Abstract

Today an increasingly digitized assemblage controls Amsterdam’s water management, providing a data-driven context to the city’s built-environment, and directly looping in architectural elements within networks of micro-infrastructures. Building on examples from contemporary Amsterdam I trace a possible trajectory for the dissolution of the singular architectural artifact into collections of digitally instrumentalized elements (micro-infrastructures) participating in data-driven urban systems. The stories of the designers who have collaborated on these projects provide a hopeful response to the question of the ultimate end of the data-driven city: will it do no more than perpetuate an unsustainable status quo, or can it be leveraged for real change?
Introduction: data, water management and Amsterdam’s urban form

The form of the city of Amsterdam – its canals, locks, bridges and dikes, clusters of rowhouses, historic defenses, infrastructural corridors – is defined by the control of water [1]. While the physical infrastructure for water control in Amsterdam is mostly visible and self-evident, managing water in the Netherlands has for centuries also required an invisible data-infrastructure to measure water flows and levels, anticipate changes, and decide how to work together to create and maintain the dikes, dams and bridges.

The co-evolution of Amsterdam’s built environment with this data-driven infrastructure for water management is the topic of this study, which forms part of a broader research project linking the field of critical data studies with theory and history of architecture [2,3,4,5]. This essay describes a series of small-scale data-mediated interventions for water management in contemporary Amsterdam, mostly involving architecture or what might be called more broadly the ‘built environment.’ These small interventions can be properly recognized as remarkable if they are understood in contrast to the 100 years or so of Dutch water management that preceded them.

As early as the 17th century careful data collection and procedural management was required to control a tidally-driven system of canal flushing in Amsterdam. (Fig. 1) The infrastructure-dependent Dutch environment and its data-intensive management has co-evolved with the culture of Dutch city planning and architecture, in a cultural condition Dutch architect Winy Maas has defined as the ‘datascape,’ where ubiquitous data overdetermines the development of the built environment [6,7].

Figure 1: Diagram of Amsterdam canal flushing system circa 1665. (Archive AGV.)
Today an increasingly digitized assemblage controls Amsterdam's water management, providing a data-driven context to the city’s built environment, and directly looping in architectural elements within networks of micro-infrastructures [8]. Building on examples from contemporary Amsterdam I trace trajectories of the dissolution of the singular architectural artifact into collections of digitally instrumentalized elements (micro-infrastructures) participating in data-driven urban systems. While the ontological collapse of architecture into a collection of ‘smart’ elements has the been the subject of recent hand-wringing in architectural discourse, the stories of these micro-infrastructures in contrast provide a hopeful response to the question of the ultimate end of the data-driven city: will it do no more than perpetuate an unsustainable status quo, or can it be leveraged for real change [8,9,10,11,12]?

Modern era mega-infrastructure: Afsluitdijk and Deltaworks

The history of 20th century civil engineering in the Netherlands is a story of modernist mega-infrastructures [13,14,15,16]. In 1933 Amsterdam was definitively protected from coastal storm surges by a gargantuan dike: the 32km long Afsluitdijk (enclosure dike) which closed off the Zuiderzee from the North Sea. (Fig. 2) Formerly a tidally-active sea inlet, the Zuiderzee became a large shallow fresh-water lake and was renamed the IJsselmeer. The Afsluitdijk became a model for Dutch civil engineering and defined a modernist era of massive civil engineering works. When a devastating flood struck the South-western delta of the Netherlands in 1953, the response of a government-assembled commission to study the problem was to propose mega-infrastructure projects in the same vein. The Delta Commission, as it was named, proposed the Deltaworks: pharaonic infrastructures designed to block storm surges before they reached vulnerable land. The Oosterschledekering (completed 1986) and the Maeslantkering (completed 1997) storm surge barriers have become national icons, representing Dutch engineering ingenuity and audacity in the face of great risk. The photogenic Delta works, however, were not the only contribution of the Delta Commission. They also laid the foundation of a national flood preparedness program that used statistical analysis of risk and cost to allocate flood-prevention resources throughout the country. This statistically controlled system of dijkringen (dike rings) is the forerunner of contemporary data-driven water management in the Netherlands.
The first datascape: David van Dantzig and the *dijkringen*

