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A collaborative hybridity design approach: enhancing urban water resilience and spatial legibility

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ABSTRACT

Within the global transition to sustainable urban water management, Dutch polder cities are also contemplating revitalising their water traditions. One of the keys to this task is to integrate water management into urban design, which is explored but not yet practically instrumentalized in the urban design process. This article introduces the concept of hybridity and develops a Hybridity Design Approach as an interdisciplinary methodology to explore the possibility of realising the extreme low impact Closed City Concept. Integration of the water environment and urban space needs interdisciplinary cooperation and sharing knowledge, as well as an innovative way of thinking about water-resilient urban design, maximising the landscape quality of a polder city while minimising its hydrological footprint in the region. Effective visualisation tools and techniques for this collaborative design process are developed and tested in the area of Zevenkamp in Rotterdam.

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Introduction

Centuries ago, the Netherlands was a free delta, an inhabitable place because of the high dynamics between land and sea. The Dutch have brought this under control by the creation of a unique polder landscape, protected by an extensive dike system that forms the fundamental condition of Dutch spatial order (Van der Woud 1987). The Dutch tradition of reworking the delta resulted in three hydrological types of cities: (upstream) river cities in the higher (eastern) side of the country with a natural water discharge (mid-stream) *boezem*[1] cities on the border of a polder, in which the discharge in the city is natural but is pumped on a larger scale and (downstream in lowland) polder cities that are situated in the polder and are completely dependent on pumping (Hooimeijer 2014). With the Industrial Revolution at the end of the 19th century and the intervention of powerful pumping stations, the connection to the natural water system and how it works was lost; technology made it possible to manipulate the water system and control it to the extent that was necessary for the desired land-use. The tradition of the water system being fundamental in the urban design of polder cities was also lost, and

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the visionary way aimed at creating coherence between socio-economic and environmental development got more focus on the socio-economic. To repair and harmonise "built environment" for both human society and ecosystems, interdisciplinary collaboration between spatial designers and specific technical fields is crucial (Sugano et al. 2019). The fact that a polder city is as complex as it is provides a good study case over river and *boezem* cities that still have a more natural working water environment due to the ability to use gravity for water discharge.

The three types of water cities, upstream, midstream, and downstream, explain their position in the hydrological system and can be found in all deltas in the world. The practice of urban design and water management is already responding to the global trends of climate change and urban densification that are specifically coming together in these deltas. Hydrological patterns are changing, continuously adding pressure in water cities, especially existing polder cities. Here, the original natural processes of the water system are altered to such an extent that local hydrologic regimes are not flexible enough to anticipate the hydrological changes (McGrane 2016). Water issues such as flood and drought, but also heatwaves, are huge challenges in the development of sustainable and healthy cities and communities (HABITAT 2017; UN General Assembly 2015). In response to these challenges, more and more cities are addressing mitigation and adaptation measures by reinvigorating integrated urban planning and design to make the spatial performance future-proof. As water is one of the most crucial topics, a transition to Integrated Urban Water Management (IUWM) approach is applied globally. Among the emerging concepts, some are widely recognized: Sustainable Urban Drainage Systems (SUDS) (CIRIA 1998), Water Sensitive Urban Design (WSUD) (Brown, Keath, and Wong 2009), Low Impact Development (Elliott and Trowsdale 2007), Green-Blue Infrastructure (GBI) (Gledhill and James 2008), Sponge City (MOHURD 2014), and Nature-based Solutions (NbS) (WWAP 2018). The transition in polder cities is framed under the concepts mentioned above; however, these are focussed on optimising and not transitioning the water system. Transitioning the water system would involve spatial interventions to, for example, making the water system more flexible (more open surface water) but also including mitigation, reducing the footprint of water use that has spatial impacts (decentralised systems and utilisation of these systems in architecture). In order to understand and connect these relations, between urban design and water management and between water adaptation and mitigation, the concept of Closed City is bringing these together.

In this paper, the Closed City Concept is considered as an approach to not only reduce the vulnerability of polder cities to climate change but also include the aspect of circularity, thus mitigation of climate change. Despite the water-related challenges addressed in above-mentioned concepts, there is a lack of theoretical and practical considerations on water circularity, which is a way to minimise water footprint of the city (Miranda et al. 2022; Velenturf and Purnell 2021). The Closed City Concept considers water circularity with possible spatial organisations and is defined as follows: "a city that does not have adverse effects on its surroundings, such as water depletion or emission of pollution" (R. De Graaf 2005; R. E. De Graaf, Van De Giesen, and Van De Ven 2007). In the Closed City Concept, stormwater and treated wastewater are recycled through either centralised or decentralised solutions. This means that the water chain (drinking water, wastewater, and the treatment of wastewater) is (re-)integrated with the (natural) water system (stormwater, groundwater, and surface water). To be able to innovate the urban water system in making it work for climate adaptation and mitigation, it is important to acknowledge the fact that it is a collaboration between the water chain and the natural water system (which in polder cities is pumped).

The Closed City Concept can be realised by combining grey solutions (e.g. water treatment plants and separated sewers) and green solutions (e.g. green roofs, bioswales, and permeable pavements) thus influencing the design of not only surface water structures but also impact the spatial quality. From the perspective of water management, the Closed City Concept can considerably reduce urban vulnerability to changing climatic conditions (R. E. De Graaf, Van De Giesen, and Van De Ven 2007). From a spatial perspective, the urban water system only exists as part of public space and representing nature as a part of spatial quality, the water chain has been invisible or engineered out of sight. However, realising a conceptual Closed City Concept design can only be done through dialogue between water managers and urban designers. Urban development is an interdisciplinary field in which spatial design integrates the built-up with the existing natural environment, linking technical, social, and economic aspects of urban development together. The determination of water solutions as well as their locations within this interdisciplinary design is not solely dependent on water managers. Cooperation with urban designers is essential. In the urban design of polder cities (where there is a high control over the urban water system), there is rising demand for a systematic analysis of urban space in relation to water management, to fix the gap between water management and urban design.

It is acknowledged that water, as a spatial element, fulfils not only the water performance ambitions of reducing environmental footprint but also improves spatial liveability and attractiveness, hence enhancing the transformation to climate adaptive polder cities (Schuetze and Chelleri 2011). Moreover, the previously mentioned IUWM concepts propose climate-adaptive solutions from the water management perspective, which requests to be included in spatial planning, while the Closed City Concept considers urban space and water system planning simultaneously. In this regard, the Closed City Concept offers opportunities to introduce interdisciplinary methodology between spatial planning and urban water management, so that urban development and water-related challenges are integrally incorporated in emerging sustainable city concepts.

The research question of this study is as follows: how to operationalize the Closed City Concept from both hydrological and spatial perspectives, to intertwine water circularity into urban design of high spatial quality. Therefore, the aim is to operationalize collaboration between water management and spatial design, which is done by introducing and testing the Hybridity Design Approach. The paper starts with the introduction of the theory and definition of Hybridity Design, followed by a section in which the proposed methodology to analyse and evaluate the hybridity and water circularity from an interdisciplinary perspective is presented. The next section reveals the results of testing the approach in Zevenkamp, Rotterdam. The performance of Closed City Concept designed through the Hybridity Design Approach is discussed to verify its operational feasibility.

Theory of hybridity design

Originating in biology, the word “hybrid,” or “hybridity,” refers to a descendant mixture produced from two different parental plants, species, or races. This term was later imported into the social sciences, humanities, literacy, and cultural studies (Coombes and Brah 2000; Lusty 2017; Tolia-Kelly 2009), and its meaning expanded and became more generic. For example, Lewis (2020) stated that, in the humanities and social sciences, hybridity can be used to describe anything resulting from heterogeneous sources or composites of incongruous elements. Brandsen (2010) defines hybridity as the combination of the characteristics of contradictory elements within a certain discipline, such as social science. And Water Europe (2021) defines hybridity as the integrated combination of green, blue, grey, and smart solutions for water management. A difference between hybridity and integration of water management components is made here, in which hybridity calls for more attention to embrace the complexity of the comprehensive urban design challenges, including the complex interplay between space, water, and many other issues, rather than isolated components (Ewert et al. 2022).

