Hybridity vs Closed City

A study about the impact of applying "Hybridity" as a concept of understanding in designing a decentralized water circulation urban model called "Closed City"

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Hybridity vs **Closed City**

A study about the impact of applying "Hybridity" as a concept of understanding in designing a decentralized water circulation urban model called "Closed City"

Delft Infrastructures & Mobility Initiative

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1. Introduction

The hydrological cycle crosses three environments: the geosphere, the biosphere, and the technosphere. The geosphere is the collective name for lithosphere, hydrosphere and atmosphere. The technosphere is the part of environment composed by wide variety of technological artefacts and the biosphere is composed of all ecosystems.

These spheres can't be analyzed and described separately but need to be understood as one hybrid space. Hybridity is defined as a system that is composed out of several separated systems [1][2][3]. Not only the spheres are hybrid, also the separated spheres, like the hydrosphere, or the hydrological cycle in urban areas consists of two systems, the natural water system and the water chain, are intertwined in a new hybrid system. The natural system of ground, open and rain water is also partly artificial in the Netherlands due to the pumping of polders. The water chain of drinking and sewer water is connected to the natural system because it also discharges rainwater (Figure 1.1). In order to be able to intervene in this system it needs to be described and analyzed to be understood. Moreover, it needs to be linked to urban space and quality to be able to harmonize urban development and water management.

The urgency at the core of this study is the contemporary issue of climate change and consequently the changing hydrological cycle. To deal with pluvial flooding in cities, reduce energy use by introducing decentralized sewer systems, improve water quality by separated sewer systems and introducing blue-green infrastructure this study aims to give proper understanding and means to improve the water system, the water chain and urban quality simultaneously.

One of the concepts to deal with water excess

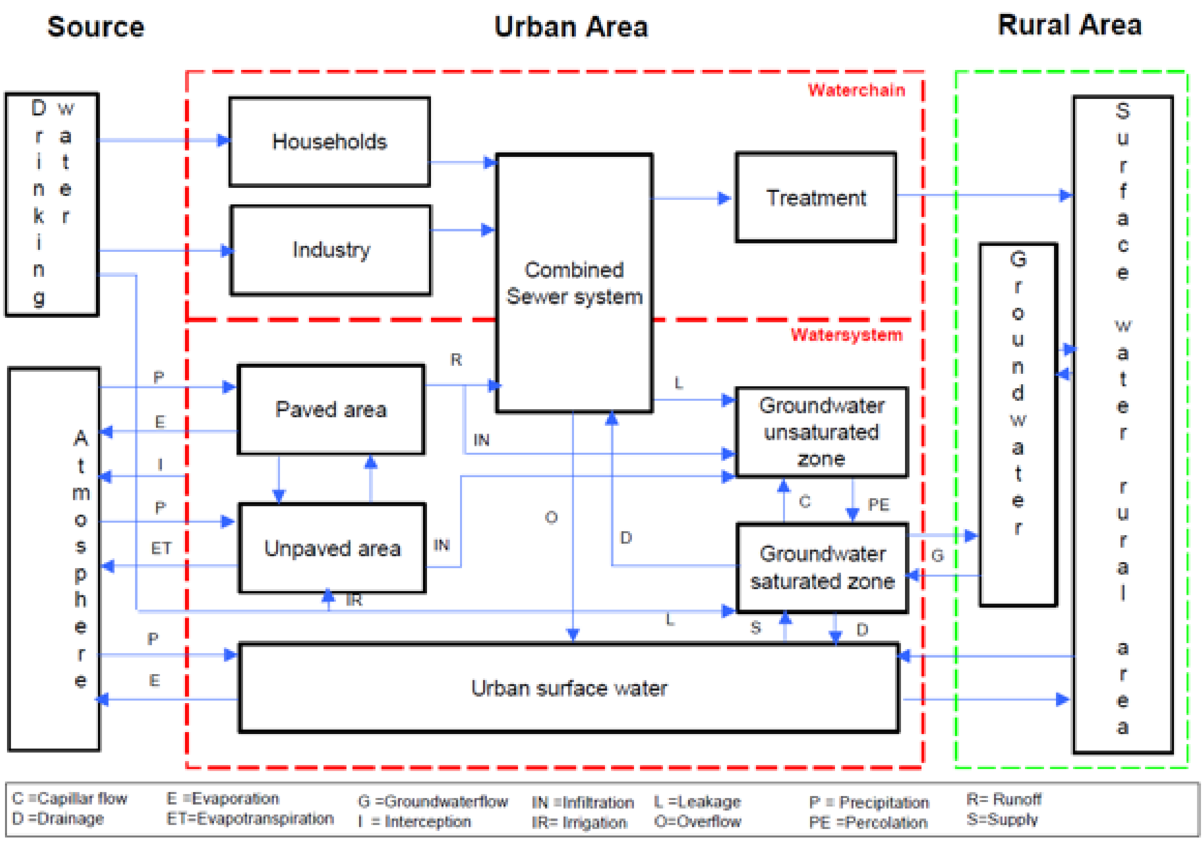


Figure 1.1: Artificial vs Natural

and energy use reduction is the application of a decentralized water circulation system called "Closed City", which was presented in 2005 [4]. Closed City is defined as “a city that does not have adverse effects on its surroundings, such as water depletion or emission of pollution”. This proposal is to improve the water storage and water purification capacity of cities, to store and recycle rainwater and sewage. This is believed possible by creating a self-sustaining water circulation system that responds to water shortages and floods.

When applying these new water cycles to urban areas, it is important to evaluate the applicability and performance of Closed City in the urban hybrid system. The urban hybrid system is defined as "Environmental Hybridity" that evaluates the relationship among the geosphere, biosphere and technosphere, and "Spatial Hybridity" that evaluates visual perception of the water system and water chain as part of urban space.

The main research question guiding this research is: how can the Closed City concept be understood and applied for designing the city as a hybrid construction?

This research is conducted by the following four steps (Figure 1.2): 1) the definition and evaluation method of environmental and spatial hybridity, and also the evaluation method of performance of Closed City are presented in chapter 3; 2) the process of collaborative design for Closed City by applying hybridity is presented in chapter 4; 3) the current situation and five future visions for Closed City based on collaborative design process are evaluated from three viewpoints of environmental hybridity, spatial hybridity and performance in chapter 5; 4) finally each vision is compared and discussed in chapter 6.

The study area is Zevenkamp in Rotterdam, the Netherlands (Figure 1.3). In Rotterdam, the municipality and the Water Board use "Waterplan 2 Rotterdam" to promote projects on water storage, water quality, protection from water, with the main aim to realize a waterproof city [5]. Several projects have already been implemented, but still many of the districts are under development, which is appropriate for the study. Especially the fact that in Zevenkamp, which was developed in the 1970s, is awaiting urban renewal to deal with renovation and social and economic issues, which makes it a good case.

Figure 1.3: Research site

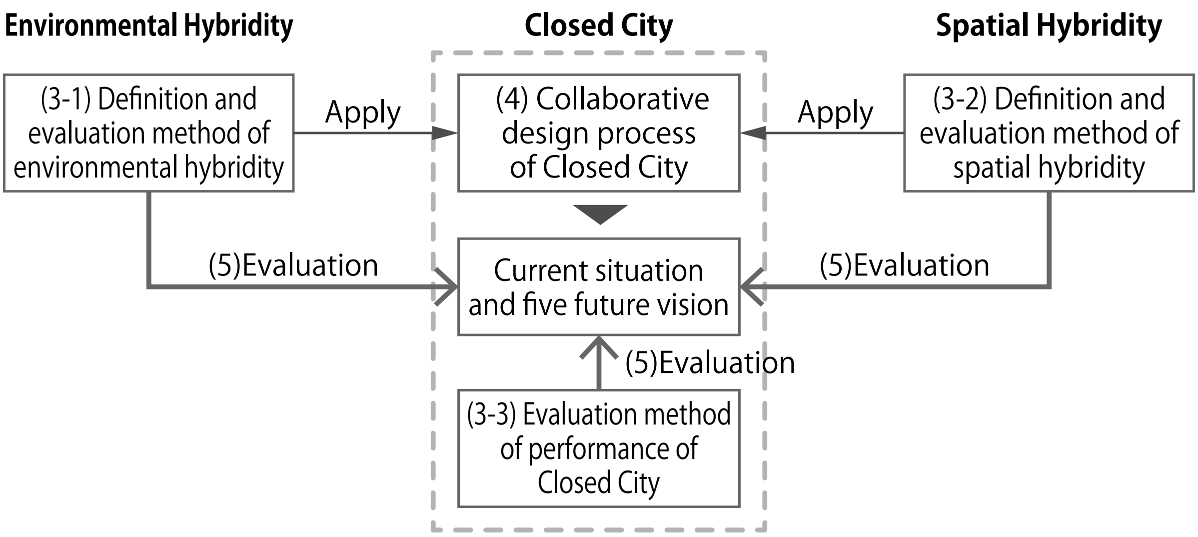


Figure 1.2: Framework of this research

2. Theoretical framework

Integrated Urban Water Management (IUWM) approach is now becoming widely-accepted to push forward the paradigm shift, providing the potential to satisfy the water demand of cities at the lowest costs while minimizing adverse environmental and social impacts [6]. IUWM is nested within the framework of Integrated Water Resources Management (IWRM), which gives an outlook for consideration over the entire water cycle, thus the idea of IUWM is to treat urban water system in a holistic manner [7], aiming at improved availability of and access to water facilities, and minimized negative impacts on water.

Based on the understandings of Global Water Partnership (GWP), an international organization that advocates IWRM as the main guideline of its operation, the intentions of IUWM can be translated into five principles [6][8][9].

First is involving all key players. Since the fragmentation of institutions is considered to be the main barrier, IUWM proposes to identify all the key stakeholders and involve them through planning, decision-making, implementation and monitoring processes continuously. The role and responsibility of each stakeholder should be clear.

Second is considering the entire urban water system holistically. Conventional water chain should be replaced by a circular way, in which each water component is part of a plan instead of isolated activity. The improved approach also has the potential to be contextualized into a broader basin scale water management framework.

Third is assessing a portfolio of water resources. To form a circular water loop, different water resources within urban catchment can be considered as potential sources, and they should be connected. By diversifying different water flows, IUWM recommends to take water quality into account so that different water quality can match different purposes.

Fourth is maximizing benefits from waste. Now that wastewater could be potential resource, reusing at local scale may be the most suitable way considering the transportation costs. In this case, decentralized systems would be promising for productive use.

Fifth is designing adaptive systems. There are still uncertainties in the future, such as climate change and demographic change. When developing IUWM strategies, the resilience of cities needs to be reserved to confront these uncertainties. Hence, urban water systems should not only be robust enough to solve existing problems, but also be flexible to cope with changing conditions in the future.

Among many researches on discussing IUWM approaches, the concept of Closed City is proposed for transitions to more sustainable urban water management within Dutch urban contexts [4]. A Closed City refers to "a city that does not have adverse effects on its surroundings, such as water depletion or emission of pollution". In the Closed City, the value of local water resources are treasured, such as storm water and treated wastewater. These water flows can be recycled through either centralized or decentralized solutions. Based on the selected solutions, three

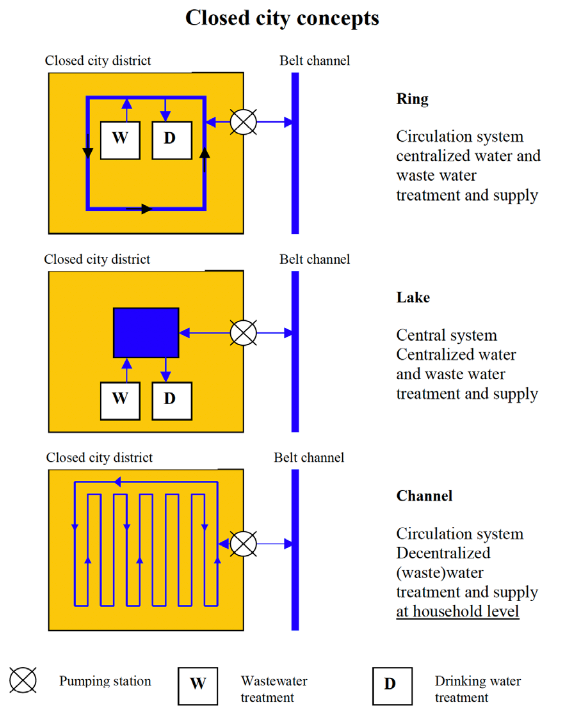


Figure 2.1: Closed city concepts [1], p.81

possible urban layouts are consequently discussed, which are presented in Figure 2.1.

The first layout is the ring type. A ring canal is structured for a circulated system. Centralized waste water treatment plant (WWTP) is located at the upstream, discharging treated wastewater into the canal, while the drinking water treatment plant stands at the downstream of the flow. This system involves the natural purifying function of surface water by adding the pumping station at the end of the canal so that adverse impacts on surrounding areas are reduced.

The second layout is the lake type. A central lake is created in the district, which is the main source of local water supply. Centralized WWTP and drinking water treatment plant are constructed, while the surplus water will be pumped outside. Besides the expected function to reduce water stress, the central lake is assumed to offer extra recreational values for local residents.

The third layout is the channel type. Longer canals are constructed for a circulated system. The use of longer canals is to connect all households to the surface water to facilitate decentralized wastewater treatment and water supply systems, which is different from the other two types of layouts. Decentralized solutions could be either grey infrastructures (e.g. settling basin) or green infrastructures (e.g. reed bed filter).

The application of either grey or green solutions in the proposal of Closed City refers to one extensively discussed issue in recent years, which is the trade-off between grey and green infrastructures. According to the 2018 UN World Water Development Report [10], green infrastructures are the application of nature-based solution (NBS), of which the feature is "proactively manage natural processes to achieve a water-related objective". Plants and vegetation are indeed water recyclers instead of water consumers [11], so that NBS are able to secure water availability, improve water quality and reduce water-related risks.

NBS also calls for a more integrated water resources management, and two tools are appreciated to be normally employed, which are integrated land use planning and IWRM [10]. Therefore, in this report, the performance of grey and green infrastructures in urban water systems will also be discussed, to examine how they can contribute to sustainable water systems.

From the above, the proposal of Closed City has deep relation with two discourses of IUWM and NBS, and its possible layouts could considerably decrease the vulnerability of cities to face climate change [4].

However, there may be some questions remaining to realize this conceptual model on existing urban areas. According to Hooimeijer et al.[12], existing urban areas have already been created with natural and human systems which are inter-connected and linking all living creatures, resources and spaces integrally. Therefore, when thinking about a new water cycle, it is important to evaluate the connection of various environments existing in human-natural systems. Also, when integrating various elements included in such environments as one, urban design is required for giving discontinuous spaces continuity.

In this research, in addition to Closed City concept based on IUWM and NBS, the indicator of hybridity is presented to evaluate the relationship among human-natural system and visual perception of this relation as harmonized space, while applying Closed City concept to existing urban area.

