems and assets. A key notion here is that just one, fixed set of design requirements will be the final option informing the engineering of a structure. The diameter of the pumping canal in a pumping station is either 1 m or 1,5 m. The act of choosing the diameter is a structuring choice[2] in relation to the system functions sustained by an asset. Innovation in this understanding enables adaptive planning by opening up new, possible adaptations.

Secondly, adequate handling of uncertainty is enhanced under conditions of variety and multiplicity. This offers a solution space that can be explored and coupled to the planning and design of infrastructure. Exploring the solution space depends on knowledge about the current situation, openness to serendipity, possibly leading to novel or disruptive interventions, attention for learning, co-construction of perspectives and increasing responsiveness to and consideration of stakeholder needs. Gained information needs to be condensed to design requirements for one, single option: the structure that is going to be built.

Third, conditions that are within the control of planners can be managed by conducting directed experiments to optimise the current situation. Planners can reduce uncertainty if reducible and necessary, study options to let the system offer the currently desired functionality and optimise system performance. Testing different operations of an asset or executing modelling studies in advance of a replacement support such asset management.

Planning for infrastructure replacements can thus be understood as a balancing act between uncontrollability and control. Replacements can be a means to restructure, transform and partially control the environment, or to choose for maintenance and conservation to uphold existing (un)control (Fig. 1). The three premises might help to develop a broadened perspective on what an adequate strategy for replacement might entail, and how a planner might go about particular choices which restructure a system through infrastructure replacements.

3. Methods

We studied the structuring aspects and related information needed for adequate replacement strategies in a single case study. We chose for a single case-study to cover the complexity and intricate dynamics within the case, although this limits generalization of our findings. A single case-study is an example of how it might be, while showing the different mechanisms and interlinkages at play. The results, thus, are a proxy to be further queried in future cases and, for example, through comparative, quantitative case-study analysis (see for example Pot et al., 2019).

Our case-study is the renovation and replacement of a pumping station, named Vissering, in the Dutch Noordoostpolder (Fig. 2). We chose this case for multiple reasons. First, the pumping station Vissering is a large pumping station (the largest in Western Europe in the combination discharge capacity (Q) * head (H)) sustaining water management in one of the largest polders in the Netherlands. Moreover, with the currently planned renovation (or from an asset managers point of view, the replacement of the pumps and engines within the structure) the Water Board Zuiderzeeland, owner of the pumping station, desires to create the most sustainable pumping station in the world. This makes it an exemplary case for the particular endeavour of creating wider system-functions through replacing and renovating particular assets. Third, the pumping station has several intricate relations with both the surrounding area and the polder's water system. Fourth, the Water Board strives for adding or changing functions, including enabling fish migration through the pumping station and winning thermal energy from the water flow through the pumping station.

We executed three types of data collection: interviews, collecting policy and procurement documents and action research. 22 semi-structured interviews with professionals of water boards and engineering companies involved in renovating and replacing water infrastructure were conducted. The respondents included both professionals from the Water Board Zuiderzeeland, owner of the pumping station Vissering, and professionals involved in asset management at other water boards and engineering firms. The interviews were aimed at identifying what in the interviewees' particular context and in their role was seen as important for an adequate replacement strategy. We also collected policy documents from Water Board Zuiderzeeland from the past 15 years to identify how the pumping station is perceived, discussed about and which considerations and demands for information were uttered about the pumping station itself and related assets (such as weirs, pumping stations and sewage treatment plants). Next to these policy documents we also included all procurement documents, technical drawings and photo's in our analysis. We also collected inside information through action research notes for over one-and-a-half year (2017–2019) by being actively involved in the ongoing procurement for

---

[2] One might even say that the *depiction* of a particular diameter already has such structuring effects. Stated differently, a figure or graph (Abbott, 2009; Alexander, 2015; Allmendinger, 2002; Allmendinger and Haughton, 2009; Belanger, 2013; Bernardini et al., 2014; Boelens and de Roo, 2016; Brown, 2014; Brugnach et al., 2008; Cardin et al., 2015; Chakraborty et al., 2011; Coutard and Rutherford, 2015; Davy, 2008; de Roo and Silva, 2010; DeLanda, 2006; Fingland, 2011; Folke et al., 2005; Giezen, 2018; Graham and Marvin, 2001; Hartmann, 2012; Healey, 2007; Hertogh and Bakker, 2016; Hopkins et al., 2004; Innes and Booher, 2010; Kato and Ahern, 2008; Lessard, 1998; Lindblom, 1959; Luque-Ayala and Marvin, 2016; Mens, 2015; Pot et al., 2018, 2019; Quay, 2010; Raaphorst, 2018; Rauws, 2017; Rauws and de Roo, 2016; Rittel and Webber, 1973; Savini et al., 2015; Smet, 2017; van der Vlist et al., 2015; van Dijk, 2011; Willems et al., 2016, 2018; Zandvoort et al., 2018a, 2018b, 2019) depicting how an asset should become can be *normatively structuring* for the options a planner has.