Under this broader sense of hybridity, polder cities can be considered as an extreme hybrid situation as a result of intervening with the natural water system and manipulating this more and more over time. The natural and urban systems are intensively intertwined, cooperating with and dependent on each other. As its performance is driven by technical, social, and economic impacts, designing it requires an interdisciplinary approach (Heemels et al. 2009) that manifests the importance of understanding hybridity from a variety of different disciplinary perspectives. The importance of reintegrating the natural water system into the spatial order to respond to climate change is captured in a recent Dutch national policy brief on sustainable and resilient urban development. The brief requires making water and soil leading in urban planning and design (Ministry of Infrastructure and Water Management 2022) which means there is a demand for a better understanding of the character and the relations in the deltaic landscape.

Beyond the "normal" city, the Closed City Concept is a model of a smart hybrid system because it makes use of the dependency between the natural and human systems in a productive way, mitigating and adapting to climate change in order to minimise the urban footprint in the environment while maximising the (co)benefits with urban infrastructure. As in the tradition of building polder cities, water in the Closed City Concept is a crucial aspect in landscape, therefore systematic analysis of urban space and water management should be considered. However, as it is conceptualised till now, the Closed City Concept only proposes grey infrastructures considering water circularity. To make it a further step, the assumption is that acknowledgement of the need for a Hybridity Design Approach is a way to operationalize a sustainable urban water system in the Closed City Concept. Instead of the traditional water – land dichotomy, where the land is only for constructions and the water is detained and drained, water – land can be taken as a hybrid environment not only to release urban land use pressure on landscape and ecosystems (Brockbank and Jonathan 2017; Smaniotto Costa et al. 2015) but also to trigger rethinking the socio-technical-natural connections within local context (Lahiri-Dut 2014). Adaptive governance is required for transitioning to these sustainable socio-technical-natural systems (Olsson et al. 2006; Smith and Stirling 2008). However, in urban water/space management, inadequate governance issues are barriers to sustainability (Mulligan et al. 2020; Water Europe 2021). To analyse the hybridity of Closed City Concept from an interdisciplinary perspective, at least the interwoven relationships between urban water, land, and space, together with governance, are critical. Relevant disciplines, therefore, include urban design, water management (civil engineering), policy, and social sciences. This research is a first step in this quest and focuses on the relationship between the water environment and spatial design. It is expected that the methods and findings in this study will serve as an entry for further research into the governance barriers to implement a Closed City Concept.

In this research "Hybridity Design" is explored and tested to support the design of the Closed City Concept. Hybridity Design is defined as "a framework for designing, evaluating, applying, and managing the integration of urban water systems and urban space, via interdisciplinary collaboration and multi-stakeholders" inclusion.' The purpose of the framework, that is presented in the following paragraph, is knowledge brokerage, to integrate different social, spatial, and natural elements that were formerly separated, leading to realising a sustainable and resilient socio-technical-natural living environment by maximising the value of urban landscape while minimising the hydrological footprint of the urban system.

Methodology: Hybridity Design Approach of Closed City Concept

This study analyses the hybridity of urban systems from two perspectives, water environment engineering, and spatial design, taking the Closed City Concept as the objective of urban design intervention. Each perspective of the hybridity can be further subdivided into different elements, since both the water- and the spatial systems are hybrid as well. For instance, the hybridity of urban space (referred to as "spatial hybridity" in this study) consists of urban structures such as buildings, roads, green and open space, surface water, etc. in their interaction with people, while the hybridity of water environment (referred to as "environmental hybridity" in this study) comprises elements of urban water systems such as rivers, canals, pipes, etc. in their interaction with the hydrological functions, including drainage, detention, evaporation, water supply, wastewater treatment and with the ecosystem services that these elements provide. The urban space and the water environment influence each other and have an impact on the circularity performance of the urban water system.

The Hybridity Design Approach is developed and operationalized by determining indicators for environmental and spatial hybridity in the following two paragraphs. All the indicators are taken into account throughout the urban design process so that water circularity and spatial quality can be both enhanced, mutually contributing to an improved performance in the Closed City Concept. These indicators form the basis for the workflow of Hybridity Design Approach presented in the last section of this paragraph. (Figure 1)

Environmental hybridity

The natural hydrologic cycle is a dynamic circulation of water between geosphere (including the hydro-, litho-, and atmo-spheres) and biosphere, while in urban areas, the water cycle is also influenced by anthropogenic activities and technological artefacts. Environmental hybridity refers to water in three spheres: the geosphere, biosphere and technosphere, and their participation in the urban water system. These spheres are not separate but cohabit within the same urban space and interact with each other.

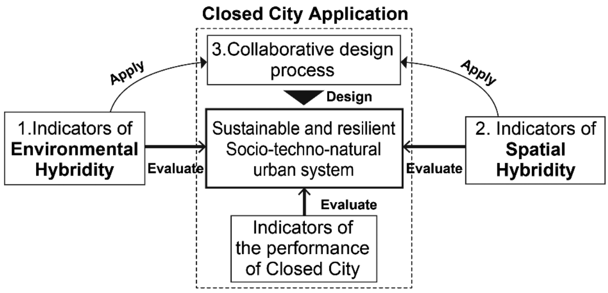


Figure 1. The Hybridity Design Approach workflow.

According to the theories of autopoiesis (Maturana and Varela 1991) and urban political ecology (Swyngedouw and Heynen 2003), human and nature systems are interconnected, integrally linking all living creatures, resources, and spaces. It is evident that the three spheres are also inter-linked in the urban environment. Natural elements and artefacts that are parts of the urban structure (buildings, roads, etc.), the urban water system (urban surface waterbodies, groundwater, and connections) and the drinking water system (water extraction, treatment, distribution, water use, sewerage, wastewater treatment, and discharge) can be categorised into each of the three spheres or their overlaps (Figure 2). For instance, buildings and infrastructures belong to the technosphere, unpaved green areas are part of the biosphere, and groundwater and natural lakes are in the geosphere.

To investigate how the three spheres contribute to environmental hybridity and how they are connected by water flows, water balance analysis is applied as an entry point for

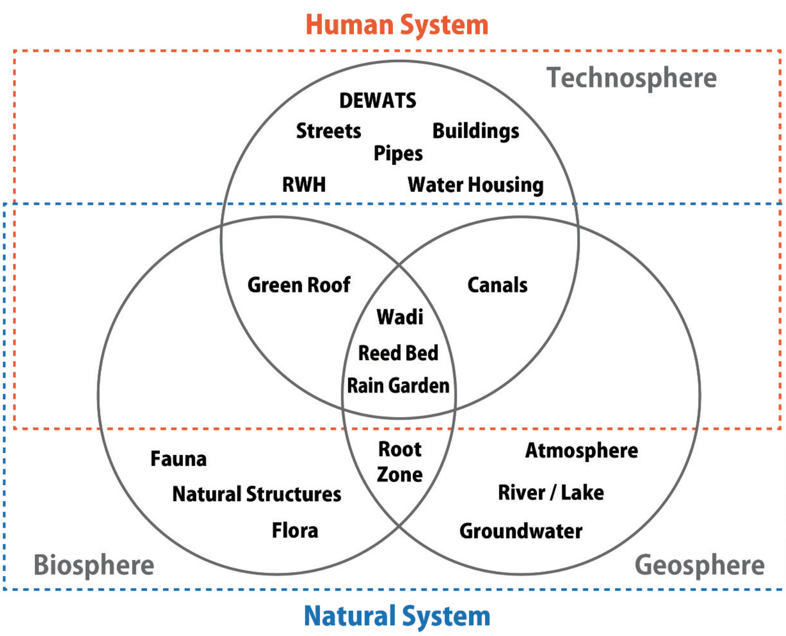


Figure 2. Relationships between the three spheres in environmental hybridity.

studying urban water systems (McPherson 1973; F. Van de Ven 1990). The water flows are quantified based on land covers and hydrological processes by a lumped, multi-reservoir urban water balance model (F. H. Van de Ven et al. 2016).