3. Methodology

In this chapter, the definition and evaluation method of environmental and spatial hybridity, and also the evaluation method of performance of Closed City are presented.

3-1. Environmental Hybridity

Environmental hybridity in this research refers to the three spheres, the geosphere, the biosphere, and the technosphere, and their participation in the water system and water chain. These spheres are not separated, they are within the same space and interact with each other. Since the nature and humans are the beneficiaries when sustainable development is discussed, the three spheres of environmental hybridity in this research should not be considered beyond the boundary of human and nature systems. According to Hooimeijer et al. [12], human and nature systems are inter-connected and they link all the living creatures, resources and spaces integrally.

In Figure 3.1 the relation between the three spheres is shown and indicated which parts are connected to the natural and human system, and which part is connected to both. The artefacts that work within the water system and chain are placed within the defined sub spheres that become specific when drawing the relations between the spheres and systems. The artefacts buildings, streets and pipes belong to technosphere, while atmosphere, groundwater and rivers/lakes can be included in geosphere, and biosphere consists of fauna and flora. The most vital message here is that the three spheres are intertwined and their interaction defines new sub spheres that are in relation to natural and human systems can become quite specific. The new sub-spheres that consist

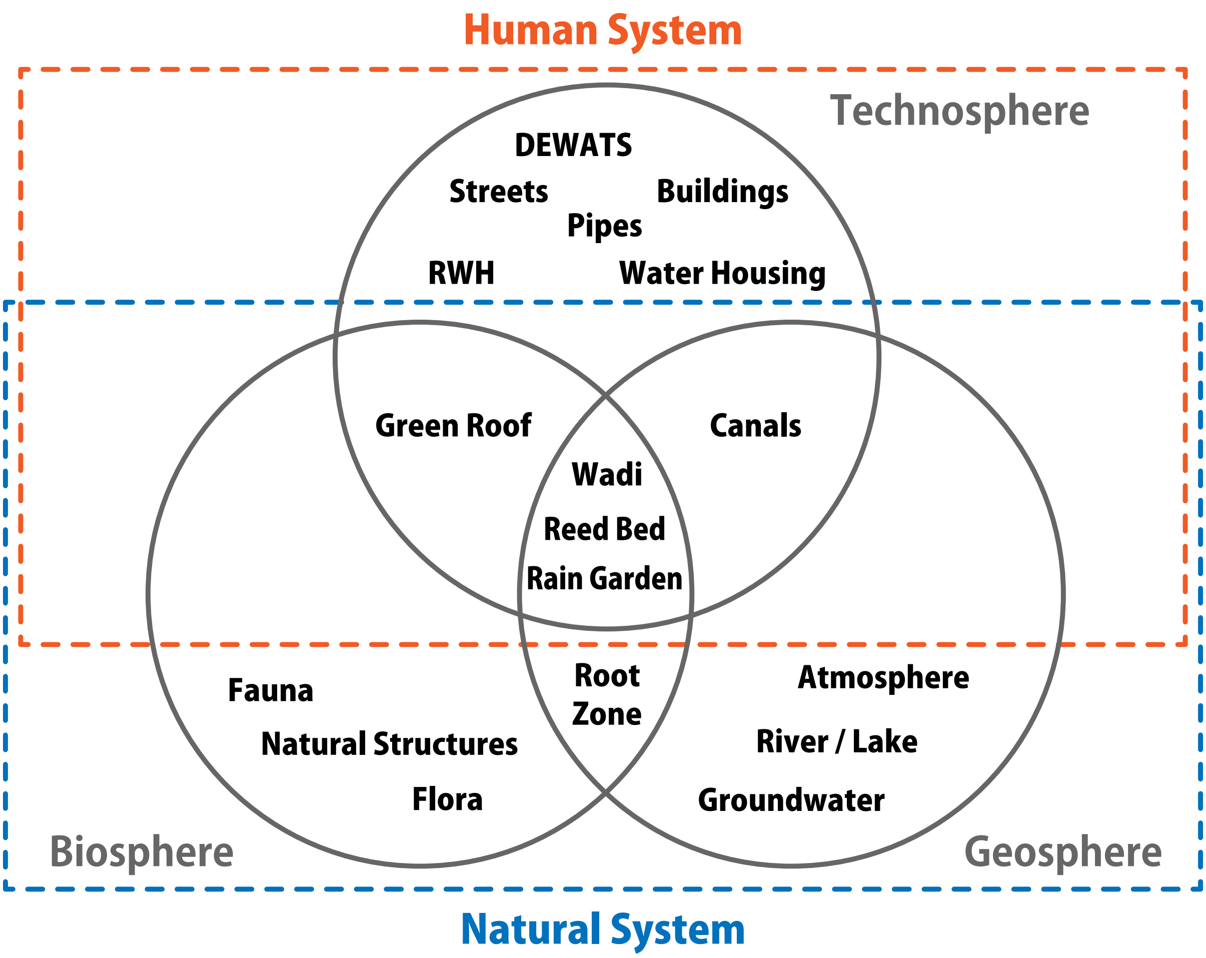


Figure 3.1: Relation of the three spheres

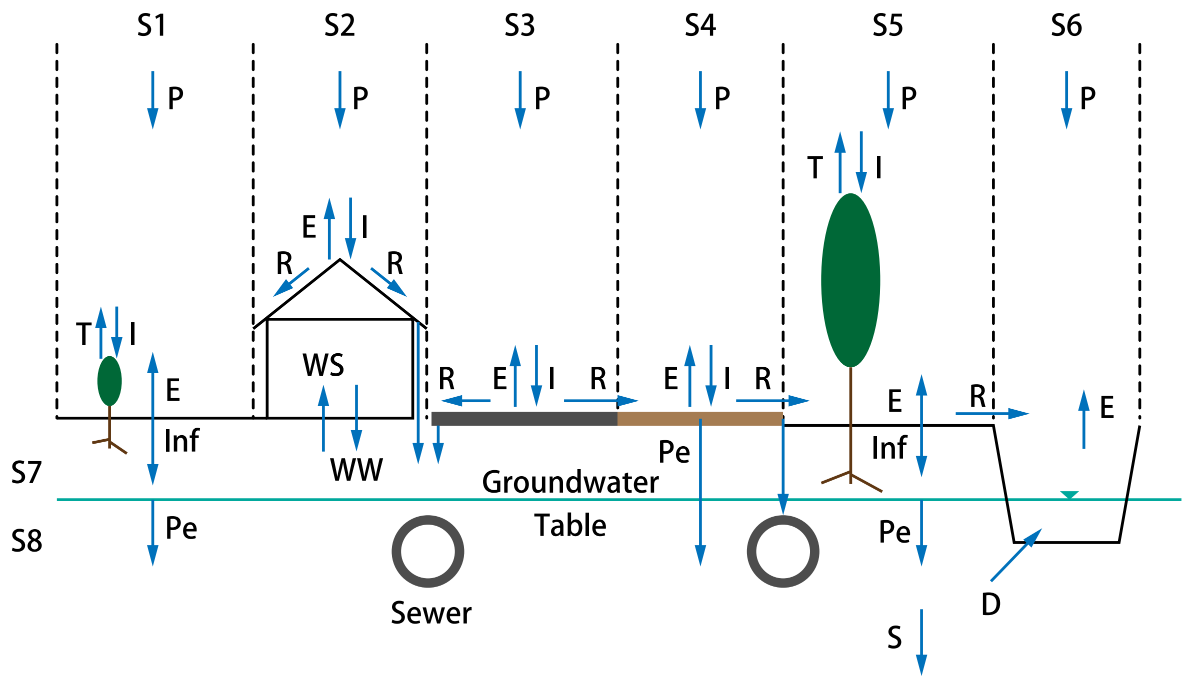
of artefacts involved in urban water systems are described in Chapter 4.

The evaluation of environmental hybridity is carried out by the following three steps:

1) Setting up the water balance model.

To investigate how the three spheres contribute to environmental hybridity and how they are connected by water flows, water balance analysis of the study area is selected as the main method. The water balance analysis is an entry point for investigating urban water systems [13][14]. For studying environmental hybridity, a water balance model is set up to calculate different water flows through the three spheres. From land use identification, the model calculates the water amounts on different land covers according to associated hydrological processes (Figure 3.2).

The water balance model set-up is based on an existing spreadsheet model [15] from Deltares (the Dutch research institute on delta issues). This spreadsheet model only considers the flow pathways in terms of precipitation, so the model was modified by adding water supply and wastewater. The water balance model considers five types of zoning areas, which are buildings, streets, unpaved space, open water and subsurface. At the city scale, there are generally four incoming sources, which are precipitation, water supply, surface water and groundwater. Correspondingly, the outflows are evapotranspiration (ET), wastewater, discharge to outside waters and groundwater recharge. The time laps of the model is one day.



Hydrologic Sectors

S1: Unpaved area - private garden, S2: Paved rooftop, S3: Closed Pavements, S4: Open Pavements, S5: Unpaved area - public green, S6: Open water, S7: Unsaturated zone, S8: Groundwater

Water Flow

P: Precipitation, T: Transpiration, I: Interception, E: Evaporation, R: Run-off, WS: Water Supply, WW: Wastewater, Inf: Infiltration, Pe: Percolation, D: Drainage, and S: Seepage

Figure 3.2: Water flows in differnt land covers

2) Visualizing environmental hybridity

The environmental hybridity is in step two visualized by a Sankey diagram which is based on the water balance results calculated by the model. A Sankey diagram distinguishes different fluxes from their sources to targets, by using the thickness proportionally to illustrate the amount of flows. This is a clear and simple way to visualize the incoming and outgoing flows of different water sectors (Figure 3.3), and directly shows how different land covers are involved in the urban water system. It is also helpful categorizing each component into three spheres and to do the numerical evaluation in following step.

To be consistent with the elements defined in spatial dimension, the colors used for buildings, streets, unpaved area and open water are respectively red, grey, green and blue. In addition, colors are also applied to represent different water flows, blue is the common water, grey color refers to wastewater while green color means ET.

All the Sankey diagrams in this report are produced in python language imported from Plotly [16].

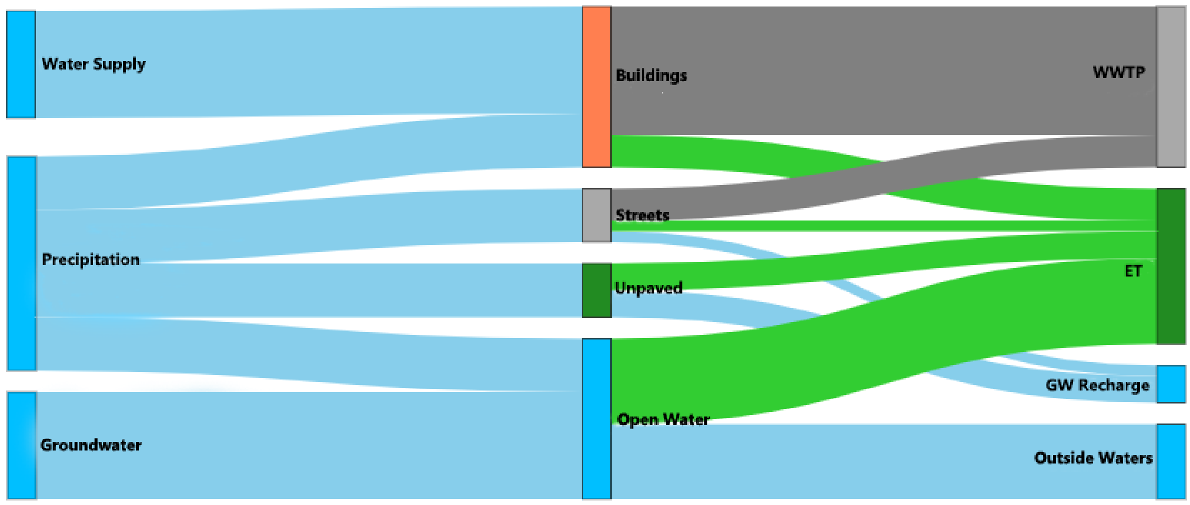


Figure 3.3: Sankey diagram of water balance

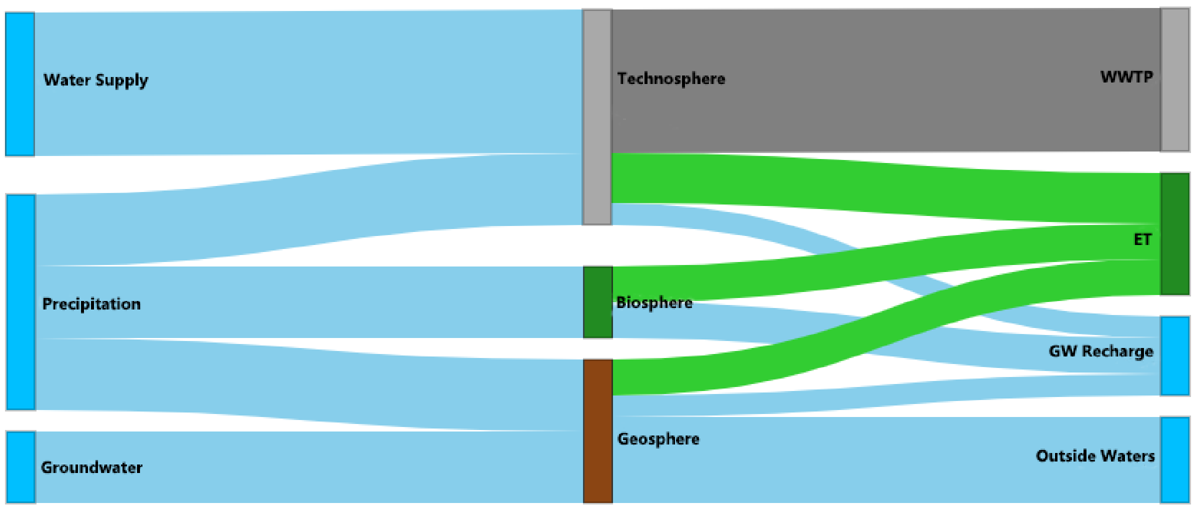


Figure 3.4: Sankey diagram of environmental hybridity

Based on the Sankey diagram in which the water flows are visualized, the different water sectors can then be categorized according to the three spheres that shape environmental hybridity. For this new categorization in there spheres the Sankey diagram is again used to visualize.
This enables the examination of the different water flows involved in each sphere and thus the level of environmental hybridity (Figure 3.4).
Whilst making the visualizations, a distinct quantity gap is observed between inflows and outflows of technosphere, i.e. the wastewater amount is much smaller than the sum of incoming drinking water and rainfall. By data analysis and model verification, the main cause is found in the fact that water supply and wastewater are managed by different organizations. While the amount of drinking water is measured by water supply company, the wastewater is calculated by water board on the base of empirical values. In addition, there is also a small quantity gap observed between bio-geosphere and geosphere, this could be attributed to moisture change in the soil.
One thing that should be mentioned is that all flows in the produced Sankey diagram are from left to right. In the case of recycling water, the visualized method is simply to add the solutions on the left side of the diagram. This drawback of the tool that is applied from Plotly, causes some quantity gaps in the proposed green solutions.
It would be better if water circulation could be illustrated in a Sankey diagram. For future analysis, an innovation of Sankey diagram is recommended.