The Delta Commission’s cost-benefit analysis was developed by mathematician David van Dantzig [17]. He approached the problem of protecting the Netherlands from flooding as an optimization problem. Beginning with the assumption that it is economically impossible to provide perfect protection from flooding, he developed a method of finding a compromise between the cost of a potential flood and the cost of given height of dike. He proposed two graphs – a linear function $L(x)$ representing the cost of building a dike depending on its height given by the variable $x$, and $R(x)$ which represents the risk of losses incurred by flooding for a given height of dike. (Fig. 3) Adding the two equations together results in a concave-up graph whose minimum (marked as, ‘A’) represents the optimal dike height.

![Figure 3. van Dantzig’s dike optimization. ‘Total cost $K$ of raising a dike $X$ meters [17].’](image)

To compartmentalize risk and allow for different cost-benefit calculations for different regions, van Dantzig proposed dividing up the country into a finite number of water-tight compartments each with an independent flood protection system. The idea of a patchwork of water-tight compartments was ultimately incorporated into Dutch national policy as the dike rings (*dijkringen*) [18]. Today a dike ring system based on the original Delta Commission report and van Dantzigs risk analysis controls every square meter of the Netherlands.

The ubiquitous deployment of the dike-ring statistical risk system recalls the condition Winy Maas described in his 1996 essay, *Datascape*: “Anti-disaster patterns, lighting regulations, acoustic treatments. All these manifestations can be seen as ‘scapes’ of the data behind it.” [6]
Maas’ response to these ‘scapes’ of data was to push architecture to big enough scales to reveal the logic of these datascapes: “When architecture becomes urbanism, it enters the realms of quantities and infrastructure, of time and relativism [6].” Today in contrast, as the world grapples with big data exponentially larger than that of the 1990s and increasingly daunting environmental challenges, Dutch government and Dutch designers are working to foster design interventions that are much smaller than Maas’ datascapes projects (micro even), but dynamically interconnected and thus performative at larger scales.

Data-driven Delta, public awareness and action

In anticipation of the growing threat of climate change in the 21st century a new Delta Committee was formed in the early 2000s [19]. Data is a protagonist of the resultant 2008
Delta committee report: making it possible to understand, manage and raise awareness about the complexity of the water system in a changing climate. The recommendations of the Delta committee report push for a new layer of digital infrastructure that both monitors the water system and interfaces with general population as an information sharing tool [19]. Data, in the 2008 report, contributes a new ability to recruit, organize and instrumentalize many smaller elements of the built environment in efforts to prevent floods or mitigate damage should they occur. These automated tools of data-collection and data-driven response interface with the built form of the city of Amsterdam via networked spatial planning and disaster-preparedness tools like overstroomik.nl and Amsterdam Rainproof [19,20,21]. Feedback loops between the representation of the city as data and the physical form of the city, motivated by the urgency of climate change, are rewriting the ways Amsterdam's buildings are understood, used, and built.

Linking flood risk with shelter scenarios: Overstroom Ik?

Overstroomik.nl, an initiative inspired by the new Delta program and created by the Rijkswaterstaat (the Dutch national water management authority) instrumentalizes existing architecture as a system of distributed flood shelters. Its interactive maps prompt users to explore personalized flood scenarios including how high water might rise and which buildings will present viable shelters in the case of a dike failure [20].

A user visiting the overstroomik.nl webpage is asked to enter the location of his home to answer the simple question ‘Overstroom ik?’ (Will I flood?). Based on the entry, the site queries an online database of flood risk maps and shows the user an infographic of a home immersed in varying levels of water. If the user’s location has a risk of flood, the response to the initial question is shown in boldface print: “Yes, you flooded up to a maximum of 2.0 meters.” It goes on to explain that there is a 10% risk of this flooding occurring in the user’s lifetime and ending, “That could be tomorrow.” (Fig. 5)