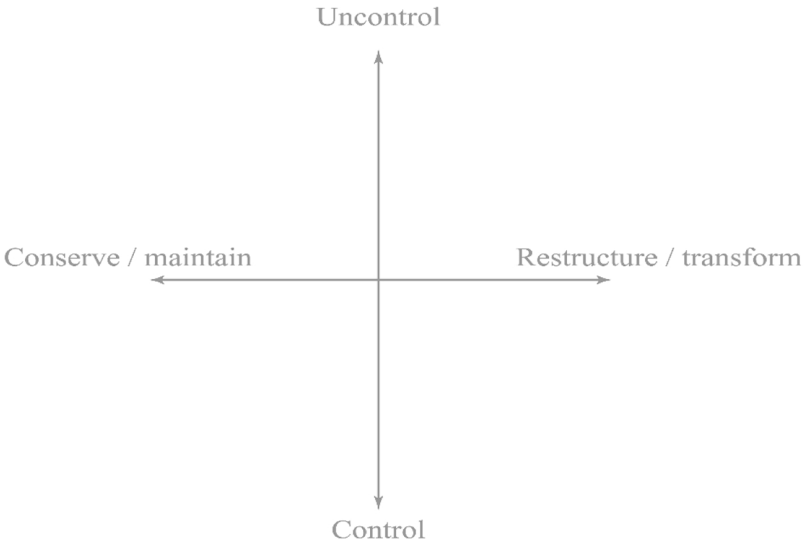


Fig. 1. Replacements as a means to exert control or not, while aiming at either conserving and maintaining status quo or restructuring and transforming the environment.

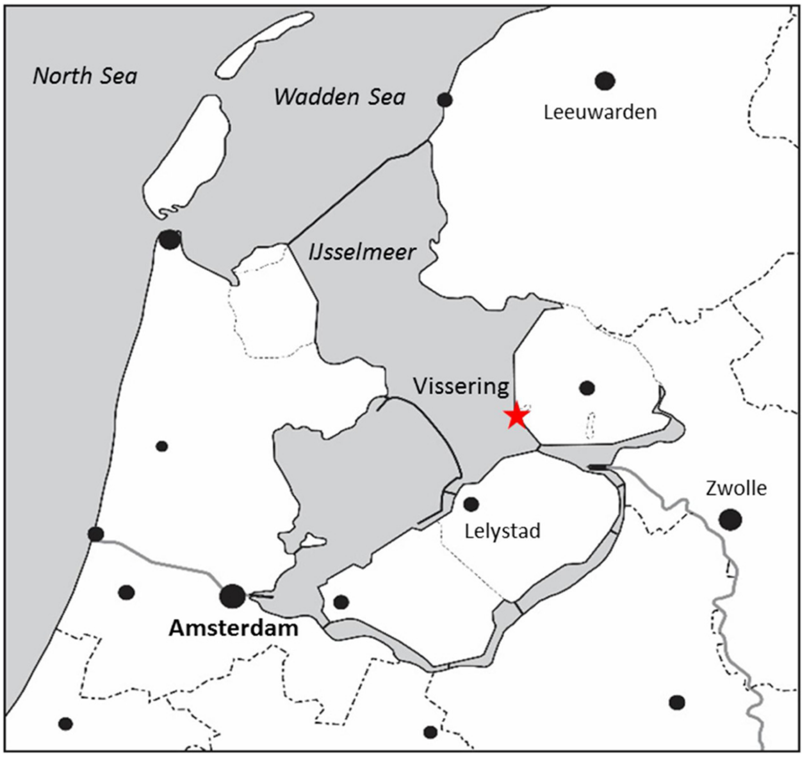


Fig. 2. The location of pumping station Vissering in the Netherlands.

the large scale renovation of the pumping station at the side of an engineering firm.

In our analysis of the transcripts and documents, and through a bottom-up coding strategy in qualitative data analysis software package Atlas.ti (version 8.0), we focused on Vissering and the general issues of how the replacement of such a pumping station is deliberately or not a (re)structuring action at multiple levels. We also analysed which demands for particular information and innovation for enhancing adaptive and flexible options existed.

4. Replacing a pumping station

To offer our findings to the reader on (re)structuring and (un) control through replacements, we first describe the different levels and their interactions at which the pumping station Vissering structures the environment. On each level, the replacement of an asset exerts some control (or not). We specify this for each of the levels and relate this to the restructuring effects of renovating or replacing pumping station Vissering. In addition to this, for each level planners need particular information to substantiate a replacement strategy. We also indicate what the key differences in innovations at each level are, because these extent the possibility for adaptive planning. This leads to several general infrastructure replacement choices for planners.

4.1. Levels at which Vissering structures the environment

The levels on which a replacement restructures the environment depends on the functions and interests related to an asset. The existence and performance of Vissering offers clues for these, as does the debate about desired functions leading up to and mentioned during the procurement of the renovation. This shows at which levels one might need to address replacement as an act of restructuring.

4.1.1. System level

The highest level we found is the water system in which Vissering functions. Vissering as a pumping station has two main functions: discharge water from the Noordoostpolder into the IJsselmeer and providing flood risk safety as a primary defence. Both functions are relevant for the whole Noordoostpolder and have an impact on the IJsselmeer (in terms of, amongst others, water quality and accessibility). Without Vissering's functioning the polder would simply fill with water. A lower than needed performance leads to more variability in the water levels in the area. Most land uses need a particular water level, both in urban and rural areas. Thus, a consequence of a lower performance would be that water levels cannot be managed strictly enough for particular land uses, such as some forms of high revenue agriculture.

At a system level, soil subsidence is a pressing issue for the owner of Vissering, both because it is irregular across space, leading to differences in relative water levels, and because it may push functions to change. Fluctuating water levels can also affect the location and speed of soil subsidence. More drainage and lower water levels increase soil subsidence speeds, while a lack of drainage makes land ill-suited for growing crops. Another major issue at the system level is the connection between soil compaction and climate change. As an interviewee mentioned: “Compaction decreases available water storage in the soil, while we need additional water storage in light of climate change”. Querying in the direction of the role of this issue for pumping stations, a water board employee said: “We now mainly look functionally, but one might also look [at assets] from the user perspective or based on risks. That is just recently on the Water Boards agenda.” Based on this claim a discussion unfolded about what change might mean for the future configuration of the system and how future extreme discharges might be anticipated. An interviewee said he could imagine that “the Water Board will work in the future with more flexibility in the water level” and he also remarked: “You can observe a shift from technical measures to the environment”. For a replacement, the observed shift, transforming the environment, has consequences for the desired discharge capacity of the pumping station. This shows that on the system level the replacement of Vissering restructures the environment. It also shows how the pumping station might enable or disable particular future transformations of the water system and depending land uses. In particular a high discharge capacity might become obsolete when the water level will become more flexible, a too low discharge capacity without an adaptive option to increase it in the future might be a risk when more intense rainfall due to climate change will occur.