The environmental hybridity is visualised by a Sankey diagram that describes the water balance. A Sankey diagram distinguishes different fluxes from their sources to targets, by drawing the thickness proportionally to illustrate the flow magnitudes. Colours are used to show the sphere that each component belongs to. Examples of the expected Sankey diagrams (Plotly Technologies Inc 2015) are shown in Figure 3. To make the Sankey diagram for all the spheres Figure 3(b), the Sankey diagram of water balance results is produced first Figure 3(a). As water balance is calculated based on land uses, Figure 3(a) gives a clear overview of flow pathways in the urban water system through various land uses. Based on this fractional water balance diagram, the spatial elements are categorised into the three spheres as defined by environmental hybridity. The amount of water flowing into and out of each sphere is the sum of the incoming and outgoing flows of the spatial elements. The Sankey diagram of environmental hybridity will serve as a reference for drawing the hybridity charts used for the evaluation. These hybridity charts summarise the environmental hybridity by showing flow connections among spheres (Figure 4). Each sphere, including overlap spheres, is shown to be a unit. The spheres are connected by arrows, indicating the flow direction.

A high environmental hybridity creates more diverse water flows which enriches the functional processes and interactions of water stocks in the three spheres; hence, the environmental footprint is reduced (Falkenmark 2020; Falkenmark and Wang-Erlandsson 2021). It is argued that the more interconnected the spheres are, the tighter the connection between the man-made and the natural environment is. Apart from the connections, the involved water amounts are also important. If the water quantity relevant to each sphere is more balanced, then each sphere is indispensable. Should a failure occur in one sphere, water flowing to this sphere may find an alternative pathway through other spheres. A circular pathway within one sphere is also possible, which can provide internal support during stress periods when incoming flows from other spheres are not sufficient or during emergency events when connections to other spheres are temporarily blocked. As a result, both the robustness and resilience of water systems are improved, which is considered to be a high environmental hybridity.

Four indicators are set to assess the environmental hybridity from the chart, which are as follows: 1) the number of involved spheres, as drawn from the chart; 2) the connection density between spheres, as the arrow-connections from the chart; 3) the number of bi-directional connection pairs, as those connections with arrows at both ends in the chart; and 4) the balance of water distributed to each sphere, as described by statistical standard deviation of all the incoming and outgoing water flows for each sphere.

The first three indicators consider the diverse flow pathways created to describe environmental hybridity. The more involved spheres give more possibilities for water connecting spheres with water-related spatial elements. Subsequently, more water connections are generated that can diversify water functional processes. More bi-directional water connections can further tighten the linkage, contributing to the robustness of water systems. The fourth indicator takes the vulnerability into account, as water systems tend to be more vulnerable if major flow exchanges only occur in limited spheres, should one of these spheres

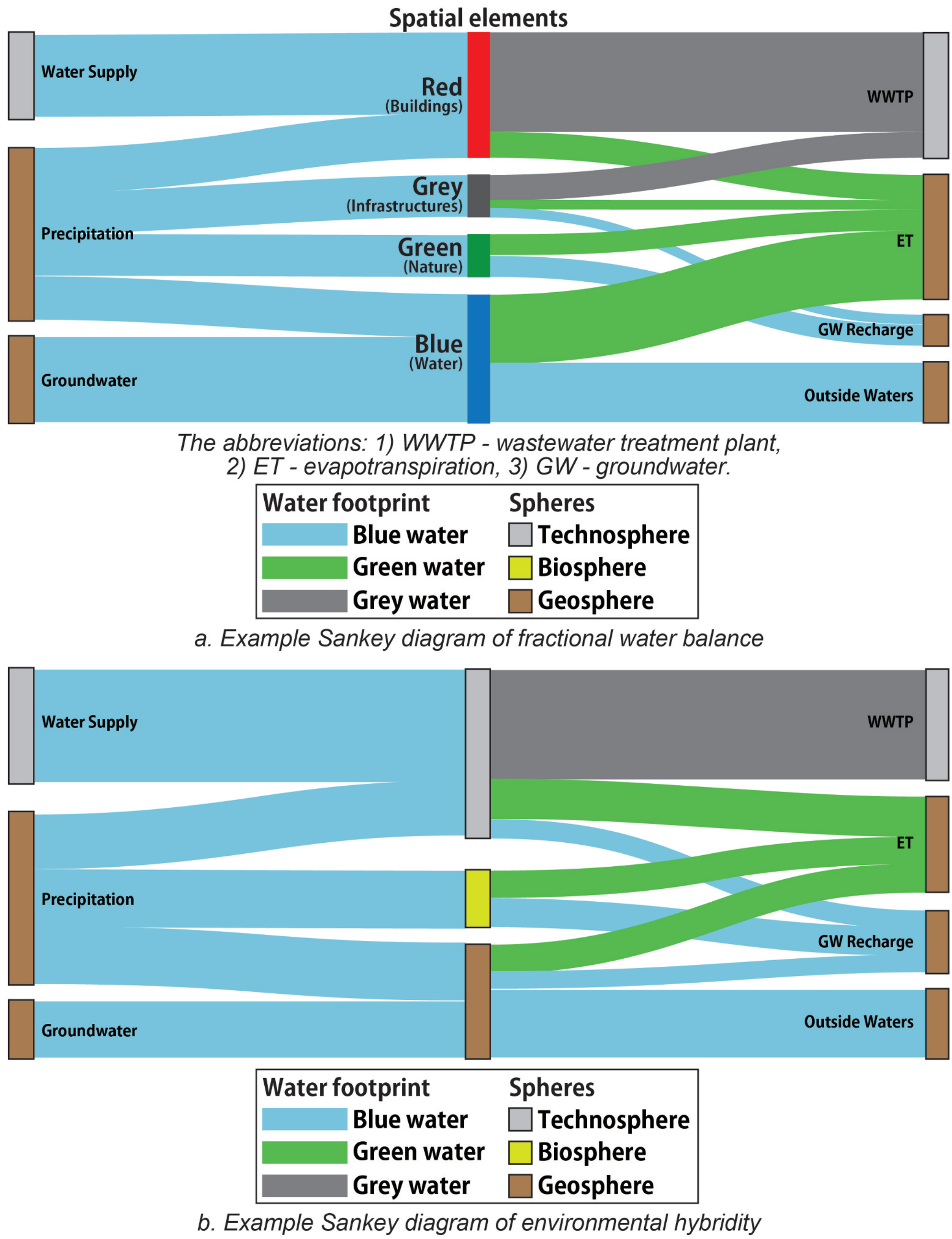


Figure 3. Example Sankey diagrams.

experience a failure. Thus, for resilience, each sphere should be of the same importance due to a more balanced water distribution. A higher level of environmental hybridity is then expected by more involved spheres with more (bi-directional) flow connections, as well as a smaller standard deviation value.

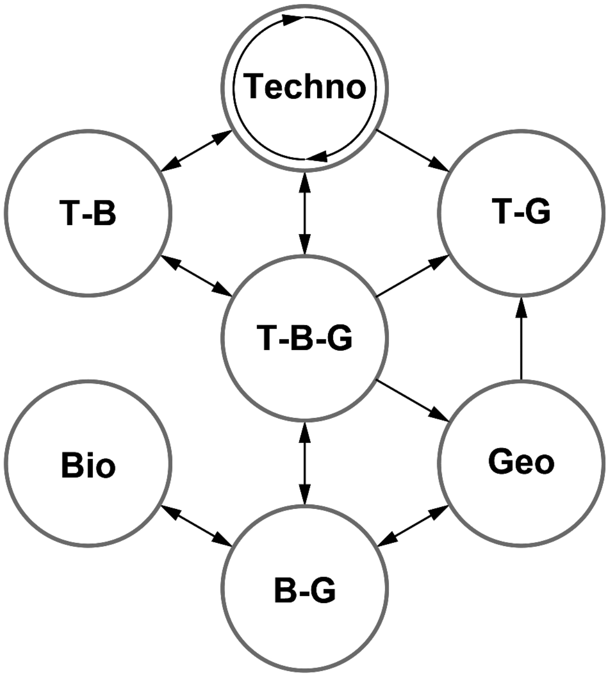


Figure 4. Example of an environmental hybridity chart.