Overstroomik.nl has a further function called ‘Wat kan ik doen?’ (What can I do?), which prompts the user to make a plan to stay or to leave during a flood. Two more interactive maps are provided to support this decision; the first, ‘Dry places in your area,’ queries the number of floors for each building within the user's search area and places a red dot on buildings completely submerged and a green dot on those with a dry floor which can provide refuge. (Fig. 6) The second map, ‘Water op de weg,’ helps the user develop an evacuation plan if he decides to leave. Roads that are likely to be flooded are marked with a red X. (Fig. 7)

Overstroomik.nl’s ‘Dry places in your area’ map re-purposes the city’s buildings as a distributed infrastructure of mini flood-shelters, by suggesting an alternative use to residents and providing targeted information to support this use. All of this is accomplished without making any physical intervention in the city.
Promoting physical changes to make the city’s built environment more flood-resistant is taken up by a different online tool: *Amsterdam Rainproof* [21]. This online portal, an initiative of *Waternet* (the public water utility of Amsterdam, and offshoot of the AGV waterboard), follows directly in the wake of the 2008 Delta Report by encouraging adaptation to climate change. Instead of the threat of a dike breach, *Amsterdam Rainproof* takes on urban flooding caused by extreme rainfall. Climate change is expected to increase the intensity of rainstorms in the Netherlands, and in recent years Amsterdam has experienced extreme rain events that have flooded streets and damaged buildings. The large percentage of impermeable surfaces in the city’s urban areas means that little rainwater is retained in the soil and is instead channeled to the city’s storm-sewer system which can be overwhelmed.
Amsterdam Rainproof presents the dilemma in the most direct terms. “It's raining more often- and our city can't handle it,” is the claim that greets a visitor to the website [21]. Prompting the user with a link, ‘Wat kan ik doen?’ (What can I do?), a catalogue of build-able interventions is presented, with explanations of how they work and often a link to a supplier or contractor who can provide the product or carry out the construction. The site focuses on modifications to the built environment that may reduce damage to existing buildings when flooding does occur. Interventions that increase water retention from rainstorms are also prominently featured. For some interventions, like green roof construction, a subsidy is available to defray the cost of construction, and a link is provided directly to the relevant municipal government website [21].

Amsterdam Rainproof presents a ‘toolbox’ of interventions that increase the retention of rainwater on roofs and other urban surfaces thus preventing it from reaching overwhelmed storm sewers. (Fig. 8) Most of the changes to the built environment proposed by Amsterdam Rainproof are meant to be carried out by individual homeowners. This strategy splits the burden of providing for water infrastructure between the city government and many private actors. The cost of flood prevention becomes a shared cost between the government’s investment in storm sewers and private actors’ voluntary investment in water retention.

Among the interventions that Amsterdam Rainproof proposes, the most directly architectural is the green roof, a mainstay of modernist architecture (toit-jardin) but a relatively rare feature among the traditional canal houses of the city. The green roof, while desirable to architects and homeowners for purely aesthetic reasons, is valuable to the city of Amsterdam for its ability to retain rainwater during potentially flood-causing storms. Rainproof proposes a variety of methods for the construction of green roofs, links to local installers, and directs visitors to the city of Amsterdam’s subsidy for green roofs. When applying for the subsidy one must provide information on the dimensions and type of green roof being installed and then complete the installation within a given frame of time. This data in hand, the city can monitor the area of green roofs constructed in Amsterdam and estimate the impact of green roof water retention on the reduction of urban flooding during intense rainfall. (Fig. 9)
Preventing flood damage via predictive analytics and small modifications to the built environment

Evaluating water management efforts presents a true big data challenge for the City of Amsterdam. Rainproof Amsterdam has implemented a data-mining approach to this challenge, collaborating with the insurance agency Achmea and the big-data analyst Synerscope [23]. This project, so far run only as a trial, pulls data sets from Achmea’s insurance claims, the Dutch meteorological agency, the national cadastral authorities, 3di’s bathymetric flooding simulations, and Google’s street photos. Using Synerscope’s algorithm, clusters of damage claims are associated with architectural elements captured from Google’s street view by machine vision.