4.1.2. Network level

At its most basic configuration three pumping stations form the main discharging network of pumping stations (Fig. 3). The three main pumping stations, including Vissering, strongly depend on both the existence of the canals and smaller weirs and pumping stations throughout the area. While the main discharge from the polder into the IJsselmeer takes place at these three locations, they cannot function without the whole portfolio of supporting assets. Weirs for example determine different small water level fluctuations while they are also designed in a dominant direction of water flow: towards the three main canals in the network to enable the three main pumping stations to discharge.

The network has some redundancies. When discharging water out of the polder, the direction of flow in the main canals can be two ways: to the North towards pumping station Buma or to the South-West to Vissering. Only during and after the most severe precipitation events, both pumping stations need to operate simultaneously. One reason for this redundancy is the receiving water body: the IJsselmeer. Because of its scale, a major influence on the water level in the IJsselmeer is wind (which, according to an interviewee, can lead to fluctuations of up to a meter), determining the efficiency of the pumping station in terms of discharge capacity. Another redundancy is the interrelation between the network and the system, where some water can be stored due to the dimensioning of the canals' sections.

4.1.3. Location

The third level important for replacement strategies is the location or area where an infrastructure is located. At this level the physical object structures both the landscape and the environment. Vissering, for example, is cultural heritage and fits into the area due to the same type of architectural style of the other buildings surrounding the pumping station. Several other considerations are also relevant at the location level. For example, for citizens the location is the primary relation they have with an asset. Systems or networks are a conceptual construct and cannot be perceived. Moreover, alterations of an asset, or of decisions to demolish or allocate an asset have locational implications, such as the sense of belonging of people using the space around an asset. This was also stipulated upon in an informal meeting, during which the cultural attachment of the inhabitants of Urk (the village in which Vissering is located) to the pumping station was indicated as an important factor for a future replacement decision.

Of major physical importance for an asset and its replacement is the soil-object interaction. An object exerts pressure on its wider environment and alters soil processes and underground water flows around it. These are of importance for the redesign of an object and may limit particular design features. For example, the construction of pipelines in the vicinity of the asset may be difficult because at the current location of Vissering, the peaty underground was not fully removed when building the pumping station (partly due to the advent of World War II). Heavy groundwork can thus lead to instability of the location.

4.1.4. Object and components

The fourth level are the asset and its components. In the current renovation, the choice for a particular kind of engine has consequences for the future operation, other design requirements (for example: is there sufficient gas supply or sufficient connection to the electricity network?) and the whole internal design of the pumping station. There are multiple components and each of the choices in design of a component has different consequences for the performance, operation and maintenance of the pumping station. For example, the choice for a particular fan within the pump can determine the efficiency of the pumping station regarding maximum discharge capacity and energy/discharge ratio. The choice for a particular fan might thus determine future changes in the water system or network through its effect on discharge and energy use. This might, possibly, hamper adaptive options.

In total, we found four levels (system, network, location and object) (Fig. 3) and their interactions which need to be accounted for in considering the restructuring effects of a replacement of a pumping station.

4.2. Control / uncontrol and restructuring choices

The pumping station exerts control over the environment. This control differs on each level, and offers considerations for replacing an object. We connect control/uncontrol to each of the levels and to restructuring choices available for planners to deliberately exert more or less control over the environment.

At the system level, a pumping station exerts control over the natural water flows. This is its primary function, but also one where

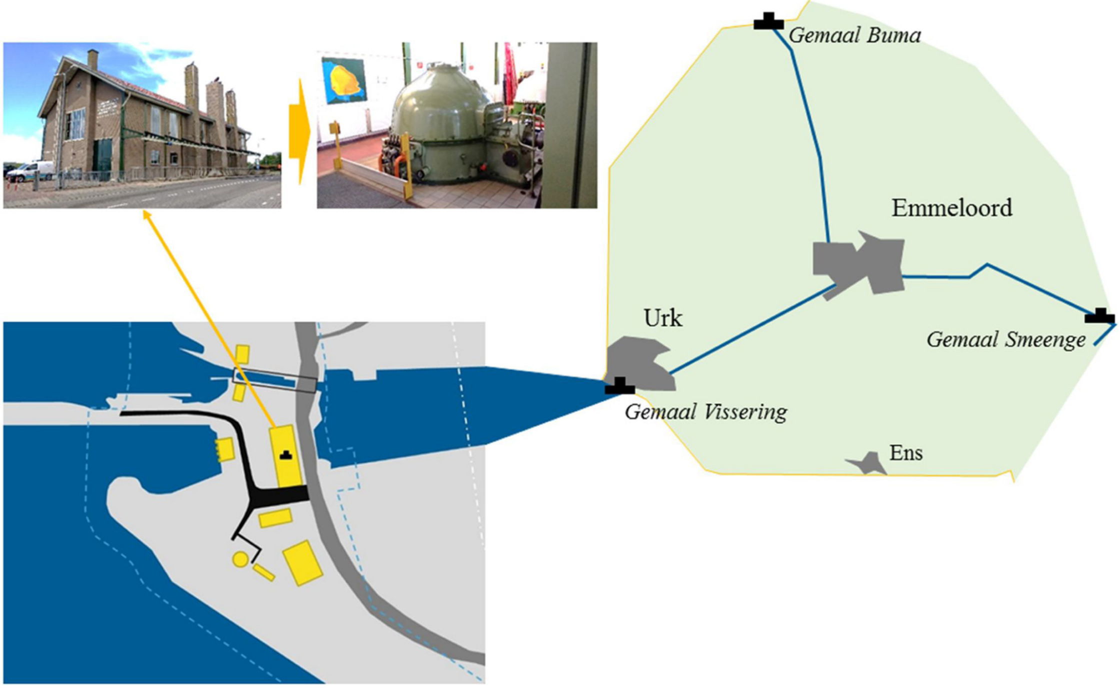


Fig. 3. The system with a network of 3 pumping stations and set of canals, the location with juridical boundaries for building permits at the primary flood defence, the pumping station as a whole building, and one component; a pump.