Spatial hybridity

Making the functionality, role and meaning of the urban water system evident and sensible as part of urban design requires mutual understanding of water systems during interdisciplinary design collaboration. The starting point from the spatial hybridity perspective is an urban design that provides high legibility that contributes to people's understanding of the urban structure (Lynch 1964). Water elements in the city contribute to this understanding of the water city. The legibility of water flow pathways and the role of drainage and treatment systems add to these didactic values of the urban landscape. Spatial hybridity refers to creating sequential legibility of spatial elements, with particular regard to the diversity of their scales and communicating their connections to water. Through the visual integration of red (buildings), grey (infrastructures), blue (water), and green (nature) with the urban water system, people can read the hydrological connections between various spatial elements in a network of urban spaces. Even if the water flow is invisible, such as with soil infiltration, the arrangement of spatial elements can reveal to people the flow directions, and thus provide orientation. The garden of Het Nutshuis in The Hague, The Netherlands, offers an example at the "architecture" scale (Figure 5). It is possible to recognize diverse connections between spatial elements through infrastructures and hydrological processes, e.g. the downspout leading to a pond is designed into the building façade, allowing visitors to recognize the connection between the building (red) and surface water (blue). The gutter attached to the bridge represents the connection between the bridge (grey) and surface water (blue) via run-off, and a green – blue connection is formed via run-off and subsurface flow exchange. Hence,

Figure 5. Example of water-related legibility of the water system in het nutshuis.

it is strongly recommended to create water-related legibility in the city's network of urban spaces, so that people can continuously identify the water connections at private housing, neighbourhood, and city levels.

Legibility of water systems is considered as the key to spatial Hybridity Design. The analysis of legibility is done by examining the connectivity and visibility of the water system. Connectivity refers to the identification of connections between spatial elements by the water flow, which is analysed based on the water balance results and Sankey diagrams of environmental hybridity. Next, the visibility of spatial elements connected via the water system is verified. It is assumed that spatial elements within the eye-range are visible and experienced. Taking Dutch people as an example, the average eye level is 1.65 m, with a central visual field $\theta = 30°$ and central depression angle $\theta' = 80°$, a distance of 10.8 m can then be determined as the region where gaze is concentrated (Sanchez-Lite et al. 2013; Schönbeck et al. 2013; Shinohara 1982; Sugano et al. 2019; Yaqub 2012). Therefore, spatial elements in the 10.8 m range are visible, where overlap regions are regarded as the legible area, see Figure 6 for calculation, and use the eye-range distance to specify legible areas. Although other senses, such as hearing and smelling, are also playing an important role, this study is limited to the visual sense as representative of human senses that is important for the perception of spatial quality (Zadra and Clore 2011).

Three indicators are set up to assess the spatial hybridity, which are as follows: 1) total water-related legible area, as measured by geographic analysis tool (i.e. ArcGIS); 2) connection diversity, as described as a ratio of legible area where people can experience more than one spatial connection types against total legible area, and it is also analysed by ArcGIS; and 3) balance of three spatial scales (i.e. household, neighbourhood, and district), which is described by statistical standard deviation of the ratios of legible area for each scale against the total legible area.

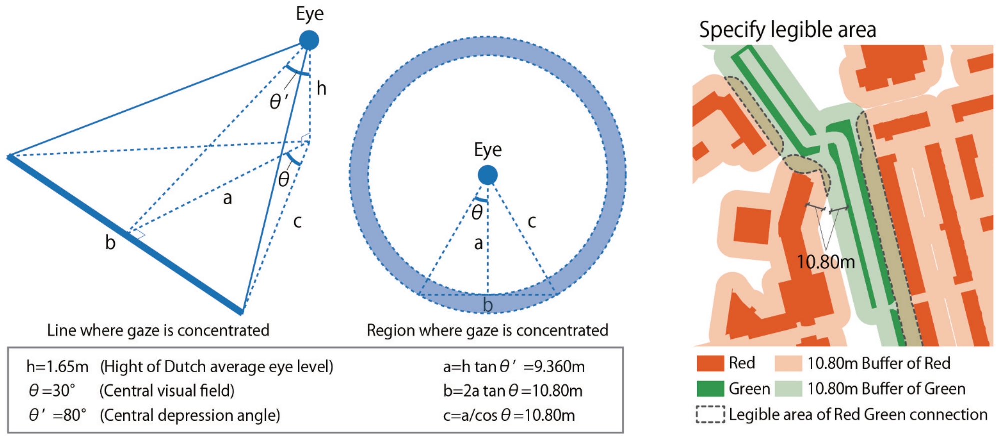


Figure 6. Calculating gaze region (left) and specifying the legible area of red–green connection (right).

All the three indicators consider sequential and diverse water-related connections in urban design for people to experience the spatial hybridity of a water city. The total area where the water system is legible is fundamental: if the legible area is larger, it then allows more opportunities for this spatial experience. A higher connection diversity brings more spatial elements together, which outstands the role of water in the identity and aesthetics of cities and contributes to a multi-functional landscape (Bacchin et al. 2014). The balance of three scales takes spatial heterogeneity into account, as the structure and function of urban landscape are scale-dependent (Turner 1989). A more balanced distribution of the scales (i.e. a smaller deviation value from the mathematical point of view) contributes to identifying the spatial features and configuration of a city (van Nes 2021). A higher level of spatial hybridity is then expected by larger legible area with higher percentage of diversified connections, as well as a smaller deviation value of three spatial scales.

Hybridity design approach

The previous sections established the indicators in the Hybridity Design Approach. The application of the interdisciplinary collaborative design is then carried out by urban designers and water managers together. The process includes:

(1) mapping current conditions of the water system and space in the area as a benchmark.
(2) shortlisting both grey and green water solutions that are most commonly used within water management and to determine their locations from the perspective of environmental hybridity.
(3) discussing water solutions and their preliminary locations with urban designers, during which the design of the infrastructures is proposed in terms of spatial hybridity to provide visual opportunities for the water system to be legible as a continuous space. This interdisciplinary discussion will include a creative design of proposed water solutions, which may take a series of back-and-forth discussions. Scenarios for applying Hybridity Design Approach are determined during this step

as well. The scenarios are set based on different combinations of grey and green solutions, with an idea of changing gradations from completely grey to completely green.

(4) evaluating the results of future scenarios against current conditions. Both indicators of spatial/environmental hybridity and the performance of Closed City Concept are assessed. The performance of the city as a Closed City Concept is assessed in terms of reducing the environmental footprint and internal water circulation of the urban area.

The most important input data include historical precipitation data, drinking water supply data, land use, population, etc. For the application to the case, this data is collected from Rotterdam municipality, Royal Netherlands Meteorological Institute and drinking water supplier Evides. Rainfall and water supply data are processed into daily values as input for the water balance model. The land use and land cover are categorised into buildings, streets, unpaved area and surface water, to serve as the input for calculating the amount of surface run-off on each land use category in the model.

Application of hybridity design approach

Description of the test area Zevenkamp Rotterdam

Rotterdam is one of the most outstanding Dutch water cities to realise a waterproof future. The municipality of Rotterdam and the Water Board drafted Waterplan 2 in 2007 to promote an IUWM approach that focuses on water shortage, water quality, and flood control (Rotterdam 2007). By learning from nature, Rotterdam keeps the focus on how the city can function as a living organism not only to solve water issues but also to provide a smart way of living for its residents. Several projects have already been implemented, and many districts are still under development.