The conclusions drawn from this data-mining are fairly mundane: for example, basements with certain types of ventilation details are particularly susceptible to flooding from heavy rain [23, p.38 fig. 12]. Some types of damage also result from one-way attachments to sewer drains which cause connected washing machines or toilets to overflow when the storm sewers become overwhelmed in a heavy rain. The granularity of the study, which can automatically pull specific words from an insurance report and associate them with an image of a building and an ultra-precise simulation of the city’s water system is, however, revolutionary. Unsurprisingly, Rainproof Amsterdam prominently links to one-way sewer connection valves and shielding systems that prevent small floods from entering basement or street level doors and windows [21].

Should architects fear the feedback framework?

A distributed system of architectural elements that as an aggregate provide a significant public infrastructure, monitored with a previously-unimaginable degree of granularity by machine-driven algorithms and coaxed into existence with a combination of modest public
subsidies and internet-driven awareness campaigns: this is one vision of the architecture of the data-driven city. It is also an instance of what Alex Pentland has called the ‘feedback framework,’ where urban monitoring is linked to urban action in a data-driven loop. [24, p.138] This feedback loop is an example of the new formal basis of architecture in the data-driven city: policy, data, finance, infrastructure incorporate the architectural artifact into a larger, software managed systems. At face value, there is little insidious to be found in the example of Amsterdam. Skeptics will rightly point out that this sort of private infrastructure cannot substitute for adequate public infrastructure. As a compliment, however, to an already excellent public infrastructure – as is the case in Amsterdam – extra measures that rely on a mix of public-private investment can only be a plus.

From the point of view of the architect, the criticism of the feedback framework is perhaps more compelling: treating architectural elements as pieces of a larger distributed system tends to encourage the ontological collapse of the work of architecture into an incoherent assembly of products, each functioning according to its own ‘intelligence’ [9,10]. This Cassandra-esque scenario, however, seems disproportionate to the banality of a government subsidy for green roofs, even if it does happen to be digitally tracked. What is true is that the changes driven by the Delta Program will without question alter the form and function of the Dutch city. How exactly these changes happen, however, will be determined by those intimately involved with the day-to-day creation of new urban spaces and forms- not least of whom are the Dutch architects. The positive impact of architects and their allies in the shaping of the data-driven future of Amsterdam is illustrated by the recent example of the Buiksloterham masterplan in Amsterdam’s north.

Buiksloterham Circular District: shaping the data-driven city

In 2015 a vision document was published for a heavily polluted post-industrial district called Buiksloterham that sits north of the IJ, directly across from the historic center of Amsterdam. The document, Transitioning Amsterdam to a Circular City: Circular Buiksloterham Vision & Ambition, laid out a vision for a circular district where material resources would be indefinitely cycled, and energy would be generated on site from renewable sources [25]. The means of achieving this vision rested not solely on the willpower of its residents, but also in hopes for a new data-driven system of digital monitoring and management.

Materials coming in and out of the district would be checked into a district database and tagged with a digital passport to monitor their use and eventual reuse [25, p. 33]. Energy, produced on site, would be distributed through smart grids, shared between neighbors and passed on to the city-wide grid in instances of surplus [25, p.167]. Water, in particular, was to be a focus of this digitally mediated urban metabolism. Storm water was to be carefully managed in a system of green roofs, water retention basis, and bio-swales- making the installation of a storm sewers in the polluted soil of the post-industrial sites unnecessary [25, p. 36]. Residential wastewater was also to be subject to digital scrutiny. Divided into gray water and black water the two streams would be diverted to a new kind of water treatment plant where the biological nutrients in black water would be reclaimed as energy in a bio-reactor, and the less soiled gray water would be filtered and returned to the cycle as drinking water [25, p.127]. An overview of this circular metabolism was proposed to be made publicly visible in an online map, the Circular Buiksloterham Interactive Metabolism Map [25, p. 69]. (Fig. 10)
The Circular Buiksloterham vision document is a radical re-imagining of what a data-driven city can be if organized around principles of sustainability and broad-based participation [26]. It's primary contributors, industrial ecologist Eva Gladek of Metabolic, landscape architect Steven Delva, and the architecture office studioninedots were a group of young designers attracted to the aesthetics and opportunities of a raw post-industrial area. Their alternative vision for what a data-driven district could be did not come out of nowhere but had been fostered on site by a local counter-cultural movement already in place for many years.