uncertainty about for example climate change complicates matters. Uncontrolled situations regarding water flow can also be a driver for how to replace a pumping station. For instance, a calamity with pluvial flooding led to replacements of several other pumping stations in the Noordoostpolder in the late 1990′s because their discharge capacity would be insufficient to prevent future flooding when the same situation would occur. On a system level the influence of the control of flow has also implications for fish. Migratory species cannot pass Vissering due to the current pumping canal and fan design. This form of control over nature is now regarded as negative by the Water Board and is something they want to change.

Related to this are the wider efforts on a system to make all assets 'fish passable'. A quote illustrates this: "Some fish passages are already realised. When other weirs are replaced in the coming years, they will also be altered." The moment of replacement can thus be decisive for restructuring a system, in this case to enable a lessening of control over migratory fish species. This also points to the mentioned lifecycle design of a portfolio of assets and strategic use of replacement as windows of opportunity to renew the system.

On the network level, control is mostly exerted by having more or less assets. Another type of control can be seen by looking at the openness to autonomous dynamics of a network. The already mentioned fish passage in Vissering illustrates this, because this offers openness at this particular object – the pumping station. The total transformation of the system is only guaranteed by other passages in the whole portfolio of assets. As in the case of water flow, the functioning of Vissering depends for the function 'fish passage' also on all other assets in the network. Structuring and restructuring choices in the network are additionally important for replacement decisions, because within a network not every location is logical. Maybe allocation might better fit with the desired restructured pattern. This can be partly informed by the interdependency within the network of Vissering with the other two pumping stations.

At the network scale we also find an interdependency between legal prerequisites for standards for dimensioning canals, which incorporate climate scenarios up to 2050 by enlarging discharge capacity of canals with 10%. Another issue with the canals is the maximum discharge capacity which can flow through the canals without problems for the stability of the quays. The canals thus also influence the design requirements for the maximum discharge capacity both as an upper limit (what amount can feasibly be pumped from a hydrological perspective) and a lower limit (what retention capacity do the canals have). An important other direction here is the scaling of a pumping station's discharge capacity. In her work, Smet (2017) outlined how this might be done for another pumping station in the Netherlands and such work into the adaptive options through scaling is also an issue on a network level (Hopkins et al., 2004).

The network level can also consist of multiple, interconnected networks. A pumping station depends on sufficient energy provision (coal, gas, oil, electricity, wind) and is as such also connected to a network of a different type of assets: pipelines, electricity cables, transformer substations, power plants, etc. Relevant in the case of Vissering is the desire to switch to another energy form: from gas to electricity. Moreover, the pumping station also delivers thermal energy to nearby industry, currently the heat waste generated by the pump engines, but with plans to also deliver coldness for refrigeration by winning thermal energy from the water. This interconnects two networks with due consequences for replacement choices, because future choices restructure more than one network.

On the location level, control is exerted in multiple ways. A judicial controlling mechanism prohibits any alterations without a permit within specific boundaries. At the location of the pumping station this 'legal' overlay is drawn (dotted lines in Fig. 3). These are the borders of what is legally defined as the primary water defence system, the dike in which the pumping station is located. There are strict rules for what may happen in the area between the 'lines'. Control is here asserted through a legal *structure*, a structure which may become restructured when an asset is allocated or replaced. This shows an intricate relation of restructuring between infrastructure and institutions. The physical object also exerts control over the area. For example, a seepage screen is an essential part of a pumping station because it prevents seepage underflowing the building (Fig. 4). It exerts control over the normal water flow from high to low. Fig. 4 also illustrates what a picture of an asset already conveys regarding the sort of control an object exerts in

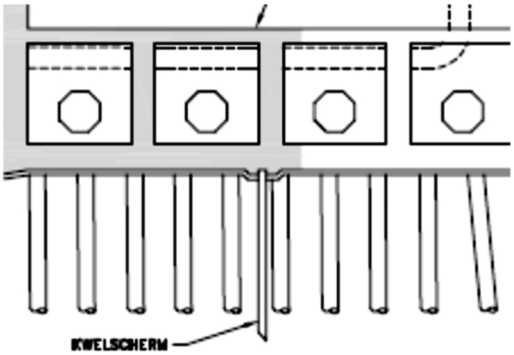


Fig. 4. Excerpt from a technical drawing showing the exertion of control through a seepage screen, preventing water to underflow the structure.

the local environment.

A third example is the already mentioned winning of thermal energy for cooling at the nearby fish industry. Coldness can be won from the water flowing through the pumping station, combined with cold water storage in the underground. This cold water storage in the deeper underground will transform the local groundwater flows and affect other infrastructure in the area of the pumping station.