Zevenkamp is located in Prins Alexanderpolder, to the north-east of Rotterdam's city centre (Figure 7). The main structure of Zevenkamp was planned in 1976 and built in the following 10 years by filling sand onto highly compressed peat and clay (Van Dorst et al. 2011). As a result, Zevenkamp became the second largest district that was developed in the 1970s in the Netherlands, covering an area of around 200 hectares.

Characteristic for the 70s urban design is that in response to a very technocratic approach to urban design of the post-war era (Modernism) and the signals of worrying about our sustainable future (Rachel Carson and Club of Rome), the design of Zevenkamp included the water system as a natural asset and buildings are again on a human scale, ground bound, and less industrial material. Although housing properties constructed in the 1970s are still functioning, some signals, such as stagnant housing prices and decreasing population, indicate a need for urban renewal so that its values can be preserved and large-scale reconstruction saved. Studying alternatives for renewal of the Zevenkamp area is expected to give an example for the sustainable regeneration of other 1970s urban districts in the Netherlands, as well as the promotion of sustainable urban water systems.

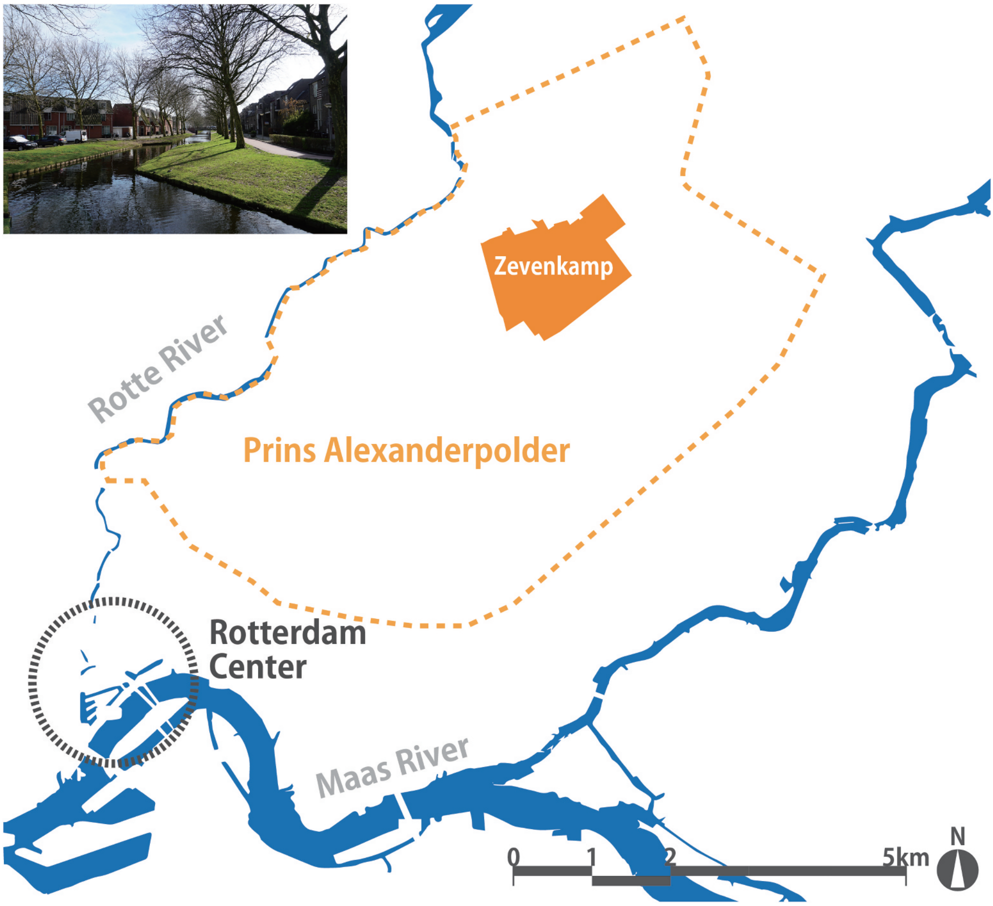


Figure 7. The location of Zevenkamp district.

Collaborative design process under hybridity design approach

A collaborative design thinking process is carried out for adopting Hybridity Design Approach in the Zevenkamp district. The projected future vision is based on the ambition of a Closed City Concept with its water solution-packages. To start with, analysing current hybridity in Zevenkamp provides a benchmark for testing the hybridity results of the future alternatives.

Commonly used blue-green and grey measures are proposed to solve water-related issues for a Closed City Concept (R. De Graaf 2005). The proposed grey measures include the separated stormwater drainage system (SWDS), rainwater harvesting (RWH), and decentralised wastewater treatment facilities (DEWATS), while proposed green solutions include green roofs, bioswales, rain gardens, and helophyte filters. In particular, RWH, DEWATS, and helophyte filters are also considered for water reuse and recycling, to meet the Closed City Concept goal of a reduced environmental footprint. The proposed grey measures are all in the technosphere, while the green infrastructures, since most of them are combined with techniques and natural processes, are in the techno-bio-geosphere (T-B-G). Thus, green roofs are particularly considered for the techno-biosphere (T-B), as they have no direct connections to the Zevenkamp geosphere. As shown in Figure 4, the more spheres are involved, the more opportunities there are to enhance environmental hybridity. For the future Zevenkamp, this is completed by selecting solutions in the missing spheres T-B and T-B-G.

After shortlisting solutions, the locations and layouts are discussed. From a water management perspective, places that are suitable for installing measures are identified. For instance, flat rooftops can be changed to green roofs and sloping rooftops for rainwater harvesting. Public greens and private gardens are possibilities for bioswales and rain gardens. Meanwhile, engineering criteria are considered for calculating the capacity of interventions, the space for a helophyte filter is related to its loading, and hence scales with population (Gokalp and Karaman 2017). In addition to water management factors, the urban structure is re-examined for its legibility for enhancing spatial hybridity. As continuous spaces in which the water system is legible provide more visible opportunities, solutions with subsurface facilities can be re-thought with a chance of bringing them above ground. For instance, harvested rainwater storage in underground tanks could instead be re-designed as an above-ground box that functions as a water fence with green covers. For the re-design of DEWATS, the facilities are placed in a small building in the public green area of the community, and named Water Houses. This public space is designed as the playground with water ponds that store extra water from the Water House. In terms of continuity, regenerating historical spatial networks and water structures is considered to have potential for making connections between spatial elements (Figure 8), giving indications of how they could function, as well as awakening cultural recognition to the tradition of making polder cities (Hooimeijer 2014).

Based on a series of back-and-forth discussions between disciplines, a final urban design is shown in Figure 9. Four zonal types are considered for the proposed measures. The first is for rain gardens and water fences (rain water harvesting) that can be installed in front yards along the street. The second type is for rain gardens in public green areas within the district. The Water House (DEWATS), helophyte filters, and bioswales in the public green areas are put in the third type, while the fourth type is for solutions that are