3) Evaluation of the environmental hybridity.

The Sankey diagram that shows the environmental hybridity is summarized into a chart for evaluation (Figure 3.5). From this chart, spheres are connected by arrows, which indicate the flow direction. In addition, the overlapped spheres are also considered as one unit in the chart. In particular, the techno-bio-geosphere

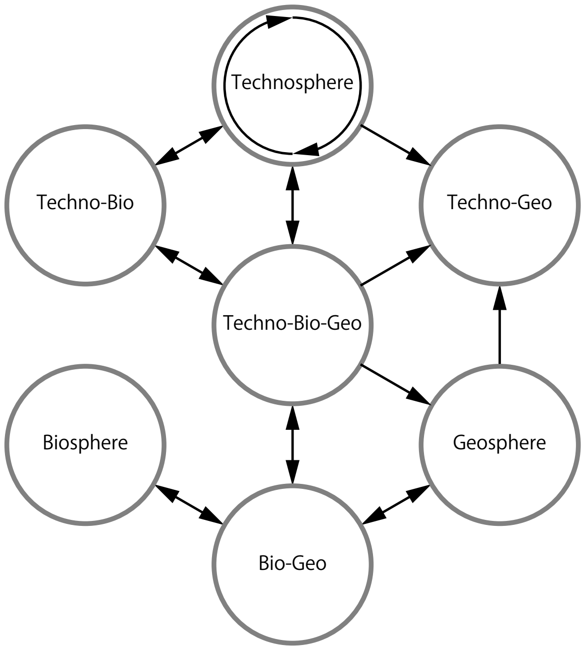


Figure 3.5: Environmental hybridity chart

(T-B-G) is the overlapped part among all the three spheres. Therefore, if the chart illustrates that the more spheres and connections are involved, the relations among three spheres are closer and tighter. If the water amount distributed to each sphere is balanced, then each sphere is equally important and one can be the alternative pathway in the case failure occurs in other spheres, thus the environmental hybridity is high.

Four indicators are set to assess the environmental hybridity. The first is the number of involved spheres, which are counted in the hybridity chart. If more spheres can be involved, then the connections are more diverse, and therefore the environmental hybridity is higher. Second indicator is the amount of connections that can be drawn on the chart after the involved spheres have been determined. Then the number of arrows is determining the environmental hybridity. The third indicator is the amount of bi-directional connections. As shown in Figure 3.5, connections (i.e. arrows) between two spheres can be bi-directional, which means there is flow exchange. This infers that the two spheres are dependent on each other and these bi-directional linkages could contribute to a robust water system. The number of bi-directional connections (in pairs) is defining the environmental hybridity, the more the higher. The fourth indicator is the balance of water distributed to each sphere. If water that flows through each sphere is not balanced, almost all the water is involved in only one sphere, then the water system relies on this specific sphere. The system thus will be less robust if failure occurs in that sphere. Hence, each sphere should be the same importance to the water system. The balance of water distribution is shown by calculating the standard deviation of involved water quantity in each sphere. Water quantities are calculated by the water balance model. The environmental hybridity is higher if deviation number is lower.

3-2. Spatial Hybridity

The creation of urban space over time is the result of the re-composition of the original landscape, addition of urban systems and occupation patterns. The city is the ultimate example of hybridity of which the environmental hybridity is the conditional set of spheres and which until the Industrial Revolution shaped the urban composition [17]. The separation of the environmental hybridity from urban development was done by thriving engineering, today, with the climate change it is urgent to reintegrate environmental and spatial hybridity to deal with the effects of climate change. Hence the aim of this research.

Two aspects of spatial hybridity (and urban design) which enable cross-over to environmental hybridity are the linking of scales and legibility. The linking of scales is both in urban design and water management key because in both systems the small scale is defined by the large scale and vice versa. For example infrastructure consists of a large network and the size or profile of a street is defined by its position in this network: a provincial street is wider and has less exits. The diversity of profiles that represent certain scales helps people's recognition and behavior accordingly.

Legibility is the visual aspect that makes functions or meaning evident. On the scale of urban design this is accomplished by the design of the main urban structure and the positioning of functions. Kevin Lynch [18] describes a method analyses in which a series of elements — nodes, edges, landmarks, etc. — make an area legible or not.

Even if the flow of water is invisible, it can be made legible by spatial elements part of the water system.

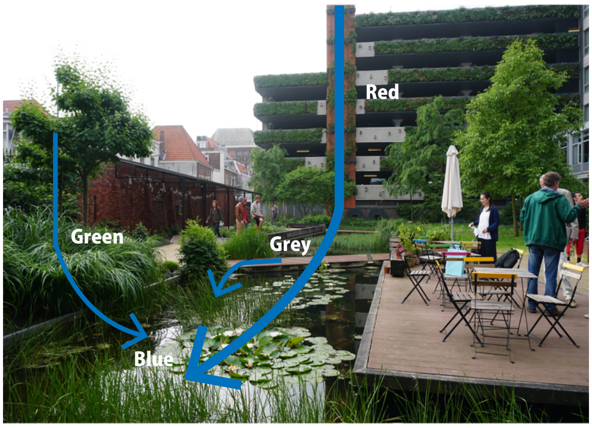


Figure 3.6: Example of legibility in the garden of Nutshuis

This can be illustrated by using the garden of Het Nutshuis in The Hague, the Netherlands as an example (Figure 3.6). Here, a drainpipe connected to a pond in the garden is designed on the facade of the building, and it is possible to recognize the connection of the building and surface water. On the surface of the bridge over the pond, gutters are attached in the direction perpendicular to the bridge, so that rainwater is discharged into the pond, and it is possible to recognize the connection of the bridge and surface water. Plants are planted on the waterside and in the lake, and it is possible to acknowledge the connection of green and surface water. In this way, there are relationship between four different spatial elements such as red space representing buildings, green space representing plants and green, blue space representing the open water of canals, waterways, ponds, lakes, rivers, and gray space representing streets and bridges in this garden.

For this research, the legibility is defined as “the collective area of viewpoints from where different spatial elements of the water system are visible”. From this definition the analyses in legibility will be done by examining the connectivity and visibility of the water system in the urban area.

The evaluation of spatial hybridity is carried out by the following three steps: Identification, Visualization and Evaluation.

1) Identification of the legibility of the water system in the area by assessing the connectivity and visibility, and classification into three scales. In identifying the legible area, first, the flow of water is grasped by using water balance model, which is explained in Chapter 3-1, and are categorized how red, green, blue, and gray spaces are connected via the water flow. Then, the legibility of water management in the area is identified by analyzing visibility of spatial elements in each type of connection.

For examining the visibility, the region of the eye-range from the average eye level of the Dutch people is identified (Figure 3.7). It is assumed that the spatial elements within the eye-range are visible. Specifically, the average eye level height of the Dutch people is set to h = 1.65 m, the central visual field is set to θ=30° in both right and left [19], and the central depression angle is set to 10°(θ'= 80° [20]. Since the average height of the Dutch people is 1.83m for men and 1.70 m for women [21], the average value of 1.77 m is taken as the average height. Since the difference between height and eye level is about 12 cm, the average eye level height is 1.65 m [22].

It became clear that the eye-range concentrates on

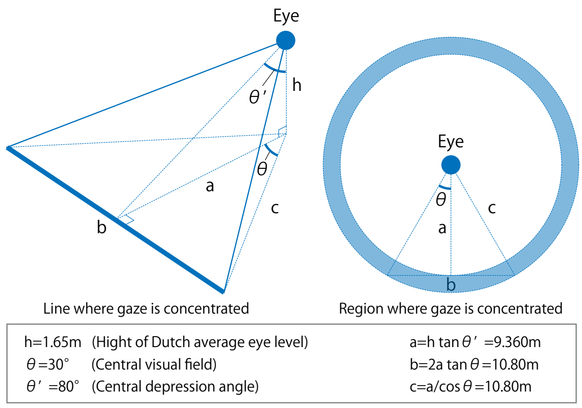


Figure 3.7: Method of calculating gaze concetrated region

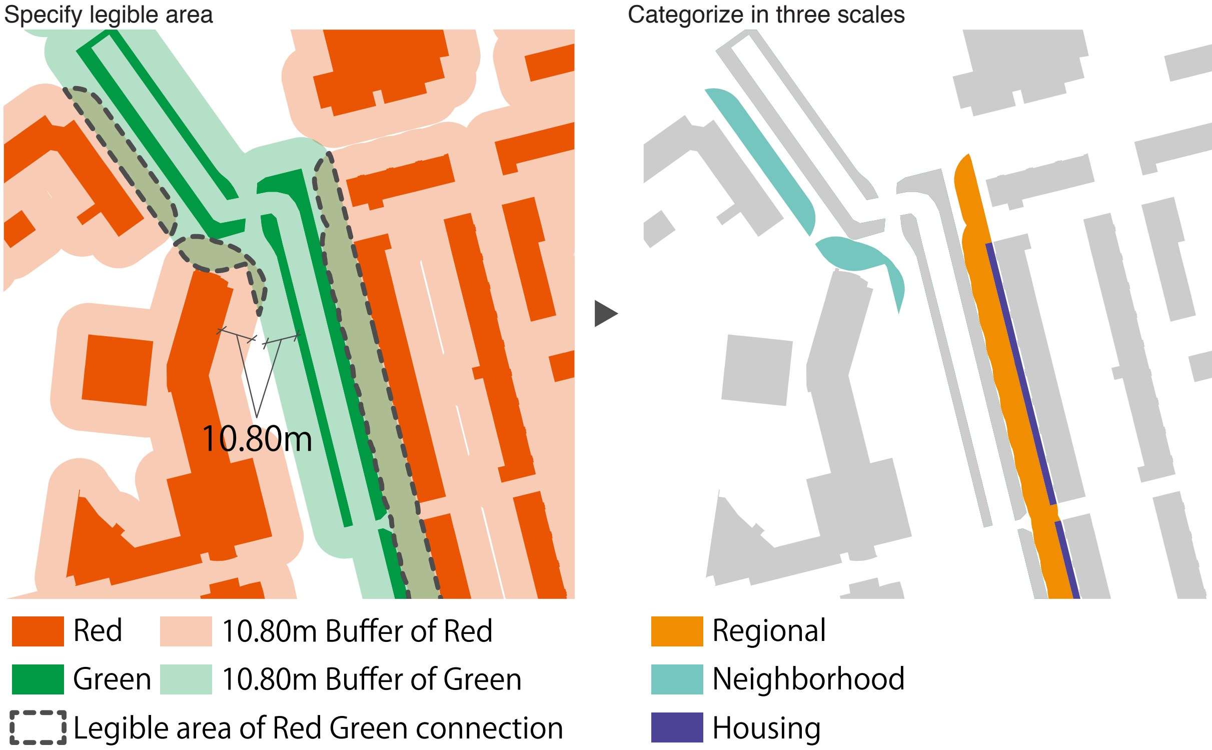


Figure 3.8: Specifying and categorizing legible area

the line of b = 2a tanθ = 10.80 m, which is at a distance of a=h tanθ'= 9.36 m from the viewpoint (Figure 3.7). Also, on the assumption that 360° rotation is possible at the viewpoint, a region excepting a circle with a radius of 9.36 m from a circle with a radius of 10.80 m was regarded as a region where the eye-range is concentrated. From the above, it was assumed that the spatial elements can be visible in the area within 10.80 m from them. Therefore, regions of 10.80 m are specified for each spatial element connected via the water flow, and the regions where these are overlapped are specified as the legible area. (Figure 3.8)

In the classification into three scales to assess the legibility is set on the regional, neighborhood and housing scale. The regional scale is recognized on the street level by the street profile and public green along the infrastructure that has through going connections beyond the urban area such as canal, tram line, highway and green axis [17] (Figure 3.9). The neighborhood scale is represented by all other streets and public green. The housing scale is set to the house and private garden.

2) The next step is visualization of the continuity and diversity of the legibility in the area by using Arc GIS 10.5. The network of the legibility elements is visualized by displaying all categories identified in the first step on the map with the same color (Figure 3.10). The positional relationship of each scale is visualized by displaying in different colors (Figure 3.11). Also, the overlapped area of different categories are visualized by displaying legibility categories in the same color and same transparency (Figure 3.12). It is helpful to examine whether the numerical value, which is calculated in following step, accurately reflects the spatial characteristics.

3) The last and third step is the numerical evaluation of the continuity and diversity of the legibility of the water system in the area. For the evaluation of continuity, the amount of the legibility in the area and the balance of the three scales are used as the

Figure 3.9: Location of regional infrastructure

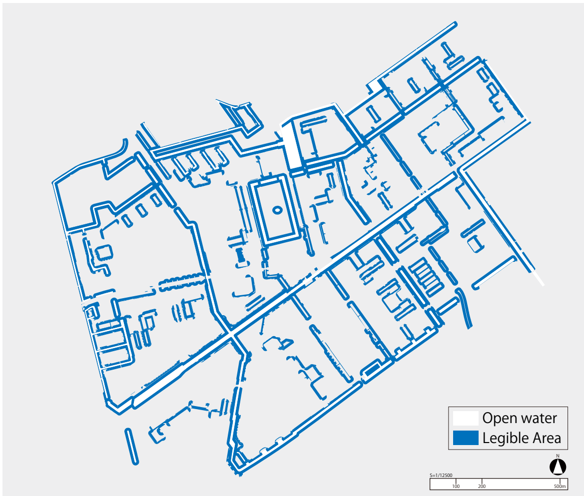


Figure 3.10: Visualizing the sequence of legible area

Figure 3.11: Visualizing the relation between three scale

evaluation indicators. The amount is calculated by the percentage of total legibility categories in whole Zevenkamp area. The balance is calculated by the standard deviation of legibility in each scale. When the value of the amount is larger, there's high possibility to make connection between the legibility categories. Besides, the value of the balance is smaller, each scale can be intertwined. This indicates that the legibility in the area is continuously going through each scale.

The diversity is calculated by the percentage of the sum of all legibility categories. When the value of diversity is larger, it indicates that the categories of legibility are layered, and people can experience more various connections of different spatial elements via the water system.

From the above, numerical values indicating continuity and diversity are calculated for all target cases, and when both are higher, the spatial hybridity is higher.

3-3. Evaluation method of performance of Closed City

The proposal of Closed City concept is trying to reduce the environmental footprint of urban area, as well as its dependence on external water resources. By applying grey and green solutions, occurrence of combined sewer overflow (CSO) is eliminated, thus decreasing emission of pollution. Moreover, these solutions will help circulate potential local water resources such as rainwater and treated wastewater so that water supply could be secured.