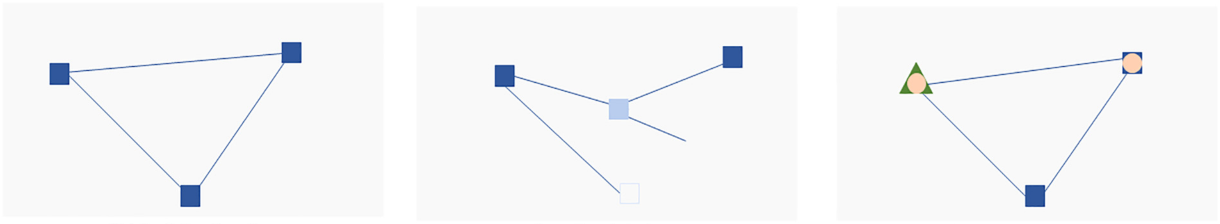
At the asset level, control is exerted through each of the different components. The choice for fan or diameter width of the pumping canal determines the amount of water which can be effectively pumped: the performance of the asset. The choice for materials and design requirements also has a relation with two other key variables of an asset: reliability of the pumping station, which should be rather high because failure of the asset might lead to economic damage, pluvial flooding (by malfunctioning) or even severe fluvial flooding if the structure is not structurally reliable as part of the primary flood defence, keeping the IJsselmeer water out of the Noordoostpolder.

Another key issue is the durability of the asset. Choices for materials determine the costs for operation and maintenance, but also for an asset's lifetime. This affects future renovations and replacements. These are issues planners wants to control to prevent unnecessary risks or costs. Material choices also limit adaptive options on a larger scale, a more temporary measure is often unfeasible due to the associated risks of failure. While an ideal adaptive situation might be to replace the structure every few decades, this is deemed irresponsible due to the high flood risk. The existing asset is often starting point for such choices. Vissering is an interesting example from this perspective due to the period it was build: slightly before and during World War II, with additions during the first decade of the Cold War. As a decision-maker at Water Board Zuiderzeeland mentions: "Those pumping stations are built in the 50′s, in a time of Cold War and tensions. There is a lot of concrete used to resist hostile attacks, and huge reservoirs for oil stocks were build." The asset, but also the whole existing structure seen from a network does have historically grown redundancies and leftovers from earlier functions or performances in it (such as the oil reservoirs becoming redundant after switching to gas engines) (cf. Coutard and Rutherford, 2015), which need to be accounted for in a replacement strategy. Restructuring at an asset level essentially takes place through design requirements such as dimensions, design types and materials for components including the head, fan, pumping canal, engines, etc.

The amount of control and uncontrol and structuring and restructuring principles together help understand what a replacement is. Moreover, with these two principles on four levels a more coherent replacement strategy might be developed (Table 1), but the question remains which information is needed for planners to address each of the levels, and what sort of innovations might be thought of at each level.

Table 1
Four principles for replacement outlined against four levels of addressing each principle.

	Control/uncontrol	Restructuring	Information	Innovation
System	Water / climate. Damming influence for fish or fish migration measures. Pluvial flooding / calamities as uncontrolled lever for change.	'Nature' based reconfiguring systems / functions & uses / altered system functions	Weather / electricity price / land uses	Reducing Q through system measures (higher water level, reducing inflow)
Portfolio of assets	More assets / less assets. Openness to autonomous dynamics of network	Choice for location, interdependency multiple pumping stations, weirs throughout the polder	Relevance for other assets upon removal / reducing functionality / other functions / interdependencies / operation of assets.	Real time control. Tailoring network to system-wide functions. Efficiency between assets. Real options for uncertainty.
Location	Legal boundaries (cultural heritage, aesthetics) / (ground)waterflow (seepage screen)	Fixing the location / choice for other place	Soil-object interaction / local hydraulics / legal requirements / stakeholder perceptions	Embedding cultural/historic values when replacing
(sub)Object	Type of fan / choice for materials / blocking mechanisms / performance / reliability / durability	Dimensions of particular objects (pumps, pumping canals, fan, head, etc.)	Proof of concepts	Objects to achieve functions: winning heat/cold collecting waste, efficiency & circularity of material/designs



Original structuration

Locational choices
same / additional / non

Functional choices
Different functions, more functions,, same / less functions

Exerted control / renewal
Same / less / more control
Remains intact / small alteration / large alteration

Innovations
System / network / asset

Fig. 5. Five schematic representations of what a replacement might enact as a restructuring choice.

4.3. *Information and innovation for replacement considerations*

Above we outlined the principle of using infrastructure to control the environment, while never being able nor wanting to fully control it due to uncertainty and autonomous change. We connected this to the structuring effects of infrastructure and the restructuring effects of replacements. Together this might inform the sort of information planners need to develop their replacement strategy and the type of innovation available at each level.

At the system level, multiple general parameters are essential for knowing the restructuring effects of particular replacement options. Parameters for Vissering may include weather data and climate scenarios, electricity prices and current and future land uses. We already mentioned issues about soil subsidence and compaction, which also need to be taken into account. In general, the sort of information depends on the systems which an asset is found to be structuring, or on the desire for future structuring with the existence and design of an object. System innovations which can be thought of in the case of Vissering are reductions of the discharge capacity through system measures. More varied water levels in the water system and on land might be a viable way to optimise pumping station - system interaction. Another possibility mentioned by an interviewee is the reduction of inflow by preventing seepage or smaller scale discharge capacity along the primary defences of the Noordoostpolder. This would also enhance the adaptive capacity of the system, but only if sufficient discharge capacity is maintained for adverse rainfall events.

On a network level information on the operation and limits of operation need to be gathered. Other important information is the relevance and role of different assets within the network and their interdependencies when (not) functioning. Choices about the performance of the network for sustaining system functions are the most important guide to collect further information needed about the functioning of the network and all assets within the portfolio. This has both effects for the system and the feasibility of sustaining functionalities. These choices also affect the objects as to their engineering and designed capacities. Innovations can be real time control and the use of real options analysis to achieve the most optimal adaptiveness, robustness or flexibility of the network.