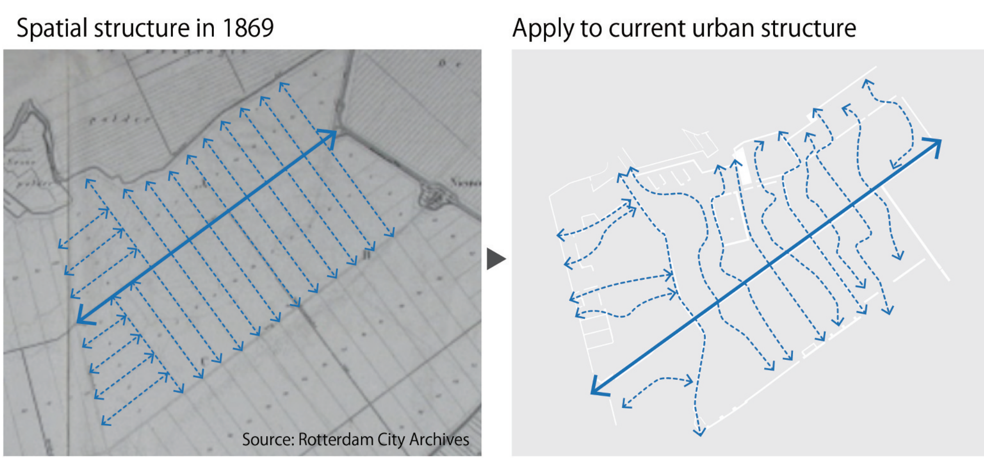


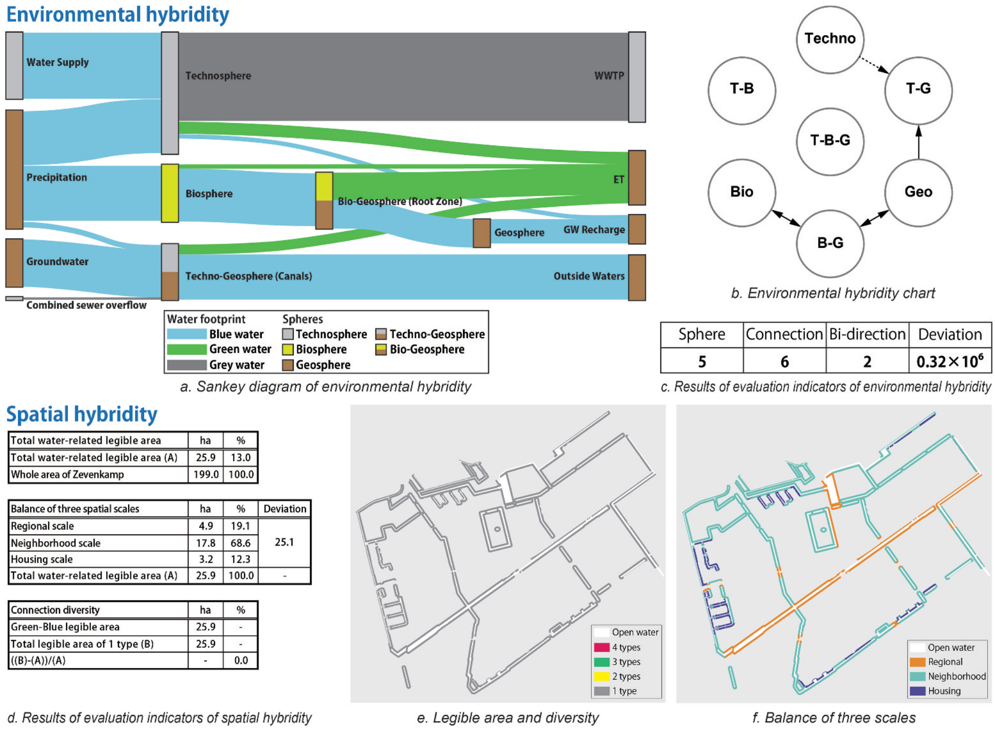
Figure 8. Regenerating historical water structures in current Zevenkamp.

Figure 9. The final urban structure with proposed solutions in future Zevenkamp.

not easily visible, including SWDS and green roofs. The green roofs are deemed invisible because, being on (private) rooftops, they are outside the ground-level gaze.

Current hybridity in Zevenkamp

Due to the fact that green solutions are currently rare in Zevenkamp, the T-B-G and T-B spheres are not involved in environmental hybridity. In the current situation, there are only a total of six connections (the number of arrows in Figure 10(b)), including the dashed arrow which represents combined sewer overflow to canals. Bi-directional connections are only found between biosphere and geosphere, as well as their overlapped B-G sphere. These interactive connections indicate flow exchanges between spheres, for example, water infiltrates into the root zone from vegetation (the biosphere) while capillary rise makes water flow from the root zone to the biosphere. Most water amounts are distributed among the biosphere, geosphere, and B-G, which could be attributed to the large unpaved area in Zevenkamp – almost 50%. The results of environmental hybridity in the current Zevenkamp indicates a lack of climate-adaptive measures, too much dependence on external water supply and disconnections within urban hydrologic cycles. For making a sustainable future Zevenkamp by reducing the environmental



Sphere	Connection	Bi-direction	Deviation
5	6	2	0.32×10^6

Total water-related legible area	ha	%
Total water-related legible area (A)	25.9	13.0
Whole area of Zevenkamp	199.0	100.0

Balance of three spatial scales	ha	%	Deviation
Regional scale	4.9	19.1	25.1
Neighborhood scale	17.8	68.6	
Housing scale	3.2	12.3	
Total water-related legible area (A)	25.9	100.0	-

Connection diversity	ha	%
Green-Blue legible area	25.9	-
Total legible area of 1 type (B)	25.9	-
((B)-(A))/(A)	-	0.0

Figure 10. Hybridity in current Zevenkamp.

footprint, these water management challenges can be addressed and solved through the process of Hybridity Design Approach.

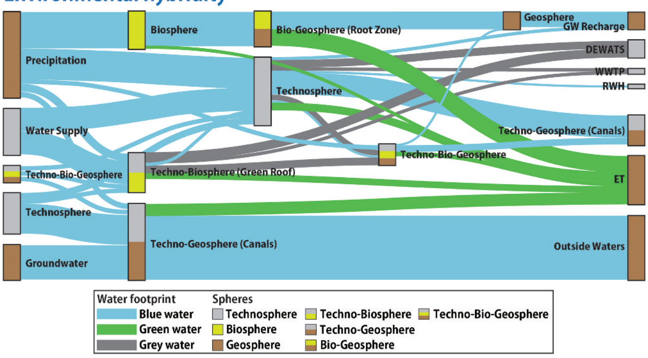
Spatial hybridity features only in the green – blue connection; red and grey are isolated from other spatial elements in Zevenkamp. The legible spatial connections form a network mainly along the open water where green space is available. The total legible area is 25.9 hectares, which takes up 13.0% of Zevenkamp Figure 10(d). In terms of the balance of three spatial scales, legible areas of neighbourhood scale take up the most, which is 68.6%. As only green – blue connection can be experienced, there is no connection diversity in Zevenkamp.

Hybridity in future Zevenkamp

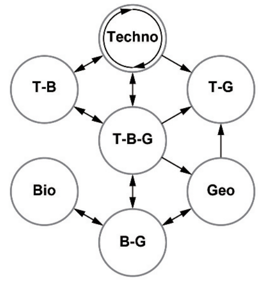
The selected grey and green solutions are applied in future Zevenkamp. Grey infrastructures, including DEWATS, RWH, and SWDS are all categorised in the technosphere. Among the green solutions, green roofs are assigned to T-B, while rain gardens, helophyte filters, and bioswales are within T-B-G. For water circularity purposes, either DEWATS or helophyte filters are applied to each neighbourhood in Zevenkamp, where twelve neighbourhoods install DEWATS and the other 13 have helophytes. Treated water from DEWATS and helophyte filters are recycled within these neighbourhoods for non-potable use.