Since all the applied solutions eliminated CSO in each future vision shown in chapter 4, in this research, the performance of Closed City will be evaluated in terms of their ability of water circulation, and two indicators are applied for evaluation: quantity of water and number of spheres.

The first indicator is the amount of water circulation and the selected measures used in this research to recycling/reusing rainwater and treated wastewater are: rainwater harvesting system (RWH), decentralized wastewater treatment systems (DEWATS) and reed bed. Therefore, if more local water resources can be collected, then the dependence on external water resources can be reduced.

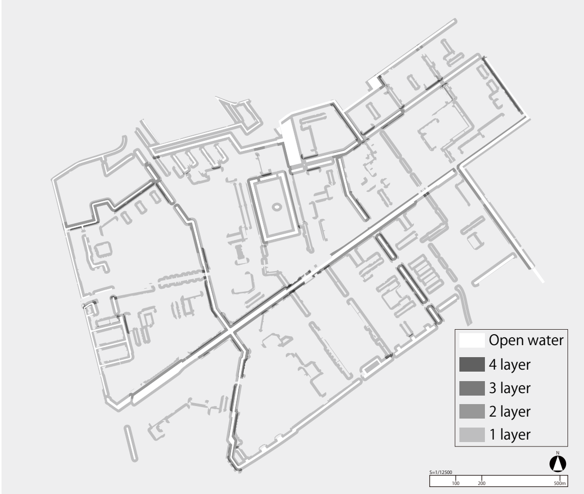


Figure 3.12: Visualizing the diversity

The amount of circulated water from each solution is calculated by water balance model, then the total amount of water circulation is calculated by summing up the amount of all applied solutions in each vision. If more water can be circulated, the performance of Closed City is better.

The second indicator is the number of spheres with internal circulation. The application of RWH and DEWATS are the type of grey infrastructure, thus they belong to the technosphere of environmental hybridity. Collected rainwater and treated waste water will be recycled back to buildings for non-potable use, which are also included in technosphere. Therefore, there would be an internal circulation in technosphere. If pathways for water flows entering technosphere are unfortunately all blocked, the internal circulation would strengthen the ability of technosphere under extreme conditions, and thus make water systems more robust.

The number of spheres with internal circulation is counted from the hybridity chart (Figure 3.5). If one sphere has internal circulation, a rotated arrow will be added on this sphere in the chart. If the number of spheres with internal circulation is higher, then the performance of Closed City is better.
of spheres with internal circulation is higher, then the performance of Closed City is better.

4. Collaborative design process

The design of future urban areas and urban renewal of existing cities need to be done by integrating the environmental hybridity as well as the performance of the natural water system and water chain. This demands a collaborative design process which is executed in this research. The approach towards the case Zevenkamp was first to analyses and understand the hybridity of the environment and the spatial hybridity of the water system and then in projecting new futures for the area by testing the extreme concept of Closed City. This created discussion and synergy as a part of the collaborative design by the two disciplines, water management and urban design.

4-1. Application of the Closed City concept

Before applying the extreme Closed City Concept the hybridity of the urban and environmental system of Zevenkamp is tested by projecting three less extreme visions onto the area. According to the Closed City concept, either grey or green solutions can be employed to solve water-related issues. The three visions are chosen to represent the range from grey to green solutions: mechanical, natural and mixed.

The first is the Mechanical Vision in which all solutions will be grey infrastructures to have optimal control of the water flows through pipes and pumps. The second vision is aiming for all green solutions. The third vision is a mixed version of the mechanical and natural approaches. This beholds both grey and green infrastructures that, however, can be different in percentages. Therefore three Mixed Visions are used, one in which grey solutions are dominant, one in which more green solutions are applied, and the third is a balanced application of grey and green. In this way, five future visions are produced in terms of the types of selected solutions. These five visions represent the gradual change from completely grey solutions to totally green solutions.

The second step was selecting grey and green solutions like the reuse of rainwater and treated wastewater that can be done with RWH, DEWATS and reed beds. To make the area climate-resilient and prevent urban flooding green solutions such as wadi, green roof and rain garden are selected. In addition, existing grey infrastructure can be improved by replacing combined sewer with a separated sewer like storm water drainage system (SWDS).

The third step is finding the potential locations of these solutions. For instance, wadis and reed beds need to be placed in public green area, while rain gardens can go both in public and the private gardens. RWH can be applied on sloping roofs, while green roofs are installed on flat roofs. The location of DEWATS is referred to a pilot-scale project in China [23], in the basement of a building within the neighborhood.

Meanwhile, engineering criteria need to be considered like calculating the capacity of the reed beds which is related to the population number: each person needs approximately 4 m² helophyte and each reed bed needs at least 200 m² [24] [25]. Reed beds and wadis should have connections to open water, while rain gardens have requirements in relation to the buildings, to avoid moisture issues. These criteria are considered for proposing the initial locations of all solutions.

Figure 4.1 shows the original urban structure. Here, the location of green roof and DEWATS, SWDS, RWH, which are installed on the roof top or subsurface, are not shown because evaluation of spatial hybridity in this research focus only on the assessment of visibility from eye level on the ground. The measures on higher levels can be assessed using the method in this research by using viewpoints on other levels.

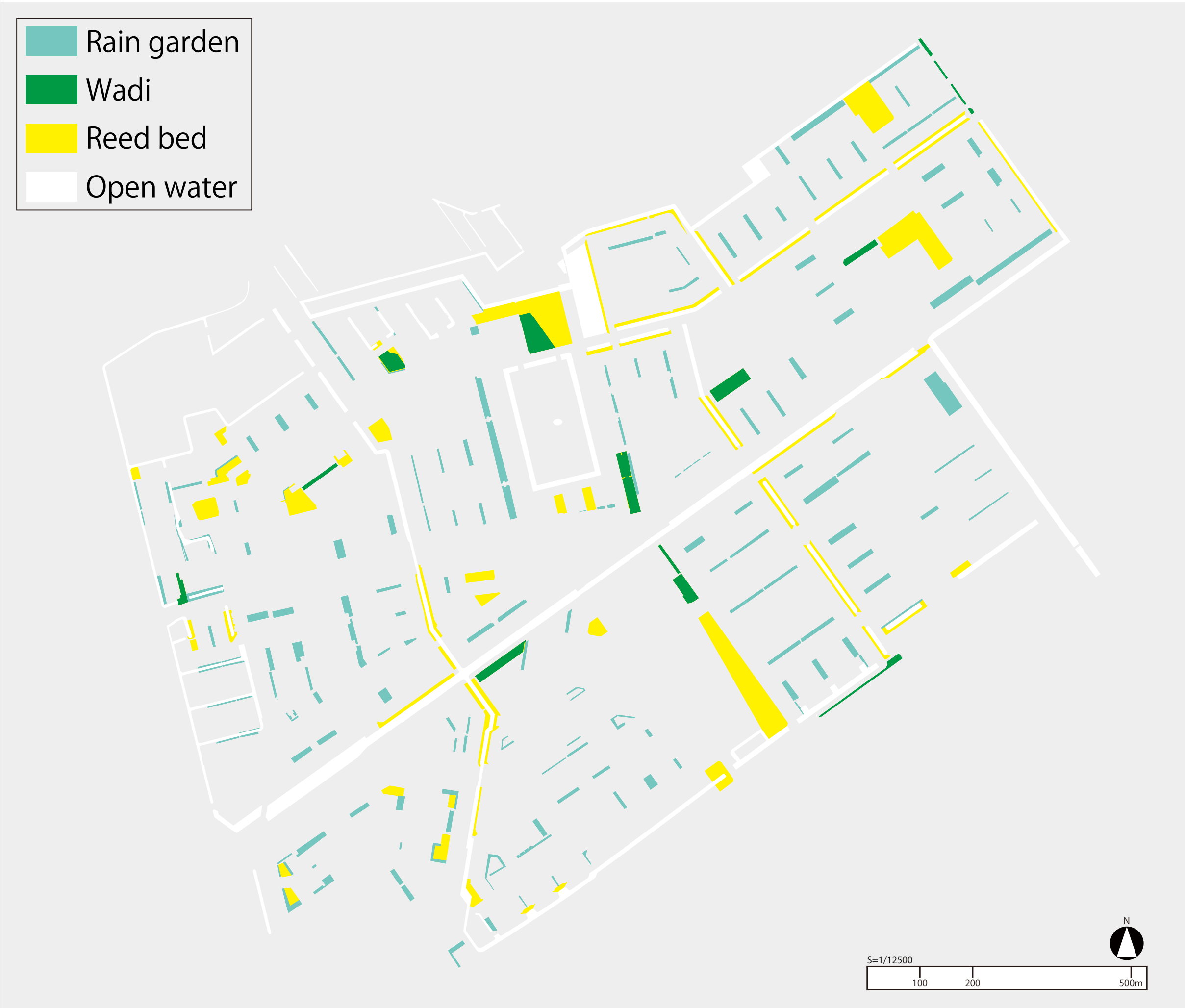


Figure 4.1: Original situation

4-2. Perspective from environmental hybridity

The boundaries and overlap between the three spheres part of the environmental hybridity are used to organize the proposed solutions (Figure 3.1). These solutions are part of the water system and water chain that are also connecting the three spheres, therefore the hybridity is measured on the base of the number of spheres involved.

To make the best start for the case of Zevenkamp, solutions are selected that are not part of the spheres present in the current situation of Zevenkamp, which are the techno-biosphere (T-B) and T-B-G.

The grey infrastructures selected in Chapter 4-1 including DEWATS, SWDS and RWH are all considered as technosphere. For green infrastructures, since they apply natural processes to solve water-related issues, and have pipes installed, most of them are categorized into T-B-G. Therefore, green roofs are selected to enhance environmental hybridity in this case because they are categorized into T-B. As rainwater on the green roof will infiltrate and finally be discharged into drainage pipes, there is no direct connections with geosphere of Zevenkamp area.

Based on this, the selected solutions have the potential to involve all the three spheres and the overlapped parts.

According to the definition of environmental hybridity the more spheres involved, the more opportunities to enhance environmental hybridity. For Zevenkamp, this is done by choosing solutions in the missing spheres

T-B and T-B-G.
The proposed grey infrastructure, DEWATS, RWH and SWDS, are all considered as technosphere. The nature-based solutions, which use natural processes to solve water-related issues, are all dependent on the artificial drainage system, are there for categorized into T-B-G. Green roofs are included in the T-B sphere because the rainwater on the green roof will ultimately be discharged into drainage pipes, thus there is no direct connections with geosphere of Zevenkamp area. By adding green-roofs in Zevenkamp the missing T-B sphere is introduced and enhancing environmental hybridity.

4-3. Perspective from spatial hybridity

For enhancing the spatial hybridity, the initial urban structure is reexamined from the perspective of visibility and continuity.

In terms of visibility, the relocation of DEWATS and RWH are proposed. Treatment facilities of DEWATS are invisible because they are placed in the basement of the buildings and extra water will be discharged to open water through pipes. To make them visible, part of the DEWATS is located in public green area in each neighborhood in a small building, given the name of Water House. This public green is designed as the playground with water pond inspired by the pilot project in China [23], to store the extra water from DEWATS. If it is difficult to transform public green to Water House, such as insufficient space, then the DEWATS will be still placed in the basement of one building in the community. Also the RWH is assumed to store the rainwater in the subsurface tank. Part of this storage tank is decided to be on the ground level. For instance, the configuration of storage facilities could be in the shape of a box so that it can function as a water fence with some plants on it.

In terms of continuity, historical spatial network are giving indications how they could function. Historical structure of Prins Alexanderpolder before urbanization is recognized to have potential for making connections among spatial elements, as well as to show cultural respect to the tradition of making polder cities. This polder structure have the open water network of canals and ditches, and housing, agricultural lands and streets have spatial continuity via the water system. Therefore, historical structure is applied on current spatial structure so that different solutions can create spatial

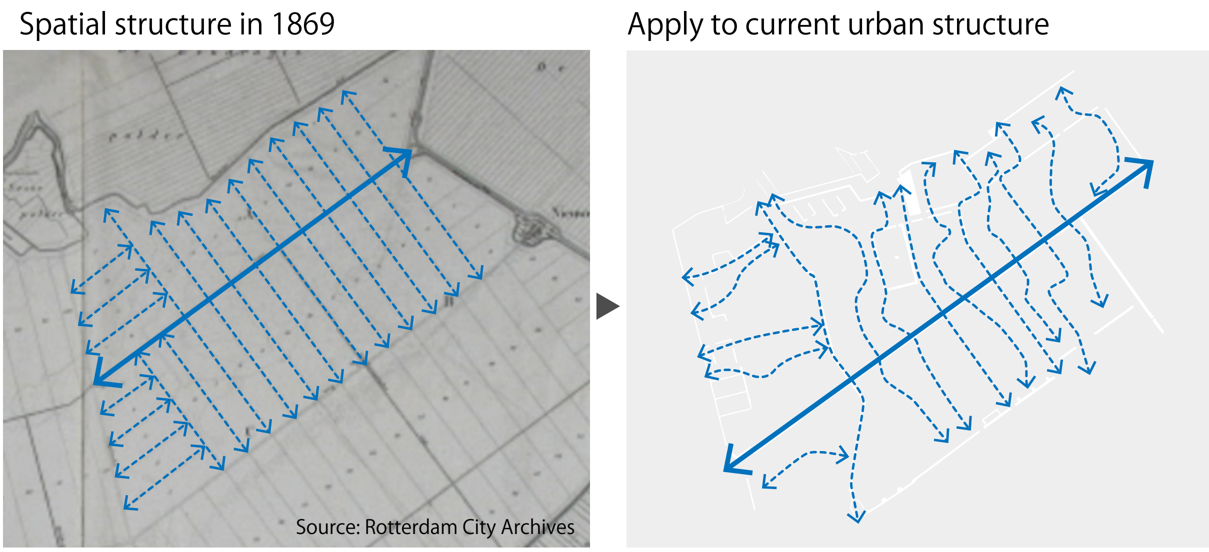


Figure 4.2: Applying historical structure of polder

connections each other (Figure 4.2).

For applying this, it is clarified that solutions have to be also installed along the street which is not proposed as initial location. Some rain gardens are relocated in the front yard of the building. The rain gardens are categorized in two types, one is the common rain garden which is inside district, and the other the front yard rain garden which is along the street. For front yard rain garden, the safety distance (8 m) applied for initial locations is shortened, but still is kept 3 meters away from buildings [26]. For applications in the future, the safe distance needs further investigation. Also, the storage tank of RWH is proposed to be put along the street.

Figure 4.3 shows the urban structures after the design. The proposed location is categorized in four zones, one is along the street for installing front yard garden and RWH of ground type, the second is inside the district for community rain gardens, the third is public gardens for reed beds and wadis. The fourth zone is not visible because RWH and DEWATS of basement type and SWDS are installed in the subsurface, and the green roof is put on the flat roof, which are not shown because of the same reason as Figure 4.1, they are not visible within eye-range. The measures on higher levels can be assessed using the method in this research by using viewpoints on other levels.