The location level needs information about soil-object interaction such as the condition of the subsoil, foundation of the structure and the local hydraulics. Particularly important at the location scale are the institutional and social aspects of a replacement. This includes stakeholder perceptions, legal requirements and institutional or cultural interests. Innovation can be social innovation such as bringing awareness through education about water system management or fish migration. Other innovations can be embedding cultural and historic values of the pumping station into replacement decisions. Physical innovations might extend to the winning of thermal energy near the pumping station, new forms of measuring soil-object interaction or the reduction and stabilisation of hydraulic underflow.

For the asset primary information should come from proof of concepts, such as new fans, pumps or other sub-objects. This relates both to their function as well as to material choices. Innovations at asset level are numerous and depend on the particular type of asset and the existing asset configuration. The renovation of Vissering might benefit from circular thinking for both its components (what can be called *legolisation* of asset design) and the used material (including tracing all materials that go into the object). Other innovations can relate to waste harvesting and winning energy.

4.4. *Interacting choices for an adequate replacement strategy*

We analysed the case of Vissering and found four levels and four principles to consider when understanding replacement or developing a replacement strategy. However, planners still need to make choices about asset replacements informed by these aspects. We found five decisive choices planners need to decide on but which interact with each other on the four levels (Figure 5).

The first choice is to leave both system, network and location intact by one-on-one replacement. This choice does not affect the current interaction, nor the existing control or structuring effects. It maintains the status quo, but might be maladaptive if the environment, water system or asset network is autonomously changing in such a way as to affect the current configuration of the object under study. If not doing one-on-one replacement, planners need to make four additional choices.

The second choice for planners is about location. The same location might be feasible, but an additional location (so adding an asset when replacing an existing one) or another location for the asset might be a desired restructuring. It may also be the demolishment of an asset. This choice, however, transfers back into the interaction with choices on the system and network scale, which relate to the third choice, which is about the functionality of an asset.

Choosing between offering similar or a different functionality, including more functions or less functions is a third choice available for planners engaged with infrastructure replacement. This choice starts at the system scale and is connected to a long term perspective about what the role and position of an asset could be, but is strongly related to the possibilities at the location and object level and can be hampered by short term perspectives (Zandvoort et al., 2018b). If there is no other location to transfer to, choices about functionality are restricted. Moreover, new functions on an object and location level limit future room to adapt on system or network level. For example, the desire to harvest energy from the water flow might in time lead to a demand for a steady stream of energy. The pumping station needs to keep pumping in such a situation even in dry times or when at network level alterations occur (such as larger pumping stations elsewhere in the network).

The fourth choice is about the control a planner wants to exert through the replacement of an asset or network, which is at the same time also a choice about system renewal, since the system is either altered or not. Meanwhile exerting more or less control influences the choice for a particular functionality. The need and possibilities for control are, however, physically constraint as is visible in the maximum Q possible for Vissering due to (sub)soil circumstances.

The fifth and last choice we found is about innovation strived for when replacing. This should be a deliberate choice for system innovation, network innovation and/or asset innovation. The important reason for innovation is both system functionality and owner desirability, as well as creating or enhancing the adaptive options for planning strategies depending on assets. Together these choices determine how a replacement is executed and what adaptiveness is available for replacement strategies.

5. Discussion

Replacements of infrastructure are interventions which restructure existing systems, asset portfolios, local areas and assets themselves. Infrastructure replacement just recently becomes a major topic in planning due to the widespread deterioration and aging of infrastructures (Willems et al., 2018). Our aim was to study what a replacements means for exerting control and restructuring environments as considerations that make up an adequate replacement strategy. We studied the process to come to large scale renovation with replacement of pumps and engines of pumping station Vissering in the Netherlands. We found that the renovation and replacement of Vissering will structure the environment on four levels, which are mutually interdependent and interacting: the water system, the network with a portfolio of assets, the location at which the pumping station is currently build and might in the future be located again, and the pumping station with its components. When replacing the pumping station each of these four levels offers information about the amount of control or uncontrol and the restructuring of the existing situation taking place. We also studied what information is needed for an adequate strategy which is cognizant of each level, and possible innovations to capitalize on adaptive choices which can be achieved through replacement. This led us to distinguish five choices which need to be dealt with in a replacement strategy.

Our findings might be particular for the replacement of a pumping station or hydraulic assets, because such structures often have multiple functions due to the structuring effect of water for both flood risk and water resource provision. Also, we executed a single, in-depth case study due to which generalizations of our findings should be interpreted with caution. We do signal, however, that the concepts of control/uncontrol and structuring/restructuring, might account for other infrastructure-based planning interventions in contemporary, highly organized systems (cf. Coutard and Rutherford, 2015; Willems et al., 2016).

A particular issue in this context are the choices we found to be important for replacing a pumping station. As our entry-point, we settled on ownership of an asset. However, the public authority Water Board Zuiderzeeland is an entity consisting of multiple persons, roles and functions who shape and restructure as a collective why and how a replacement takes place. This is somewhat fluid since the role of the asset manager differs from the policy-makers, planners and politicians at a distance from the particular asset. Also, the different roles and functions makes the relation to the asset a different one, the maintenance engineer working in the pumping stations for decades perceives it very differently from the hydrologist involved in calculating discharge capacities at the head office of the water board. This relates to what Pot et al. (2018) explain regarding the intricate dynamics and relations in how decision-makers produce decisions about replacements. An interesting quote from our data illustrates this point: “Mr. O. mentions that ‘If you have 3 scenarios, you normally pick the middle one’. In the previous meeting the General Board has heard that the employees at pumping station Vissering want to realise the most sustainable pumping station.” Here a member of the Board has a quite different idea about the renovation of Vissering compared to the employees located at the pumping station. There are, thus, some issues when implementing the choices for planners who structure a replacement.