In the future Zevenkamp, water flows among the environmental spheres are more diverse, due to the green solutions (Figure 11). All seven spheres are involved, with 16

Environmental hybridity



a. Sankey diagram of environmental hybridity



b. Environmental hybridity chart

Sphere	Connection	Bi-direction	Deviation
7	16	6	0.23×10^6

c. Results of evaluation indicators of environmental hybridity

Spatial hybridity

Total water-related legible area	ha	%
Total water-related legible area (C)	44.2	22.2
Whole area of Zevenkamp	199.0	100.0

Balance of three spatial scales	ha	%	Deviation
Regional scale	8.8	20.0	19.3
Neighborhood scale	26.8	60.6	
Housing scale	8.6	19.4	
Total water-related legible area (C)	44.2	100.0	-

Connection diversity	ha	%
Green-Blue legible area	25.9	-
Green-Blue-Grey legible area	6.6	-
Red-Green-Blue legible area	25.3	-
Total legible area of 3 types (D)	57.8	-
((D)-(C))/(C)	-	30.8

d. Results of evaluation indicators of spatial hybridity

e. Legible area and diversity

f. Balance of three scales

Figure 11. Hybridity in future Zevenkamp.

connections and six pairs of bi-directional connections Figure 11(b-c). Green roofs (T-B) drain water to SWDS and DEWATS in the technosphere, while the DEWATS also supplies water for green roofs. Similarly, some of the green roofs also drain into helophyte filters in the T-B-G sphere, and treated water is cycled back to T-B. In the technosphere, stormwater run-off from roofs and streets is collected by the green infrastructures in T-B-G, while helophyte filters supply treated water to buildings in the technosphere. The excess water from T-B-G is discharged into canals in T-G. The connections between T-B-G and B-G/ geosphere are the natural processes of subsurface flow exchanges. Deviation of water distribution to involved spheres is reduced as more spheres and flow connections are created.

Spatial hybridity also increases because of the urban design solutions (Figure 11). The connection between red-green-blue takes place through rain gardens, helophyte filters, DEWATS, and RWH; and the grey-green-blue connection flows through bioswales. In the future Zevenkamp, people will thus have more opportunities to feel diverse spatial connections that are composed of different parts of urban water systems. The spatial network of legibility includes space along the open water and various locations within the district. The total legible area is 44.2 hectares, comprising 22.2% of Zevenkamp. Figure 11(d) In this legible network, housing, and neighbourhood scales are linked to Zevenkamp's regional axis. Although the legible area of neighbourhood scale is still the largest portion (60.6%), its ratio has slightly decreased and thus gives higher ratios of housing and regional scales, which means the distribution of spatial scales is less deviated.

Table 1. Evaluating the performance of closed-city concept.

Water circularity [m^3/year]		Circulation within technosphere [m^3/year]
DEWATS	180×10^3	80×10^3
RWH	50×10^3	50×10^3
Helophyte	150×10^3	-
Total	380×10^3	130×10^3

[a]A *boezem*, roughly translated as "basin" in English, is a (dug) watercourse or system of watercourses for the storage of excess (polder) water.

Moreover, there are overlap areas along the open water where more than one type of spatial connection can be legible. These overlap areas contribute to the diversity of spatial hybridity, which is 30.8% of the total legible area.

Performance of Closed City Concept

The Closed City Concept seeks to reduce the environmental footprint of urban areas, including its dependency on external water resources. By applying grey-green solutions, combined sewer overflow is reduced, thus decreasing pollution. Moreover, these solutions will help the (re)use of local water resources such as rainwater and treated wastewater for water supply.

Currently in Zevenkamp, there are no recycling measures for water circulation, and all the water consumption is supplied by drinking water companies. It should also be noted that CSO still occurs (the dashed line in Figure 10(b)), which is not expected in a Closed City Concept. In the future Zevenkamp, water circulation can be realised by the designed hybrid grey and green measures (i.e. DEWATS, RWH, and helophyte filters). The annual total amount of water circulation is 380×10^3 m^3 (Table 1), in which one-third of it is circulated internally in technosphere (i.e. the closed arrow in Figure 11(b)). Internal circulation can reduce vulnerability of urban systems under extreme conditions, if incoming flow pathways to the technosphere are all blocked.

Discussion

Acknowledging water as a spatial element strengthens not only the water performance ambition of reducing hydrological footprint but also improves the liveability and attractiveness of urban landscape (some examples of Dutch cities that acknowledge water as a spatial element: Moeder Zernike in Groningen (Roggema 2021); Groot Wielen in Den Bosch (Wielen 2024); The City of the Sun in Heerhugowaard (Gemeente Dijk en Waard 2012)), hence enhancing the transformation to sustainable and resilient polder cities.

As it has been tested in Zevenkamp, introducing the lack of green solutions in current Zevenkamp for a higher environmental hybridity is identified through Hybridity Design Approach, i.e. green roofs, helophyte filters, etc. of T-B and T-B-G spheres. Possible locations for water solutions along historical water structures are discussed for regenerating polder-making traditions and thus for an improved spatial hybridity. The design of future scenarios was studied through interdisciplinary evaluation, resulting in both improved values of spatial and environmental hybridity compared to the current situation in all indicators. In addition, environmental footprint is reduced by eliminating sewage overflows and water circularity is enhanced instead, by making use of local rainwater and wastewater resources due to the recycling solutions. The performance of Closed City Concept is thus improving the current situation.

Intertwining environmental and spatial hybridity

In the analysis of spatial hybridity, it was evident that connections between green space and water can be found in any city, due to natural processes such as infiltration and subsurface flows. Connections are similarly inevitable when considering the spheres involved in environmental hybridity: the biosphere and geosphere are always connected, specifically between open green space in the biosphere, and surface water in the geosphere. Connections between spatial elements indicate such connections between spheres. In particular, the urban design outcome that contributes most significantly to the improvement of spatial hybridity is the increase in waterfront space and green space within the city. This will not only increase liveability by providing a recreational value of public space but also enhance the functionality of the city by acting as a water storage and retention space during heavy rainfall.

Installing grey-green solutions and their design can give visual indications for improving hybridity. Solutions selected to enhance environmental hybridity can also produce potential for spatial hybridity connections. For instance, installing rain gardens contributes to a higher environmental hybridity, and it also communicates connections between buildings (red), green space, and open water (blue), which may lead to a higher spatial hybridity. On the other hand, attempting to connect specific spatial elements also gives a clue to choose possible measures of environmental hybridity. If designers plan to connect red and blue, expected solutions can be picked from those that are categorised in the technosphere, the geosphere, or their overlap in the techno-geosphere.

It should also be noted that higher spatial hybridity does not necessarily mean higher environmental hybridity, or vice versa. In this study, the assessment of spatial hybridity considers visibility of spatial elements under general conditions, i.e. viewing from public space with access to most citizens. Viewpoints at other locations (e.g. private space or rooftops) may also be tested by adopting the Hybridity Design Approach in future work. Specifically, the intertwined design of environmental and spatial hybridity can, in practice, be achieved through the integrated design of water systems and waterfront spaces. For example, designing urban hubs integrated with waterfront spaces at functional nodes of the water system could be implemented in practical urban design. Based on the existing conditions and desired requirements of each city, different future scenarios can be set-up (i.e. different proportions of applied grey and green infrastructures for a more technology-oriented city or a more nature-oriented city) and can then be evaluated with the Hybridity Design Approach.

The argument for a high level of environmental hybridity is that more diverse flow pathways will increase resilience and reduce the environmental footprints of the city. As shown in the environmental hybridity chart, this can be done in many different ways, including closing the cycle within the technosphere. Likely and feasible alternatives are found in T-B, T-G, and T-B-G. The results of future Zevenkamp show the potential of designing robust and resilient urban water systems with integral arrangements of spatial elements. Urban areas put hybridity on display, as they are composed of multiple systems that are hybrid by both themselves and also by being intertwined with each other. The urban water system is, thus, no longer just natural: water is fundamental to environmental hybridity, and is also indispensable to spatial hybridity. Based on this understanding, the Closed City Concept design opens more chances to make smart productive relations between and within the systems. Realising this, however, requires interdisciplinary design.

Interdisciplinary cooperation and knowledge exchange

The starting point from the spatial hybridity perspective is that an urban design with high legibility of water systems contributes to people's understanding of water flow pathways and the role of drainage and treatment systems, which adds didactic values, diversity, and legibility to the urban landscape. The spatial design of the water system is the result of intensive collaboration and knowledge exchange between the urban designers, water managers, and related disciplinary experts and local stakeholders; this also has the potential to generate new knowledge (Norrman et al. 2016).

With reciprocal discussions and a sharing of common visions, the Hybridity Design Approach is operationalized by developing a method to visualise and quantify this characteristic in any specific design case, so that it can be evaluated from the different viewpoints of the participants in the planning process. The assessment outcomes also make it possible to make decisions on what is the most preferred solution rather than the best solution, as enhancing spatial hybridity may not contribute to higher environmental hybridity simultaneously and vice versa.