Figure 4.3: Urban structure after categorization

5. Evaluation results

In this chapter, the evaluation of the five visions is presented along the three analyses of environmental hybridity, spatial hybridity and performance as Closed City.

5-1. Current Situation

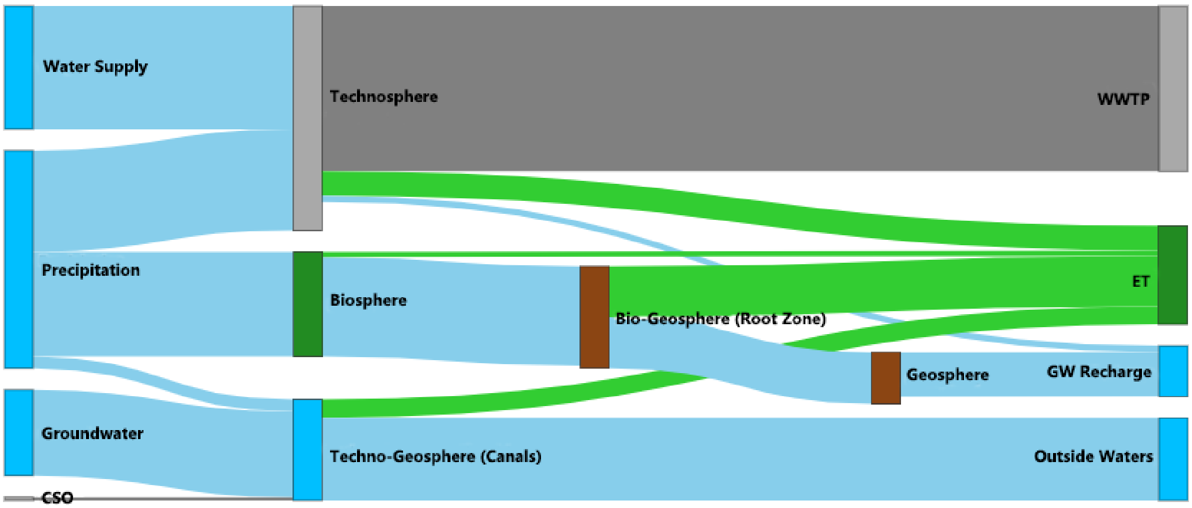
The technosphere includes all buildings, pavements and subsurface infrastructure. Hence, sewer overflows can be considered as outflows from technosphere, creating a quality hazard in the open water system. The unpaved surface, or open soil, is recognized as biosphere, which creates infiltration and evaporation capacity. The infiltrated water enters the root zone, which is defined as the overlapped part of bio-geosphere (B-G). Two outflows from the root zone are the transpiration of vegetation and seepage to deeper subsurface area, the geosphere. From geosphere, the water will be stored for groundwater recharge. It should be noted that the incoming groundwater drainage is also from the geosphere. The canals are categorized into overlapped part of techno-geosphere (T-G), because they are man-made rivers.

The environmental hybridity is composed out of five spheres which are the technosphere, the biosphere, the geosphere, the T-G and B-G. Due to the fact that the use of green solutions in the current system in Zevenkamp is limited, two spheres T-G-B and T-B are not used. There are now six connections in total, represented in the arrows, However, the dashed line arrow from the technosphere to T-G represents the CSO occurrence. There are two pairs of bi-directional connections, which can be found between biosphere and B-G, B-G and geosphere. These interactive connections refer to exchange flows between two spheres, for example, water infiltrates into root zone from biosphere, while capillary rise takes place from root zone to biosphere. Actually, these connections are the natural processes, thus in any city, at least two pairs of bi-directional connections should be present. The standard deviation value of all water amounts is $315*10^3$. Most water amounts are between biosphere and geosphere, and this could be attributed to the largest percentage of unpaved area in Zevenkamp. The two biggest water quantities are from biosphere to B-G, and from geosphere to T-G (i.e. canals).

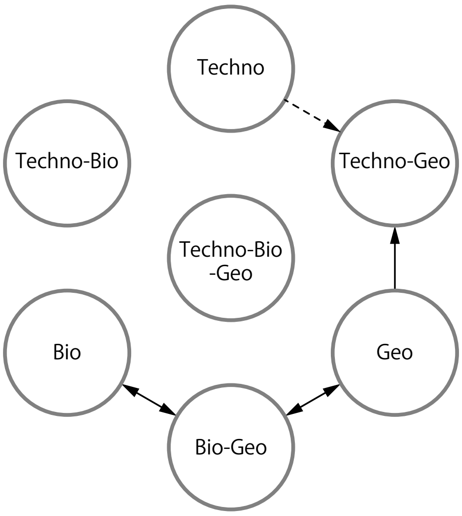
In the spatial hybridity, the connection of green-blue can be confirmed but red and grey have no connection with other spatial elements in Zevenkamp. The way of connection is one type which is green-blue. A network of space in which the water is legible is formed only along the open water. The amount is 259,372.1 m^2, which is 13.0% of the whole area of Zevenkamp. The axis of the regional scale penetrating the east and west, and the loop line of the neighborhood scale constitute the framework of space in which the water system is legible. There are some linkages in this network with the housing scale situated along the loop line and with open water inside the district next to the private gardens. But the east-west axis doesn't have any connection with the private gardens, so it is independent from housing scale. The ratio of each scale is 19.1% for the regional scale, 68.6% for the neighborhood scale, 12.3% for the housing scale, and the standard deviation is 25.1. There is no overlapped area, and the value showing diversity is 0.0%.

Because no recycling measures are taken in the current situation, there's no water circulation.

Environmental hybridity Sankey diagram



Environmental hybridity chart



Number

Environmental hybridity

Unit	Sphere	Connection	Bi-direction	Deviation (10^5)
Value	**5.0**	**6.0**	**2.0**	**3.2**

Spatial hybridity

Unit	Whole Area	Amount	Legible Area	Diversity
%	100.0	**13.0**	100.0	**0.0**

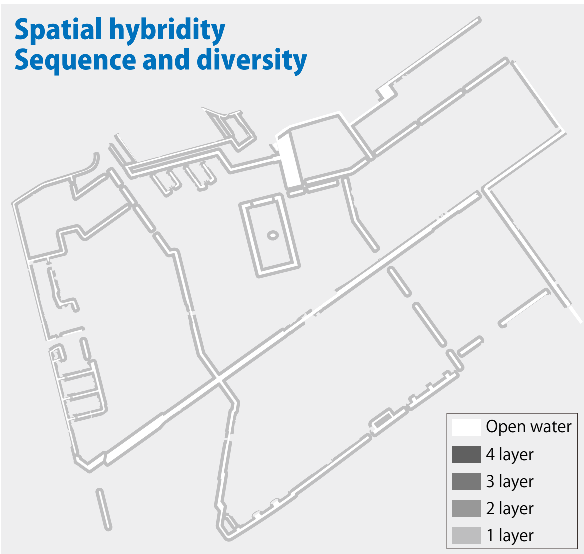
Unit	Regional	Neighborhood	Housing
%	19.1	68.6	12.3

Unit	Deviation
Value	**25.1**

Performance

Unit	Recycling (10^4)
m^3	**0.0**

Unit	Internal Circulation
Value	**0.0**



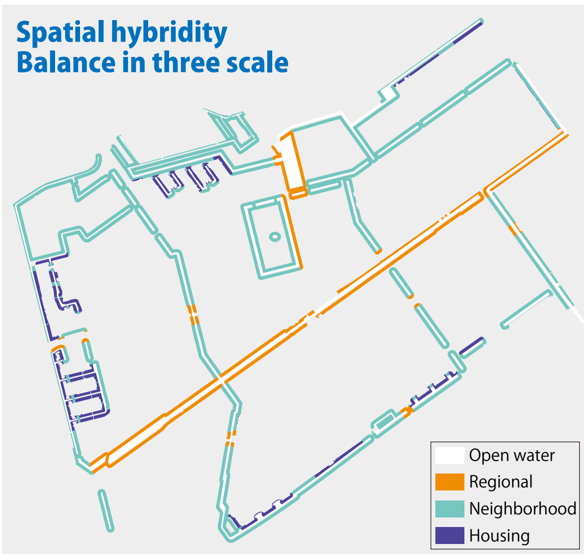


Figure 5.1: Current Situation

5-2. Mechanical Vision

Only grey infrastructures are selected to improve the water system, these are RWH, Water Houses, DEWATS and SWDS categorized in technosphere.

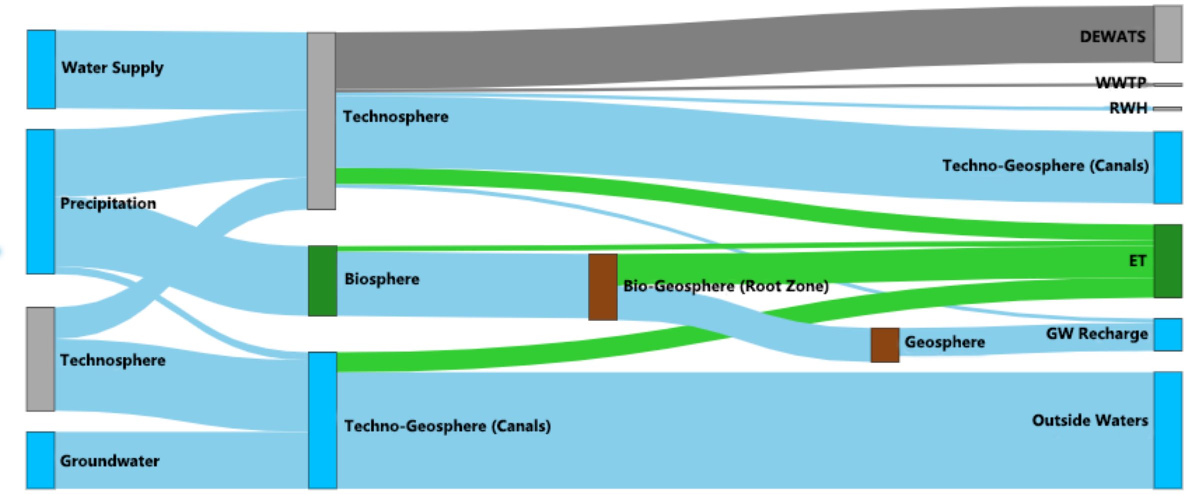
The environmental hybridity is composed out of five spheres, of which two combinations with the biosphere are lacking, thus applying only grey infrastructure will involve more spheres. There are six arrows connecting the five spheres, which is the same as the current situation. However, the negative connection caused by CSO has been eliminated. DEWATS and RWH from the technosphere supply water to buildings in the same sphere, and discharge extra water to canals (i.e. T-G). By installing SWDS, clean rainwater is discharged to the canals situated in the technosphere. Connections among biosphere, B-G and geosphere are the same as current situation. The number of bi-directional pairs is also the same as current situation. The standard deviation of water amounts is calculated as $318*10^3$. This is a bit larger than the current situation, which means water distribution in each sphere deviates more. Most water is related to the technosphere. This could be attributed to the application of grey infrastructures.

In the spatial hybridity, the relationship between red-green is added by RWH and Water House. The connections are two types in total which are red-green in red-green and green-blue in the current situation.

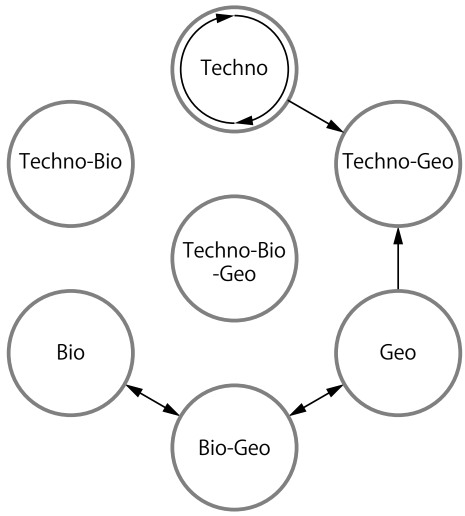
A network of space in which the water system is legible is formed along the open water, but not linked to other space because they are fragmented over the area. The amount of space in which the water system is legible is 315,074.3 m^2, which is 15.8% of the whole area. The axis of the regional scale penetrating the east and west, and the loop line of the neighborhood scale constitute the spatial framework in which the water system is legible. The scales of housing and neighborhood are linked partly to this regional network. The ratio of each scale is 16.2% for the regional scale, 70.5% for the neighborhood scale, 13.3% for the housing scale, and the standard deviation is 26.3. There are overlapping areas only on the boarder of each type, and those are also situated fragmented. The value of diversity is 0.7%.

To improve the performance of the water system, the water circulation is stimulated by applying DEWATS and RWH. DEWATS treats wastewater from households in the technosphere and supplies back to the geosphere, while the rainwater from sloping roofs is collected and supplied to the house for non-potable use. The total amount of the water circulation is $410*10^3$ m^3, in which $366*10^3$ m^3 is from DEWATS and $45*10^3$ m^3 from RWH. Only the technosphere has internal circulation, because DEWATS and RWH are in technosphere, all treated wastewater and harvested rain are circulated within technosphere. However, the treated water flows back into the T-G.