**NDSM and de Ceuvel: Counterculture in data-driven Amsterdam**

Most influential for the development of the Circular Buiksloterham vision was a project sited at former shipyard, de Ceuvel Vlharding. In 2010 a group of young designers won a competition for a ten-year lease from the city of Amsterdam to build what they called a ‘sustainable workplace.’ The shipyard had been vacant since 2002 and the site, like much of Buiksloterham, was heavily polluted. In order to build on the site a protective layer of clean earth up to a meter thick would need to be placed on top of the polluted soil. Lacking the time or resources for such an extreme intervention the designers needed to develop a cheaper and temporary solution [27, 28].
and lifted and placed onto the site by a crane. *Space&matter* also proposed a sinuous boardwalk that would connect the houseboats together and allows visitors to walk above the ‘forbidden garden’ and polluted soil. [28,29] *DELVA* landscape architects proposed a phyto-remediative garden that would clean the site's soil over time. Tying the project together was a sustainability concept developed by *Metabolic*. Proposing on-site food production, energy creation, composting toilets and biofiltration of wastewater, *Metabolic* aspired to make *de Ceuvel* a circular system capable of sustaining itself independent of outside material and energy flows.

The *de Ceuvel* development was nurtured during its creation by cultural activist Eva de Klerk who had spear-headed the reuse of the nearby NDSM dockyards in the early 2000s and the creation of the NDSM *Kunststad* in 2007. (Fig. 12) *Metabolic* was incubated in a trailer on the NDSM site and mentored by de Klerk, and the initial retrofitting of the *de Ceuvel* houseboats took place at the NDSM wharf. By 2012 the house boats had been lifted onto the *de Ceuvel* site, and the young designers responsible were gaining notoriety at home and internationally for their boot-strap approach to sustainable design.

**Fig. 12 NDSM Kunststad. (Author's photo)**

When *Waternet*, Amsterdam's water utility, proposed taking on Buikslotherham as an urban lab for water innovation in 2014 they turned to *DELVA* and *Metabolic* as natural partners. Bringing de Alliantie and the City of Amsterdam on board they also recruited a new office of architects *studioninedots* [25]. Together they produced the Circular Buikslotherham vision document which was released the next year. Building on the non-conformism of *de Ceuvel*, the vision document emphasized a pluralistic approach to the founding of a smart district [26].
**Schoonschip:** architectural prototypes within data-driven systems

The promise of Circular Buiksloterham is perhaps best represented by a houseboat collective designed by space&matter for the adjacent Hasseltkanaal. The initiator of the project is Marjan de Blok, another Eva de Clerk protégé, who in 2008 created an ‘autarkic geWoonboot’, which was moored outside the NDSM shipyard [30]. The geWoonboot, which translates roughly to ‘communeBoat,’ is an entirely self-sufficient home floating in the IJ on a concrete buoyancy tank. The autarkic (self-sufficient) elements include rainwater capture, solar panels and a garden-like purification system that floats next to the home and processes all its liquid waste. De Blok became convinced that the autarkic houseboat had potential not just as a one-off green icon but could be implemented in greater numbers in an autarkic floating community [28].

In 2010 de Blok settled on the Hasseltkanaal in Buiksloterham as the site for the Schoonschip community, and in 2011 she brought architects space&matter onto the team, along with Metabolic to design sustainable systems [30]. While each houseboat would have many of the self-sufficient features of the original geWoonboot they would also be able to work together in a common framework to create a more resilient whole. The physical framework permitting this cooperation and resilience was conceptualized by the design team as a branching network of piers that would provide physical mooring for each houseboat, but also contain an infrastructure bundle. (Fig. 13)

![Figure 13. Schoonschip site plan. (space&matter architects)](image)