A dominant issue is the fuzzy allocation of how a choice is shaped, altered and made through internal framing, deliberation and the interaction of individuals, also with others outside the public authority. This may happen either through small talk and informal meetings and the debates within a formal procurement setting (Allmendinger and Haughton, 2009; Pot et al., 2018). Since a final, fixed facility will be engineered and built, there is something at stake when not considering adaptive or flexible options and innovations. The lock-in or lock-out of future alterations might be costly. Designing an asset should be approached with caution and a replacement strategy must weigh the benefits and costs of different choices.

With respect to future adaptations and their anticipation across the whole system, we did not consider time as such. Over time, however, other structures need to be replaced or renovated, enabling a wider portfolio of options when considering the lifetime of all assets. The system capabilities are essential, but anticipating an uncertain future is difficult (Quay, 2010). Taking the lifetime of other assets into account might open up possibilities if external forces are monitored properly (Chakraborty et al., 2011). The current renovation or replacement is not necessarily in need of a capacity increase if another hydraulic structure replacement can abate the problem in the future. The issue of time is important for future studies because timing of investments, the time to be able to scope while confronted with uncertainty and implementation time of a replacement are essential infrastructural planning choices to be made.

We focussed on the structuring effects of both physical and social interventions. We found such effects in both talk, text, collaboration and in the structure itself. This raises the question how we not only should understand such structuring forces and the amount of force they exert over structures in the environment, it also asks from us to rethink the connection between the material and immaterial itself and the role of different utterances as a structuring force on the studied object (van Dijk, 2011). One might say that the depiction of a particular design or design option already has structuring effects. A figure or graph depicting how an asset should become can be normatively structuring for the options a planner has. Thus, to better understand ‘replacement’ as restructuring infrastructure-based systems, it might be needed to develop a semiotic understanding of the different aspects which do have such a structuring effect (Raaphorst, 2018).

A last critical question is how to generate flexible or adaptive options in light of the existing structures and functionalities of these structures. This demands insight in where to get options from and why (hence the need for innovation), and how to make a valid choice about how to weigh options. Some first work is done in this direction, amongst others based on systematic ideation (Cardin et al., 2015), but in light of our study more emphasis should be put on these questions, especially because planning is -always- a normative activity (Hartmann, 2012). For adequate restructuring in light of just partial control for planners, plannners need to find or develop and subsequently include and exclude particular options in a legitimate way in planning infrastructure replacements.

6. Conclusions

We studied how planners should think and go about the replacement of infrastructure, despite being confronted with uncertainty and interdependencies interacting on infrastructure. To understand what replacements are and what planners do when altering an infrastructure we used the notions of (re)structuring and (un)control. Based on a case study of the renovation and replacement of pumping station Vissering, we conclude that a replacement enables planners to exert control over the environment, but always limited by uncertainties and physical impossibilities. Replacements restructure on four levels: the system for which an asset is build, the network through which functionalities are provided, the location of an asset and the asset including its components. Possible innovations to open up adaptive choices, necessary information for developing a replacement strategy, exerted control and uncontrol and restructuring through replacement all differ among these levels.

We therefore conclude that for replacement strategies, the interactions between these levels and choices on each of them open up and close down possibilities for restructuring environments. When planners are cognizant that infrastructure replacements, no matter how large or small, restructur the environment and include control-oriented decisions, the need for adaptive planning and proper scaling choices becomes paramount. Adequate replacement strategies are therefore transparent about both these choices on the interacting four levels and show the arguments about the (non)use of adaptive options during the replacement. Planners are at the forefront of making deliberate choices about how and why infrastructure is replaced for the benefit of restructuring and transforming the systems supported by infrastructure. By understanding (un)control and (re)structuring, planners have theoretical and practical insights in what replacements constitute in infrastructure-based systems.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was funded by Rijkswaterstaat, the Netherlands.

References

Abbott, J., 2009. Planning for complex metropolitan regions: a better future or a more certain one. J. Plan. Educ. Res. 28, 503–517.

Alexander, E.R., 2015. There is no planning – only planning practices: notes for spatial planning theories. Plan. Theory 15, 91–103.

Allmendinger, P., Haughton, G., 2009. Soft spaces, fuzzy boundaries, and metagovernance: the new spatial planning in the Thames Gateway. Environ. Plan. A 41, 617–633.

Allmendinger, P., 2002. Planning in Postmodern Times. Routledge, London.

Bernardini, P., van Vuren, S., van der Wiel, W.D., Wolters, M., Roovers, G., Tosserams, M., 2014. Integrative Framework for Long Term Reinvestment Planning for the Replacement of Hydraulic Structures. PIANC World Congress San Francisco, USA, pp. 2014.

Belanger, P., 2013. Landscape Infrastructure. Urbanism Beyond Engineering. PhD Thesis, Wageningen UR, Wageningen.

Brugnach, M., ARPJ, D., Pahl-Wostl, C., Taillieu, T., 2008. Towards a relational concept of uncertainty: about knowing too little, knowing too differently, and accepting not to know. Ecol. Soc. 13 (2), 30–46.

Boelens, L., de Roo, G., 2016. Planning of undefined becoming: first encounters of planners beyond the plan. Plan. Theory 15 (1), 42–67.

Brown, H., 2014. Next Generation Infrastructure: Principles for Post-Industrial Public Works. Island Press, Washington.

Cardin, M.A., Kolfschoten, G.L., Frey, D.D., de Neufville, R., de Weck, O.L., Geltner, D.M., 2015. Empirical evaluation of procedures to generate flexibility in engineering systems and improve lifecycle performance. Res. Eng. Des. 24 (3), 277–295.

Chakraborty, A., Kaza, N., Knaap, G.J., Deal, B., 2011. Robust plans and contingent plans: scenario planning for an Uncertain world. J. Am. Plan. Assoc. 77 (3), 251–266.