Environmental hybridity Sankey diagram



Environmental hybridity chart



Number

Environmental hybridity

Unit	Sphere	Connection	Bi-direction	Deviation (10^5)
Value	**5.0**	**6.0**	**2.0**	**3.2**

Spatial hybridity

Unit	Whole Area	Amount	Legible Area	Diversity
%	100.0	**15.8**	100.0	**0.7**

Unit	Regional	Neighborhood	Housing
%	16.2	70.5	13.3

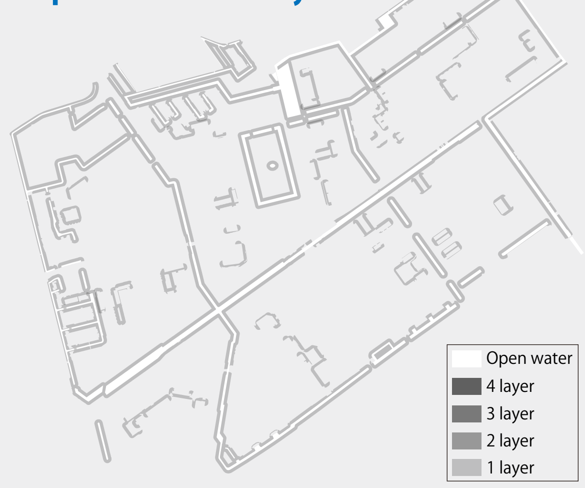
Unit	Deviation
Value	**26.3**

Performance

Unit	Recycling (10^4)
m^3	**41.0**

Unit	Internal Circulation
Value	**1.0**

Spatial hybridity Sequence and diversity



Spatial hybridity Balance in three scale

Figure 5.2: Mechanical Vision

5-3. Mixed Vision 1

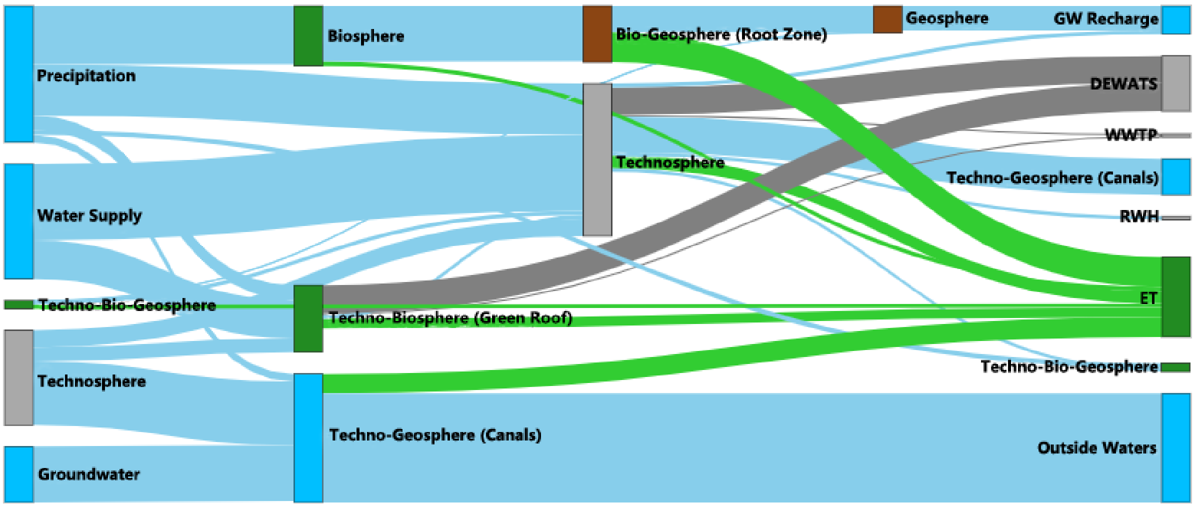
Both grey and green solutions are applied in this vision, but recycling treated wastewater is done mechanically. The grey infrastructure that is applied is Water House, DEWATS, RWH and SWDS which are all categorized as technosphere. Next to these green roofs are used, which is T-B, community rain gardens, front yard rain gardens and wadis which are T-B-G.

The number of involved spheres is raised to seven because of the introduction of green solutions that now include T-B and T-B-G. There are in total 13 connections. Although T-B and T-B-G are involved, there are no connections between these two spheres. The technosphere receives extra rainwater from the green roofs in T-B and then discharges to T-G via SWDS. In addition, generated wastewater from T-B is treated by DEWATS in the technosphere and sent back. Between the technosphere and T-B-G, storm water run-off from buildings and streets goes to rain gardens and wadis, and extra rainwater is discharged to open water through SWDS in the technosphere. From the wadis and rain gardens in T-B-G, a small amount of water goes to the geosphere. The connections between T-B-G and B-G is similar to the current situation. Connections among the biosphere, B-G and the geosphere are the same as in the current situation as well. The number of bi-directional pairs is five, which are between the technosphere and T-B, technosphere and T-B-G, T-B-G and B-G and the original two in the current situation. The standard deviation of water amounts is calculated as $252*10^3$. Because more mechanical measures are used, more water is involved in the technosphere.

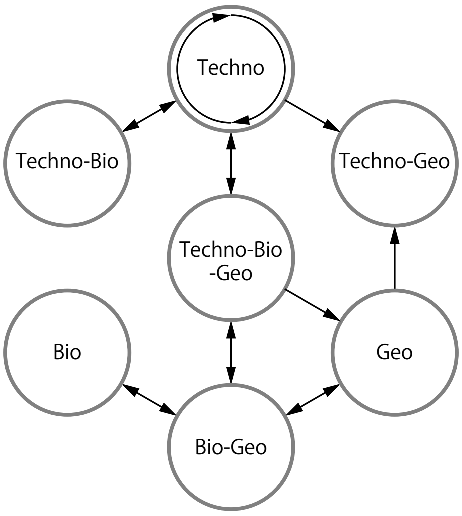
In the spatial hybridity, the relationship between red-green-blue is added by front yard rain garden, RWH, community rain garden and Water House, also green-blue-grey is added by implementation of wadis. The total connection is seven types: green-blue, red-green, red-green-blue in red-green-blue connection, and green-blue, green-grey, green-blue-grey in green-blue-grey connection, and green-blue in the current situation. A network of space where the water system is legible is along the open water and in other districts. The amount is 418,956.3 m^2, which is 21.1% of the whole area. The axis of the regional scale run through the east, west, north and south from the center of the Zevenkamp, the loop line with the regional and neighborhood scale constitute the framework of the space in which the water system is legible. The scale of the neighborhood and housing are linked to this network along the regional axis. The ratio of each scale is 19.6% for the regional scale, 60.9% for the neighborhood scale, 19.5% for the housing scale, and the standard deviation is 19.5. There are only overlapping areas on the edge of each scale, and some overlap fragmented in the area. The value showing diversity is 0.7%.

To improve the performance, the water circulation is enhanced by DEWATS and RWH. The total amount of water circulation is $410*10^3$ m^3, in which $366*10^3$ m^3 is from DEWATS and $45*10^3$ m^3 is from RWH. Only the technosphere has internal circulation. However, because DEWATS also provides water to green roofs in T-B, not all treated wastewater is recycled within the technosphere. The amount of internal circulation is $226*10^3$ m^3.

Environmental hybridity Sankey diagram



Environmental hybridity chart



Number

Environmental hybridity

Unit	Sphere	Connection	Bi-direction	Deviation (10^5)
Value	**7.0**	**13.0**	**5.0**	**2.5**

Spatial hybridity

Unit	Whole Area	Amount	Legible Area	Diversity
%	100.0	**21.1**	100.0	**4.0**

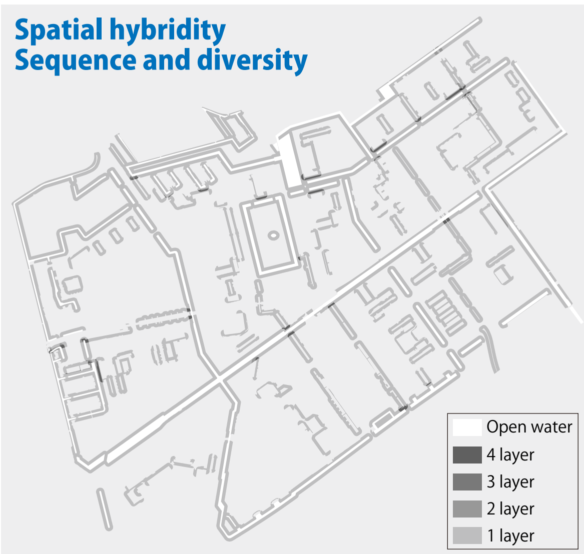
Unit	Regional	Neighborhood	Housing
%	19.6	60.9	19.5

Unit	Deviation
Value	**19.5**

Performance

Unit	Recycling (10^4)
m^3	**41.0**

Unit	Internal Circulation
Value	**1.0**



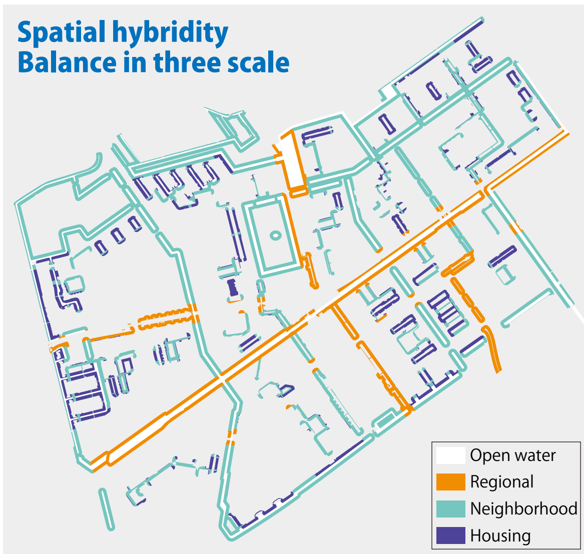


Figure 5.3: Mixed Vision 1

5-4. Mixed Vision 2

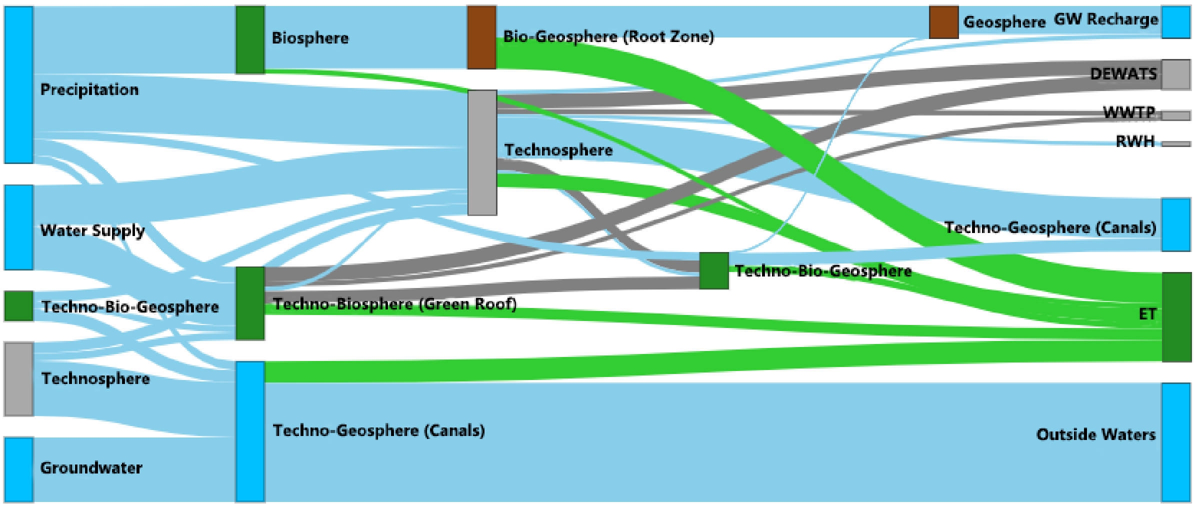
In this vision both grey and green solutions are selected to improve the water circulation. There are 23 neighborhoods in Zevenkamp, and DEWATS is installed in 12 neighborhoods, while the rest is supplied with reed beds. It means that treated wastewater is recycled in a balanced way. The installation of grey infrastructure, Water Houses, DEWATS, RWH and SWDS increases measures part of the technosphere. Green roofs, which is T-B, community rain gardens, front yard rain gardens, reed beds and wadis, which are T-B-G, are chosen as green infrastructure measures.

The number of involved spheres is raised to seven due to the application of all selected green solutions. There are in total 16 connections. Because reed beds and DEWATS are both selected, generated wastewater from green roofs in T-B is treated in the technosphere and T-B-G and then recycled back. The technosphere receives extra rainwater from the green roofs in T-B and from the rain gardens and wadis in T-B-G; storm water is discharged to T-G via SWDS. Storm water from roofs and streets in the technosphere goes to rain gardens and wadis in T-B-G. From the reed beds in T-B-G, extra water is discharged directly to T-G. Because of applied green solutions in T-B-G, a small amount of water goes to the geosphere. Connections between T-B-G and B-G are similar to the natural processes in the current situation. Connections among the biosphere, B-G and geosphere are the same as in the current situation. There are six bi-directional pairs, which are between technosphere and T-B, T-B and T-B-G, T-B-G and B-G, and the original two pairs between biosphere and B-G and between B-G and geosphere. The standard deviation of water amounts is $234*10^3$.

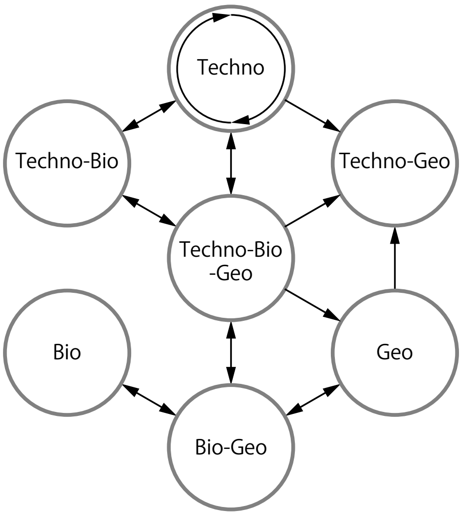
In the spatial hybridity, the relationship between red-green-blue is increased by front yard rain gardens, RWH, community rain gardens, reed beds and the Water House; also the green-blue-grey connection is added by wadis. There are seven types of connections: green-blue, red-green, red-green-blue in red-green-blue connection, and green-grey, blue-grey, green-blue-grey in green-blue-grey connection, and green-blue in the current situation. The spatial network in which the water system is legible includes space along the open water and locations in all districts. The amount is 441,543.8 m^2, which is 22.2% of the whole area. The axis of the regional scale run through the east, west, north and south from the center of the Zevenkamp, the loop line with the regional and neighborhood scale constitute the framework of space in which the water system is legible. The legible area of the neighborhood and housing scale is linked to the regional axis. The ratio of each scale is 20.0% for the regional scale, 60.6% for the neighborhood scale, 19.4% for the housing scale, and the standard deviation is 19.3. There are overlapping areas along the open water. The value showing diversity is 30.8%.

To improve the performance, the water circulation is realized by implementing DEWATS, RWH and reed beds. The total amount of water circulation is $370*10^3$ m^3, in which $175*10^3$ m^3 is from DEWATS, $45*10^3$ m^3 is from RWH and $150*10^3$ m^3 is from reed beds. Only the technosphere has internal circulation because of DEWATS and RWH. However, because DEWATS also provides water to green roofs in T-B, not all treated wastewater is recycled within technosphere. The amount of internal circulation is $132*10^3$ m^3.