The Schoonschip pier would not just be an umbilical cord delivering resources to hungry nodes, but a smart network allowing the houseboats to autonomously exchange information and negotiate the sharing of energy and manage a circular water system. (Fig. 14) Though space&matter have designed one of the houseboats in the commune, their larger contribution has been to the design of an urban system (with Metabolic) and the parameters of the architectural elements which participate in this system.
Micro-infrastructures: prototypes instead of singular artifacts

The history of Amsterdam's water management sketched out in this essay suggests that the elements of the built-environment (not only in Amsterdam) are increasingly likely to be subsumed into large-scale data-driven urban systems. Architects practicing in this emerging context will need to develop a theory not of singular architecture artifacts but rather of distributed networks of architectural elements acting together as emergent urban infrastructures. To write this theory we can begin to document its pioneers like Sascha Glasl of *space&matter* and Eva Gladek of *Metabolic*.

Fragmentation of the architectural artifact does not necessarily mean a sidelining of the architect, but an evolution in that role. The toolbox of flood-adaptive architectural interventions proposed by *Amsterdam Rainproof* described earlier in this essay is paralleled by a catalogue promoted by the Delta Commission for all of the Netherlands. The, ’*Groen Blauwe Netwerken* design tool,’ was developed by an office of architects and designers, *Atelier Groen Blauwe*, led by the architect Hiltrud Potz [31]. Though all instances of these interventions will not be authored and executed by Potz, her cumulative impact on the form of architecture in the Netherlands may be ultimately larger than that of a traditional architect creating singular works of architecture. The impact of this design work extends beyond the enclave of capital-A Architecture, and into the wider world of urban form and anonymous building. Design in the data-driven city may thus have a broader horizon of impact even if its product is more nebulous than the singular master works of 20th century modern architecture.

Projects like *space&matter*’s *de Ceuvel* or *Schoonschip* take on a procedural, exemplary logic that is presented as a model for wider application. The prototypical nature of these projects is enforced by the systems logic *Metabolic* has built into their design. Today *Metabolic* is beginning to apply circular metabolism concepts at a city-wide scale in Amsterdam via development regulations [27]. *Space&matter* is also achieving broader recognition for building architectural prototypes that create meaning in the data-driven city. Their recent opening of the *Sweets* hotel, twenty-eight refurbished bridge houses re-grouped into a single hotel via an online interface, has won numerous awards, suggesting that their approach to distributed architectural micro-infrastructures will continue to expand in influence [33]. (Fig. 15)
Visioning/versioning the data-driven city

The Buiksloterham district of Amsterdam provides evidence of a complicated inter-mixture of an incipient data-driven urban ‘feedback framework’ and an architectural/social movement, which allows us to return to one of the central questions of the data-driven city: can the implementation of data-driven urban systems produce change-in civic practice or sustainability- or will it act to entrench existing hierarchies?

While criticism of the smart city, like Shannon Mattern’s perceptive study of Hudson Yards, often reveals a problematic reinforcing of existing urban hierarchies, the works of space&matter in Buiksloterham like de Ceuvel and Schoonschip offer an alternative possibility [32]. Space&matters’s projects employ technologies in autarkic networks instead of in centralized hierarchies, and encourage a culture of self-build, self-sufficiency, and self-determination based on the intense collaboration of small groups with shared values and aspirations [23]. These architectural propositions use the creation of the data-driven city to break down existing strata of hierarchy, bureaucracy and technological process. They tend toward an ideal of techno-nomadism, and also toward the formlessness of found solutions like re-purposed houseboats, or the frameworks of the de Ceuvel boardwalk or the Schoonschip infrastructural pier.

In Buiksloterham, the data-driven city did not precede an architectural/cultural movement, but rather arose in reciprocity with it. In this mix the architectural form, in the case of de Ceuvel, provided the physical framework for experimentation and ultimately the physical proof of its success, becoming a totemic figure in attracting interest and confidence in the experiment and accelerating its development. Buiksloterham suggest not only that the data-driven urban systems can challenge existing hierarchies, but also maps out roles that designers can play in nudging that evolution toward more sustainable and socially engaged directions [5].

REFERENCES