Coutard, O., Rutherford, J., 2015. Beyond the Networked City: Infrastructure Reconfigurations and Urban Change in the North and South. Routledge, London.

Davy, B., 2008. Plan it without a condom!. Plan. Theory 7 (3), 301–317.

de Roo, G., Silva, E.A., 2010. A Planner's Encounter With Complexity. Ashgate Publishers, Farnham.

DeLanda, M., 2006. A New Philosophy of Society: Assemblage Theory and Social Complexity. Continuum., London.

Fingland, D., 2011. In: Better to Be Roughly Right than Exactly Wrong: the Concept of Certainty in Land-Use Planning. SOAC. Melbourne University, November 29th – December 2nd.

Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social-ecological systems. Annual Review of Environmental Resources 30, 441–473.

Giezen, M., 2018. Shifting infrastructure landscapes in a circular economy: an institutional work analysis of the water and energy sector. Sustainability 10, 3487.

Graham, S., Marvin, S., 2001. Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition. Routledge, London.

Hartmann, T., 2012. Wicked problems and clumsy solutions: planning as expectation management. Plan. Theory 11 (3), 242–256.

Healey, P., 2007. Urban Complexity and Spatial Strategies: Towards a Relational Planning for Our Times. Routledge, London.

Hertogh, M.J.C.M., Bakker, J., 2016. Life cycle management to increase social value at renovations and replacements. Proceedings of the 5th IALCCE 2016, 57–64.

Hopkins, L.D., Xu, X., Knaap, G.J., 2004. Economies of scale in wastewater treatment and planning for urban growth. Environ. Plann. B Plann. Des. 31, 879–893.

Innes, J.E., Booher, D.E., 2010. Planning With Complexity. An Introduction to Collaborative Rationality for Public Policy. Routledge, London.

Kato, S., Ahern, J., 2008. 'Learning by doing': adaptive planning as a strategy to address uncertainty in planning. J. Environ. Plan. Manag. 51 (4), 543–559.

Lessard, G., 1998. An adaptive approach to planning and decision-making. Landsc. Urban Plan. 40 (1), 81–87.

Lindblom, C.E., 1959. The science of 'muddling through'. Public Adm. Rev. 19, 79–88.

Luque-Ayala, A., Marvin, S., 2016. The maintenance of urban circulation: an operational logic of infrastructural control. Environ. Plan. D 34 (2), 191–208.

Mens, M.J.P., 2015. System Robustness Analysis in Support of Flood and Drought Risk Management. PhD Thesis. University of Twente, Enschede.

Pot, W., Dewulf, A., Biesbroek, R., van der Vlist, M.J., CJAM, T., 2018. What makes long-term investment decisions forward looking: a framework applied to the case of Amsterdam's new sea lock. Technol. Forecast. Soc. Change 132, 174–190.

Pot, W., Dewulf, A., Biesbroek, R., Verweij, S., 2019. What makes decisions about urban water infrastructure forward looking? A fuzzy-set qualitative comparative analysis of investment decisions in 40 Dutch municipalities. Land Use Policy 82, 781–795.

Quay, R., 2010. Anticipatory governance. J. Am. Plan. Assoc. 76 (4), 496–511.

Raaphorst, K., 2018. Knowing your audience: the contingency of landscape design interpretations. J. Urban Des. 23 (5), 654–673.

Rauws, W.S., 2017. Embracing uncertainty without abandoning planning: exploring an adaptive planning approach for guiding urban transformations. disP-The Planning Review 53 (1), 32–45.

Rauws, W.S., de Roo, G., 2016. Adaptive planning: generating conditions for urban adaptability. Lessons from Dutch organic development strategies. Environ. Plann. B Plann. Des. 43 (6), 1052–1074.

Rittel, H.W.J., Webber, M.M., 1973. Dilemmas in a general theory of planning. Policy Sci. 4, 155–169.

Savini, E., Salet, W., Majoor, S., 2015. Dilemmas of planning: intervention, regulation, and investment. Plan. Theory 14 (3), 296–315.

Smet, K.S.M., 2017. Engineering Options: a Proactive Planning Approach for Aging Water Resource Infrastructure Under Uncertainty. PhD Thesis, Harvard University, Cambridge, MA.

van der Vlist, M.J., Ligthart, S., Zandvoort, M., 2015. The replacement of hydraulic structures in light of tipping points. J. Water Clim. Chang. 6 (4), 683–694.

van Dijk, T., 2011. Imagining future places. How designs co-constitute what is, and thus influence what will be. Plan. Theory 10 (2), 124–143.

Willems, J.J., Busscher, T., Hijdra, A., Arts, J., 2016. Renewing infrastructure network: new challenge, new approach? Transp. Res. Procedia 14, 2497–2506.

Willems, J.J., Busscher, T., van den Brink, M., Arts, J., 2018. Anticipating water infrastructural renewal: a framing perspective on organizational learning in public agencies. Environ. Plan. C Politics Space 36 (6), 1088–1108.

Zandvoort, M., van der Vlist, M.J., Klijn, F., van den Brink, A., 2018a. Navigating amid uncertainty in spatial planning. Plan. Theory 17 (1), 96–116.

Zandvoort, M., van der Vlist, M.J., van den Brink, A., 2018b. Handling uncertainty through adaptiveness in planning approaches: comparing adaptive delta management and the water diplomacy framework. J. Environ. Policy Plan. 20 (2), 183–197.

Zandvoort, M., van der Vlist, M.J., Haitsma, R., Oosterveld, E., 2019. Lifecycle management and replacement strategies: two of a kind? In: Proceedings of the 6th international Symposium on Life-Cycle Engineering (IALCCE 2018). Ghent, Belgium.