Visualisation is believed to be a crucial tool for the interdisciplinary communication needed in Hybridity Design Approach. The visual representations of charts, diagrams, and maps provide a blueprint for interdisciplinary cooperation, showing the perceptions of capacities and constraints of each field. These tools and representations are particularly useful during the collaboration process, for more effective and efficient interactions. Visualisations will inspire water managers and designers to organise the operational logic of the Hybridity Design Approach, which leads eventually to a combined language, shared method, and integrated scales (Hooimeijer and Maring 2018). The visualised outcomes are expected to simplify the explanatory presentation for multi-stakeholders planning, and thus support the decision-making process.

Pre-requisite for Hybridity Design Approach is a legal planning system that allows for transdisciplinary and multi-stakeholder collaboration in the planning process and the willingness of the urban designers and water managers to co-create the plan. Tradition, organisational culture, regulations, existing policies, lack of experience and lack of time and energy to overcome the barriers of this co-creation process can hinder or even prevent effective cooperation. Despite the fact that the Hybridity Design Approach as presented here can help to overcome some of these hurdles, other barriers just have to be levelled out by the willingness of the participants to make a breakthrough for the benefit of the environmental and spatial quality of the final plan.

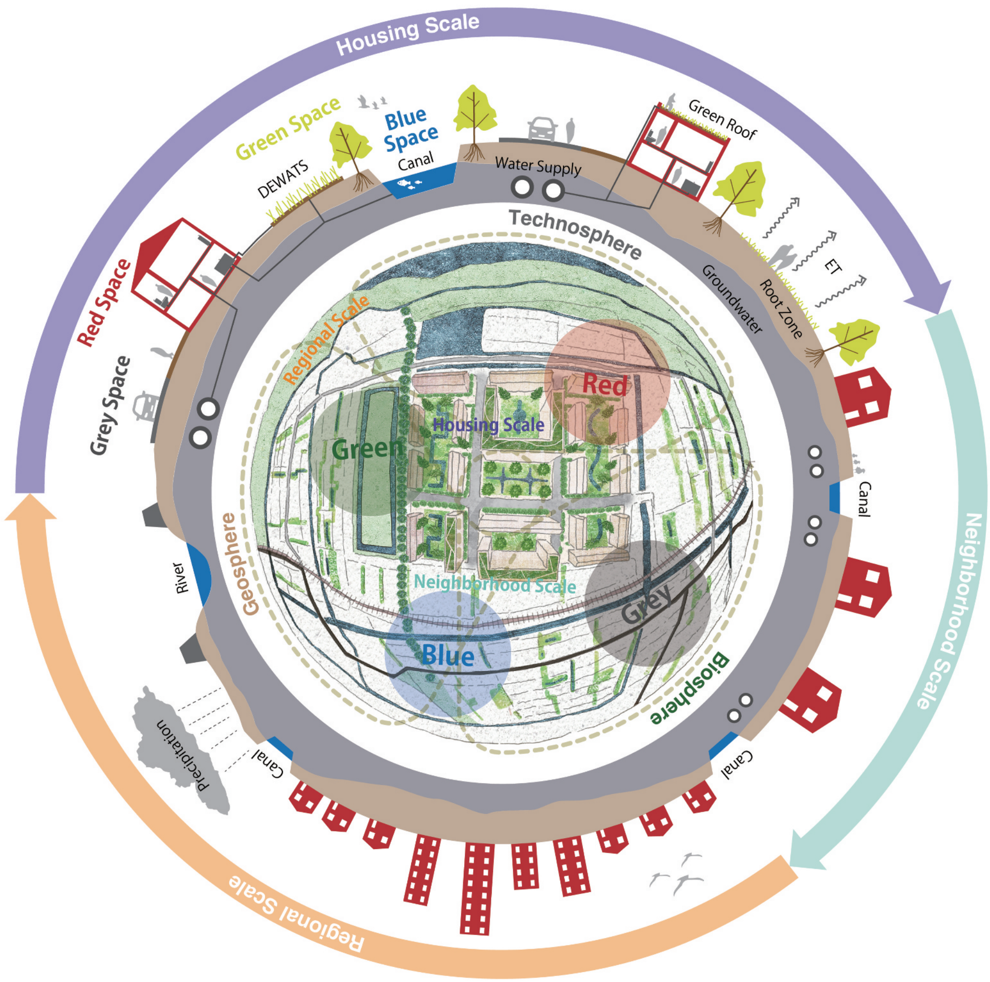


Figure 12. A future image of urban design adopting the Hybridity Design Approach.

Conclusion

The resilience of water cities in response to climate change can be improved by collaboration of water management and spatial design. The position of the city in the water system (upstream, mid-stream, and downstream) and the level of land are crucial aspects for proper urban design. From an interdisciplinary perspective, the starting point is an urban design with high legibility of water systems, which not only creates diverse water (circular) flows and thus reduces the environmental footprint of the city, but also helps people get an understanding of urban structures. However, this paper takes the downstream and low-lying Dutch polder city as a study case, which has a higher hybridity than cities that have a water system that is making use of gravity for discharge. Therefore, it is a good case to learn from since it is more complex.

This paper introduces the Hybridity Design Approach as an interdisciplinary design approach to realise the Closed City Concept, a water-resilient urban prototype rooted in Dutch polder landscape and water management. The main purpose is to value water as the cornerstone in urban (re)development, based on which the natural environment and human society can be integrated.

Main conclusions can be drawn from the application of the Hybridity Design Approach. First, based on a review of previous studies, Hybridity Design was defined, accommodated with indicators of environmental – and spatial hybridity. A workflow to integrate the perspectives of water environment and spatial design was tested in Zevenkamp. The workflow is important to include and integrate knowledge and ideas from both perspectives, step by step. This makes for a genuine design process and not the mere application of solutions. Both the indicators and the workflow are open for discussion and further elaboration. The Hybridity Design Approach can be considered as an interdisciplinary approach that provides dialogues between water managers and urban designers, and quantifies the robust quality of a design from both perspectives.

Second, the Hybridity Design Approach was (virtually) tested and evaluated by applying the Closed City Concept to a real setting. The study shows that the fundamental basis created by the Hybridity Design Approach can bridge water management and urban design through (hybridity) analysis. This is the basis to perform urban design which is the integration of local stakeholders' interest, with the local qualities in a new resilient future. The results for the Zevenkamp case indicate that spatial hybridity and environmental hybridity are intertwined across different elements and can be bridged smartly by system and spatial cooperation. Their connections and impacts on each other can finally have a positive influence on the performance of urban water systems in terms of closing water cycles. It was found that enhancing spatial hybridity does not simultaneously enhance environmental hybridity, and vice versa. In other words, the evaluation results do not indicate the best solution, but provide a basis for determining what is most favourable for local contexts not only within polder cities but also within river or *boezem* cities through interdisciplinary discussion. It is the new knowledge that emerges in the course of these discussions, which is the hybrid product of the two disciplines.

In addition, recent urban challenges such as climate change, urban sprawl, and water scarcity must be addressed holistically, while in this study, the core among these issues is recognized as the dynamic connection between urban water and land. From a perspective of interdisciplinary collaboration, the Hybridity Design Approach is introduced and expected to be inspirational to address the complexity of urban challenges holistically.

Sustainable water environment will be realised by implementing the results of this study in concrete spaces as urban design and through continuous management. This will require the participation of various stakeholders in the Hybridity Design Approach. Experience in the application of Hybridity Design Approach is to be built up by testing it in many practical cases; in this way the practitioners will also learn how to overcome the many potential barriers that can hinder the co-creation process. Only "learning by doing" can help here, as these barriers are unique in each specific case.

Finally, a blueprint for a future Closed City in which the Hybridity Design Approach is applied is presented as a summary of this study (Figure 12).

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