Environmental hybridity Sankey diagram



Environmental hybridity chart



Number

Environmental hybridity

Unit	Sphere	Connection	Bi-direction	Deviation (10^5)
Value	**7.0**	**16.0**	**6.0**	**2.3**

Spatial hybridity

Unit	Whole Area	Amount	Legible Area	Diversity
%	100.0	**22.2**	100.0	**30.8**

Unit	Regional	Neighborhood	Housing
%	20.0	60.6	19.4

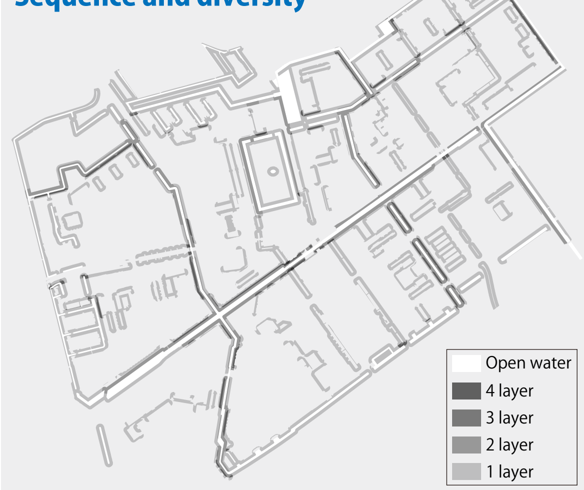
Unit	Deviation
Value	**19.3**

Performance

Unit	Recycling (10^4)
m^3	**37.0**

Unit	Internal Circulation
Value	**1.0**

Spatial hybridity Sequence and diversity



Spatial hybridity Balance in three scale

Figure 5.4: Mixed Vision 2

5-5. Mixed Vision 3

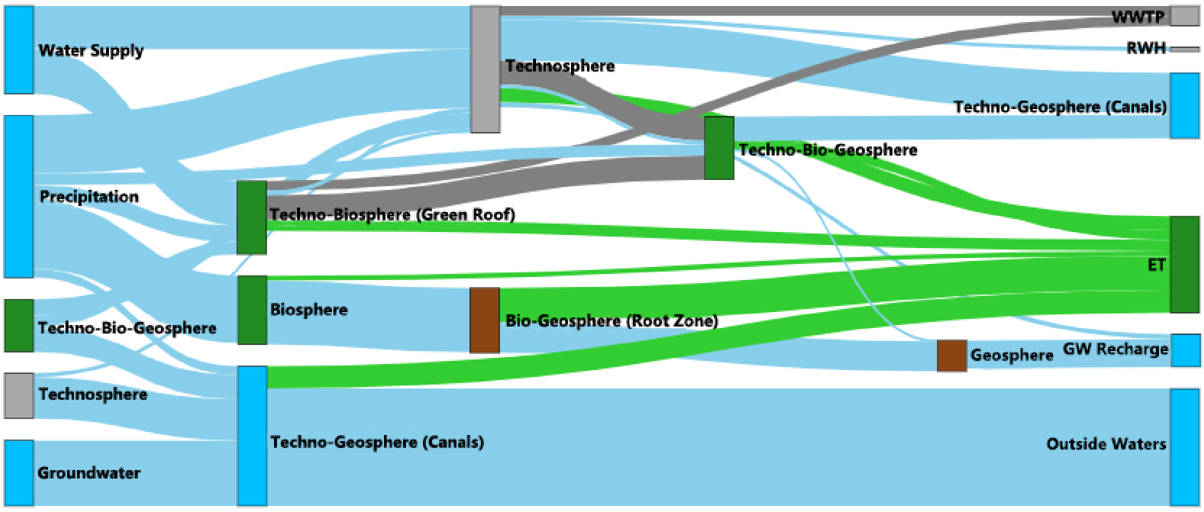
Both grey and green solutions are applied in this vision, but for the recycling of treated wastewater green instead of grey measure are chosen. The grey infrastructure is RWH and SWDS, participating in the technosphere. Green roofs, part of T-B, community rain gardens, front yard rain gardens, reed beds and wadis, all T-B-G, are installed as green infrastructure.

All the seven spheres are involved due to the green solutions that are applied. The number of connections is in total 15. There are no flows from the technosphere to T-B because DEWATS is not applied. The technosphere receives extra rainwater from T-B, and from rain gardens and wadis in T-B-G. The storm water is discharged to T-G via SWDS. Reed beds in T-B-G receives generated wastewater from T-B and the technosphere, and treated wastewater is sent back to the two spheres for recycling. Storm water run-off from roofs and streets goes to rain gardens and wadis. Extra water from reed beds is discharged to T-G directly and because of the green solutions in T-B-G, a small amount of water goes to the geosphere. Connections between T-B-G and B-G are the same as the current situation. Connections among the biosphere, B-G and geosphere are also the same as the current situation. Bi-directional pairs are five in this vision, which are between the technosphere and T-B-G, T-B and T-B-G, T-B-G and B-G, and the original two as in the current situation. The standard deviation value of water amounts is $233*10^3$.

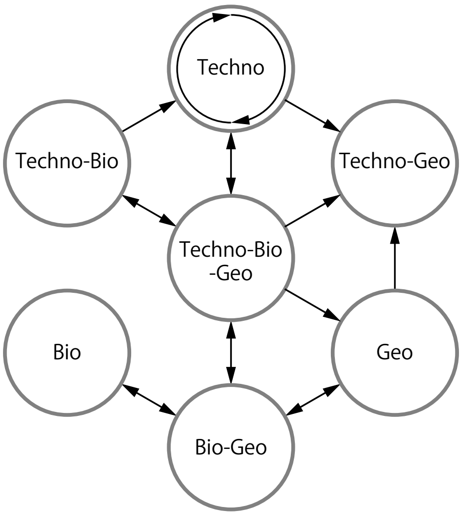
In the spatial hybridity, the relationship between red-green-blue is added by front yard rain gardens, RWH, community rain gardens, reed beds, also green-blue-grey is added by wadis. The way of connection is total seven types which are green-blue, red-green, red-green-blue in red-green-blue connection, and green-blue, green-grey, green-blue-grey in green-blue-grey connection, and green-blue in the current situation. A network of space in which the water system is legible includes the space along the open water system and public space in other districts. The total area is 450,194.4 m^2, which is 22.6% of the whole. The axis of the regional scale run through the east, west, north and south from the center of the Zevenkamp, the loop line with the regional and neighborhood scale constitute the framework of the space in which the water system is legible. On the scale of the neighborhood and housing the links to the regional scale are made through the main axes. The ratio of each scale is 19.9% for the regional scale, 60.7% for the neighborhood scale, 19.4% for the housing scale, and the standard deviation is 19.3. There are overlapping areas along the open water. The value showing diversity is 37.8%.

In aiming for an improved performance the water circulation is realized by RWH and reed beds. The total amount of water circulation is $320*10^3$ m^3, in which $45*10^3$ m^3 is from RWH and $275*10^3$ m^3 is from reed beds. Only the technosphere has internal circulation because of RWH. All harvested rainwater is circulated within the technosphere. The amount of internal circulation is $45*10^3$ m^3.

Environmental hybridity Sankey diagram



Environmental hybridity chart



Number

Environmental hybridity

Unit	Sphere	Connection	Bi-direction	Deviation (10^5)
Value	**7.0**	**15.0**	**5.0**	**2.3**

Spatial hybridity

Unit	Whole Area	Amount	Legible Area	Diversity
%	100.0	**22.6**	100.0	**37.8**

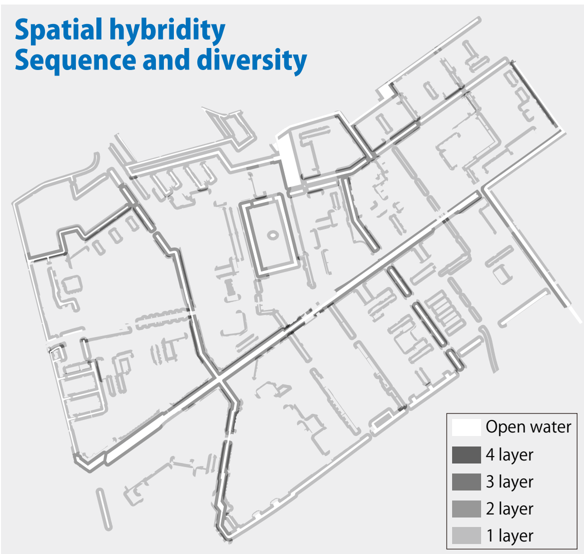
Unit	Regional	Neighborhood	Housing
%	19.9	60.7	19.4

Unit	Deviation
Value	**19.3**

Performance

Unit	Recycling (10^4)
m^3	**32.0**

Unit	Internal Circulation
Value	**1.0**



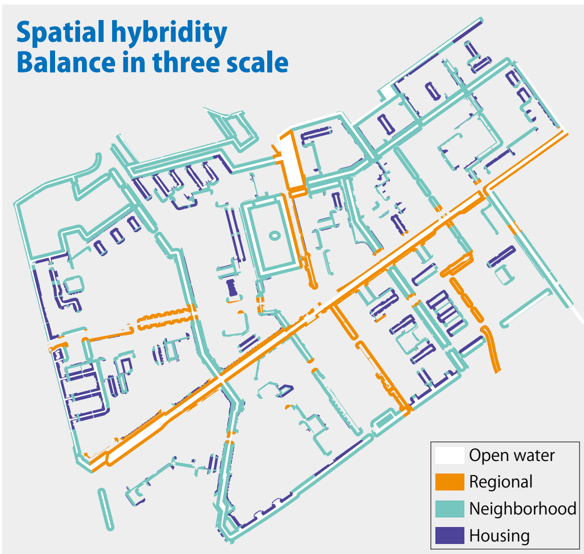


Figure 5.5: Mixed Vision 3

5-6. Green Vision

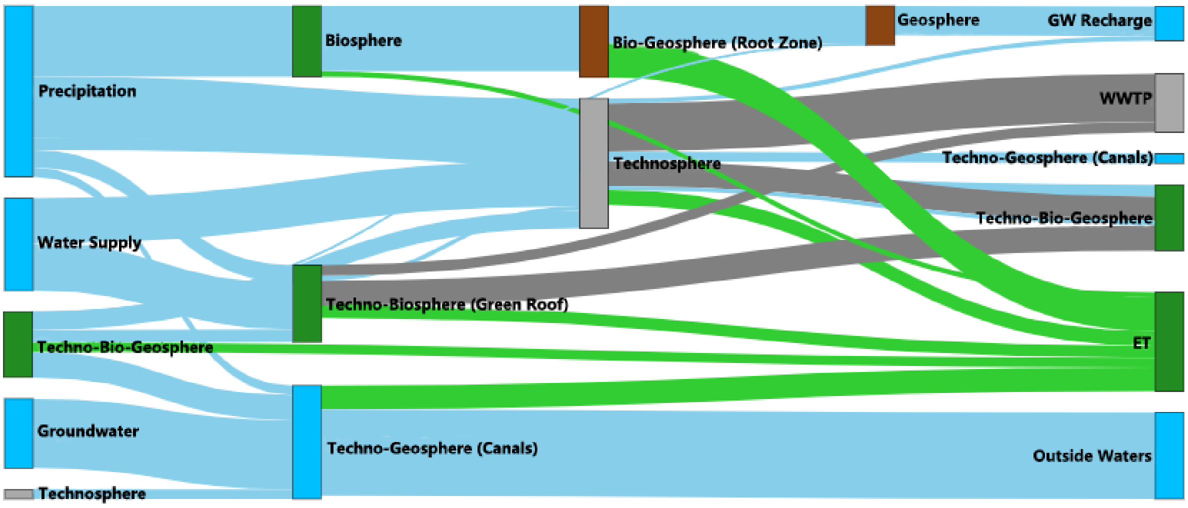
The Green Vision is applying all green solutions: green roofs categorized in T-B, community rain gardens, front yard rain gardens, reed beds and wadis categorized in T-B-G.

The complete set of spheres is involved, especially the spheres coming from overlapping spheres. In total there are 15 connections. Although the combined sewer system is kept, there are no negative impacts on the water quality caused by CSO. The technosphere receives extra rainwater from green roofs in T-B and from rain gardens and wadis in T-B-G. The storm water is discharged to T-G via SWDS in the technosphere. Wastewater from the technosphere goes to reed beds in T-B-G, and storm water run-off from roofs and streets goes to rain gardens and wadis of T-B-G. Wastewater from T-B is treated by reed beds in T-B-G and then recycled back. Connections between T-B-G and B-G are similar natural processes described in current situation. The application of reed beds in T-B-G discharges extra water directly to T-G, and also a small amount of water goes to the geosphere from applied measures in T-B-G. Five bi-directional pairs can be found, which are between the technosphere and T-B-G, T-B and T-B-G, T-B-G and B-G, and the original biosphere and B-G, B-G and geosphere. The standard deviation of water amounts is $230*10^3$. This value is less than current situation ($315*10^3$), which means although more spheres are involved, water distribution to each sphere is in a more balanced way. However, water amounts between T-B-G and the geosphere are not large. This could be explained as extra storm water flowing to green solutions are drained to open water via installed pipes so that less water infiltrates into subsurface.

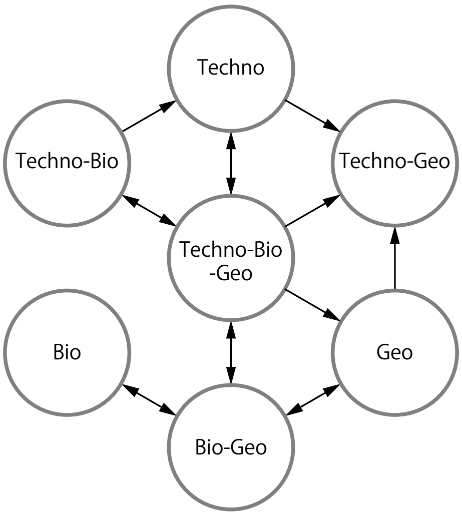
In the spatial hybridity, the relationship between red-green-blue is added by front yard rain gardens, community rain gardens, reed beds, also green-blue-grey is added by wadis. The connection is a total seven types: green-blue, red-green, red-green-blue in red-green-blue connection, and green-blue, green-grey, green-blue-grey in green-blue-grey connection, and green-blue in the current situation. The network of space in which the water system is legible is formed by space along the open water system and public space in the different districts. The total area is 450,194.4 m^2, which is 22.6% of the whole area. The axis of the regional scale run through the east, west, north and south from the center of the Zevenkamp, the loop line with the regional and neighborhood scale constitute the framework of the space in which the water system is legible. The legible space of the neighborhood and housing scale are linked to the regional axis. The ratio of each scale is 19.9% for the regional scale, 60.7% for the neighborhood scale, 19.4% for the housing scale, and the standard deviation is 19.3. There are overlapping areas along the open water. The value showing diversity is 37.8%.

In the performance, the water circulation is improved by reed beds. Grey water from buildings with and without green roofs is treated by reed beds and is recycled back for non-potable use. The total amount of water circulation is $270*10^3$ m^3. No sphere has internal circulation, because buildings with green roofs are in T-B and those without green roofs are in the technosphere, while reed bed is included in T-B-G, therefore, no internal circulation can be found.

Environmental hybridity Sankey diagram



Environmental hybridity chart



Number

Environmental hybridity

Unit	Sphere	Connection	Bi-direction	Deviation (10^5)
Value	**7.0**	**15.0**	**5.0**	**2.3**

Spatial hybridity

Unit	Whole Area	Amount	Legible Area	Diversity
%	100.0	**22.6**	100.0	**37.8**

Unit	Regional	Neighborhood	Housing
%	19.9	60.7	19.4

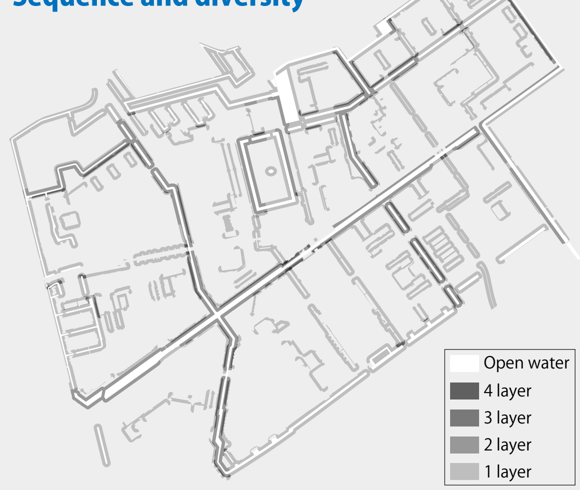
Unit	Deviation
Value	**19.3**

Performance

Unit	Recycling (10^4)
m^3	**27.0**

Unit	Internal Circulation
Value	**0.0**

Spatial hybridity Sequence and diversity



Spatial hybridity Balance in three scale

Figure 5.6: Green Vision

6. Comparison and discussion

6-1. Environmental hybridity

In terms of involved spheres, in the current condition of Zevenkamp only five spheres are involved. All the proposed visions, except for the Mechanical Vision in which the involved spheres remains the same, the environmental hybridity has become higher through the involvement off all spheres. The Mechanical Vision does not involve more spheres due to the fact that only grey infrastructures are applied; they are part of the technosphere and thus no new spheres are involved, while the applications of green solutions include T-B and T-B-G. Therefore, in terms of the number of involved spheres, the Mixed Visions and Green Vision produce a higher environmental hybridity.

Also in terms of connections between the spheres the current condition Zevenkamp and the Mechanical Vision perform the same with 6 connection. The Mixed Vision 1 scores 13, the Mixed Vision 2 scores 16, and both the Mixed Vision 3 and Green Vision score the highest of 18 connections. Although the current condition of Zevenkamp and Mechanical Vision score the same on the same number of connections, the Mechanical Vision improves the connection between technosphere and T-G because it prevents CSO.

The Mixed Vision 3 and the Green Vision have the same number of connections because they apply the same green solutions. While grey infrastructures including SWDS and RWH are installed in the Mixed Vision 3, SWDS only contributes to the connection between the technosphere and T-G, and RWH recycles rainwater within the technosphere, which is not connecting two spheres.

Mixed Vision 1 is outnumbered with two connections by Mixed Vision 3 and the Green Vision. The missing two are between T-B and T-B-G, and T-B-G and T-G. Because reed beds are not applied in Mixed Vision 1, wastewater from T-B goes to DEWATS in

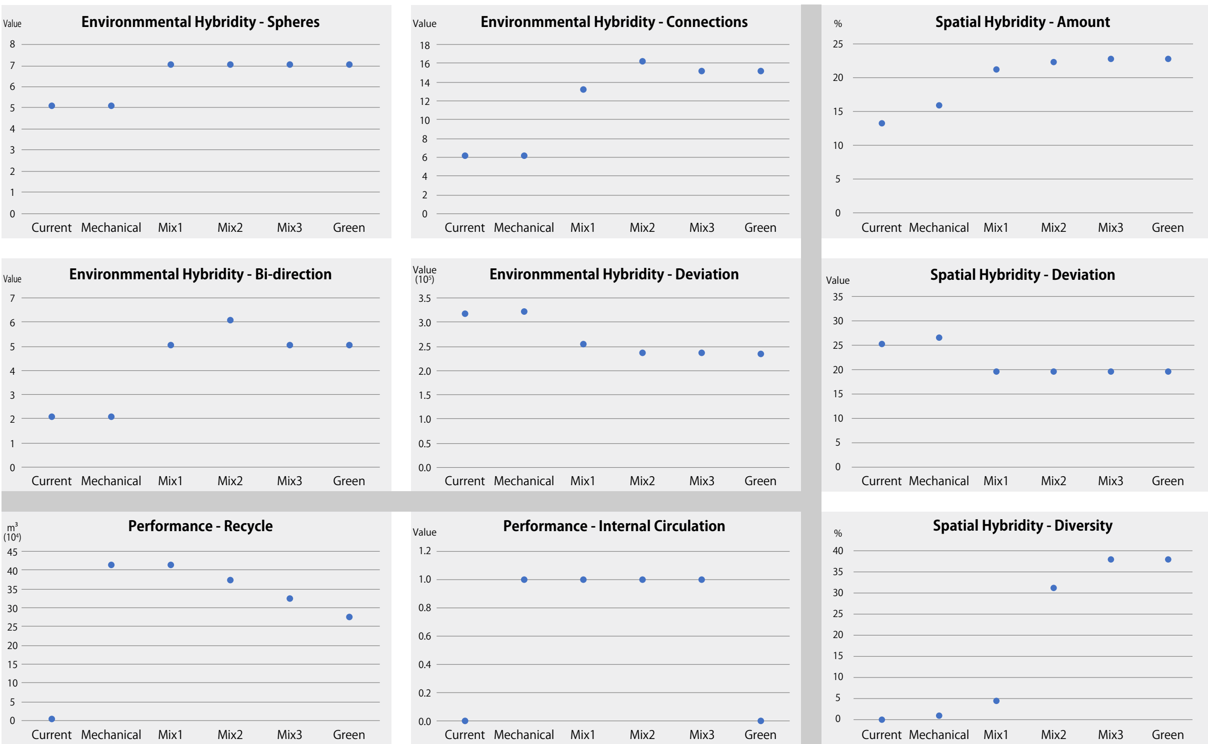


Figure 6.1: Comparison chart

technosphere, and then the treated wastewater is sent back from technosphere, thus bi-directional connections between T-B and T-B-G are replaced by the connection from technosphere to T-B. The missing connection between T-B-G and T-G is also caused by excluding reed beds as a measure. Extra water from the reed beds is directly discharged to open water, while water from the wadis and rain gardens have to be discharged to open water through pipes part of the technosphere. Therefore, Mixed Vision 2 has the most connections due to the applications of both DEWATS and reed beds, and this vision has the highest environmental hybridity in terms of connections.

In terms of bi-directional connections, current Zevenkamp and the Mechanical Vision have both 2 pairs of bi-directional connections, which are between biosphere and B-G, and B-G and geosphere. These two pairs of connections refer to exchange flows between unpaved area and subsurface, which are actually natural processes. Hence, these two pairs can be found in any urban condition and are not specific for these situations. Mixed Vision 1, Mixed Vision 3 and the Green Vision all have five pairs of bi-directional connections. For Mixed Vision 1, the connections are between the technosphere and T-B, technosphere and T-B-G, T-B-G and B-G, and the two pairs that are found in the current condition of Zevenkamp and Mechanical Vision. The Mixed Vision 3 and the Green Vision both have bi-directional connections between T-B-G and T-B instead of between technosphere and T-B in Mixed Vision 1, and the other four pairs are the same. The cause of this change is again due to different applications in either DEWATS or reed beds, which is explained above. In Mixed Vision 2, there are 6 pairs of bi-directional connections as a result of applying DEWATS and reed beds creating connections between the technosphere and T-B and between T-B-G and T-B. In this case, Mixed Vision 2 has the highest environmental hybridity regarding to the number of bi-directional connections.

In terms of balance of water distributed to each sphere, Mechanical Vision ($318*10^3$) and current situation ($315*10^3$) have higher value, which means water distributed to each sphere is the most unbalanced, while water involved in each sphere of the Green Vision is the lowest ($230*10^3$) among all the visions. Since more water is involved in technosphere because of applying grey infrastructures and no new spheres are involved in Mechanical Vision, thus the water distribution to each sphere deviates more. While in the Green Vision, although more spheres are involved, water distributed to each sphere is brought in a balanced way. However, water amounts between T-B-G and other two spheres (i.e. B-G and geosphere) are not large. This could be explained as extra storm water flowing to green solutions are drained to open water via installed pipes so that less water infiltrates into subsurface. For the three Mixed Visions, because the combination of grey and green solutions is in a gradational change, therefore, the deviation is also similar to this trend. Mixed Vision 1 has the higher deviation value ($252*10^3$) because it is more mechanical, while the value of Mixed Vision 3 is lower ($233*10^3$) due to more green solutions, and deviation of Mixed Vision 2 is between the other two Mixed Visions ($234*10^3$). Hence, Green Vision has the least deviation thus could be considered as the highest environmental hybridity among all visions. But it can be observed from Figure 6.1 that Mixed Vision 2 and 3 are really close to Green Vision.

In summary, based on the four indicators, Mixed Vision 2 shows higher environmental hybridity than the others.

6-2. Spatial hybridity

In terms of amount, the current situation is the lowest (13.0%) and the Mechanical Vision (15.8%) the second in low values, due to the fact that the network of spaces in which the water management is legible is limited to the space along the open water. Mixed Vision 1 (21.1%), Mixed Vision 2 (22.2%), Mixed Vision 3 (22.6%), Green Vision (22.6%) show higher values than the others, and a network of space in which the water system is legible includes, next to the space along the open water also public and private space in the several districts.

In terms of deviation, the Mechanical Vision (26.3), the current situation (25.1) show higher values because the link between three scales region, neighborhood and district is limited. Mixed Vision 1 (19.5), Mixed Vision 2 (19.3), Mixed Vision 3 (19.3), and the Green Vision (19.3) all show lower values than the others because in these visions the framework of space where the water system is legible does connect the three scales and is continuous.

In terms of diversity, the current situation (0.0%), the Mechanical Vision (0.7%) and Mixed Vision 1 (4.0%) show lower values, because there are no overlapping areas or only marginal spaces. Mixed Vision 2 (30.8%), Mixed Vision 3 (37.8%) and the Green Vision (37.8%) show higher values of over 30%, and the areas where each type overlap are continuous along the open water. From this, it can be seen that Mixed Vision 2, Mixed Vision 3 and the Green Vision can experience more various connections of different spatial elements through the water system compared with the other three.

From the above, it was found that Mixed Vision 2, Mixed Vision 3 and the Green Vision have higher spatial hybridity due to continuity in scales and diversity in typology .

6-3. Performance of closed city

In terms of amount of water circulation, the Mechanical Vision and Mixed Vision 1 have the strongest ability to recycle water ($410*10^3$ m^3), while the Green Vision has the least amount of water circulation ($270*10^3$ m^3). Water circulation quantity in the Mixed Vision 2 and Mixed Vision 3 are reduced gradually from the value in the Mechanical Vision, which are respectively $370*10^3$ m^3 and $320*10^3$ m^3. It is not surprising that the Mechanical Vision can recycle the most. As DEWATS and RWH are applying certain advanced technologies to treat water, their capacity is higher than reed beds which only employs natural processes to treat water. In the current situation in Zevenkamp, there are no circulation measures applied.

In terms of the number of spheres with internal circulation, there is no internal circulation in the current situation and the Green Vision, while for the other visions, only technosphere can recycle water internally. This is attributed to the application of grey solutions. Because they are categorized into technosphere, and treated water from them are supplied to buildings which are also included in technosphere, then flow remains internal. In the Green Vision, water circulation is realized by applying reed beds, and recycled water is provided from T-B-G to the technosphere. However, due to different number of grey solutions applied in each vision, in relation to green solutions, the levels of internal circulation differ. Similar to the total amount of water circulation, the Mechanical Vision circulates the highest amount ($410*10^3$ m^3). Mixed Vision 1 has $226*10^3$ m^3 recycled in the technosphere, which is less than the Mechanical Vision. This is different from the results of total water circulation, because part of the water is supplied to green roofs (i.e. T-B). The Mixed Vision 2 circulates less than Mixed Vision 1, only $132*10^3$ m^3 is circulated within technosphere. This is because only half of the neighbourhoods are supplied with DEWATS, reducing the internal circulation. For Mixed Vision 3, the internal circulation is the lowest ($45*10^3$ m^3) due to the fact that only RWH is applied in this vision.

In summary, based on the two indicators of evaluating performance of Closed City, both the Mechanical Vision and the Mixed Vision 1 perform best as Closed City.

7. Conclusion

The research into the question: how can the Closed City concept be understood and applied for designing the city as a hybrid construction? is done along the lines of:

1. The definition and evaluation method of environmental and spatial hybridity, and also the evaluation method of performance of Closed City;
2. The process of collaborative design for Closed City by applying hybridity;
3. The current situation and five future visions for Closed City based on collaborative design process are evaluated from three viewpoints of environmental hybridity, spatial hybridity and performance;
4. Finally each vision is compared and discussed. The analyses and discussion brought forth three main conclusions.

First, hybridity as an approach can be considered as an interdisciplinary concept that provides a method for dialogue between water managers and urban designers because it relates green and grey infrastructure, as well as spatial quality and functionality.

In this research this concept is operationalized by developing a method to visualize and quantify the hybridity. As a result, it becomes possible to compare the various visions with the viewpoint of spatial hybridity (urban design) equally to the evaluation of performance which can be quantified from the viewpoint of water management, environmental hybridity. The Mechanical Vision and Mixed Vision 1 have a higher performance but score less on hybridity, while the other visions score higher on hybridity but less on water management performance. Based on this, the qualitative values generated by hybridity such as bio-diversity, social inclusiveness, aesthetic sense, and culture can be related to the technical and functional aspects of the water system.

Secondly, when hybridity is considered as a concept it supports examining the balance between the combination of green and grey infrastructure because it offers the larger context. In this research, the current situation and the five future visions have been evaluated with hybridity as the indicator. As a result, it is clarified that Mixed Vision 2, which combines green and grey solutions in balanced way, has the highest environmental hybridity and also higher spatial hybridity similar with Mixed Vision 3 and Green Vision. It turns out that this result is not conflicting with the discussions about the importance of the combination of green and gray infrastructure which has been debated so far. Hybridity as a concept could support and enhance the decision making in finding a balance between green and grey infrastructure.

Thirdly, hybridity as a concept provides the way of thinking and theorizing about interdisciplinary design process. Here, hybridity is presented as a concept or common vision which can be assessed from the viewpoint of both water management and urban design, and it helps constructing a collaborative relationship. The main difference is that it enables cross-over between the performance verification by water management and spatial analysis and design by urban design. Considering a concept is integrating the practical and visionary aspects in urban planning and design, both fields can relate to this concept due to the fact that it considers the city as a technical and social construction. Making this concept instrumental with the method of assessment, it also becomes possible to make decisions on what is the most preferred solution over the best solution. It made clear that there are causal relations between the spatial and environmental hybridity, but this relation is not based in the fact that the highest spatial hybridity leads to the highest environmental hybridity. Hybridity as a concept shows that collaboration and discussion between two disciplines is crucial in reaching the preferred option.

Figure 7.1 shows an iconic image that represents the collaborative design using the hybridity concept. In the city, projects with uncertainty dynamically occur on various scales. Ecological principles that crosses the three environments gives the order to discontinuous projects and harmonizes as one city. This kind of "Ecological Urban Design" is necessary in the present era when considering coexistence with nature.

Figure 7.1: Future image of Zevenkamp by applying hybridity concept

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