GREENBLUE INFRASTRUCTURE TO ESTABLISH A NET-POSITIVE URBAN WATER CYCLE IN AN OPEN BUILDING NEIGHBOURHOOD HYBRID

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ABSTRACT

An interdisciplinary approach of the building process is needed in order to achieve a more resilient outcome. The aim within this paper will therefore be about the implementation of GreenBlue infrastructure with Open Building to strive for a circular water cycle within the built environment. The following topics have been investigated in order to find out how this can be achieved. Firstly, distinguishing between different levels of decision making in Open Building is brought into connection with the levels that constitute the built environment through which the water cycle circulates. Secondly, the interdependency between the constituents of Open Building and the water cycle is formulated. Thirdly, it is clarified how Open Building can contribute to a high-density neighbourhood and nature inclusive public space. Lastly, the impact of densification on a net positive water cycle is explained and the possibilities of nature inclusive public space to mitigate these effects are given. By structuring the connection of GreenBlue infrastructure with Open Building at different levels of abstraction, a better understanding of the interdependency within planning for urban renewal is put forward. The spatial implications are clarified and substantiated by research through literature study, case study and by design. Eventually, the outcome is analysed/ tested against the thematic research question. It is concluded that

KEYWORDS: *Urban Water Cycle, Water system, Water chain, Green-blue Infrastructure, Open Building, Circularity*

I. INTRODUCTION

Although water is the most valuable resource on our planet, it is not being used to its full potential. It stands at the basis of all life on earth as we know it, yet it is hardly implemented within the physical appearance of the built environment. Within a given ecosystem, the built environment is merely a part of the several layers in which biotic and abiotic factors are influencing one another. An interdisciplinary approach of the building process is needed in order to achieve a more sustainable balance between the natural and what is man-made. By combining different fields of expertise, new opportunities will arise that will contribute to solving the current problems revolving around the climatic crisis. Among others, the effects of climate change concerning the urban area are an increased risk of flooding, flooding due to extreme precipitation and land subsidence. Potentially resulting in the pollution of water and soil. Longer periods of drought and heat retention in urban areas lead to heat stress during extremely hot summers and the acidification of soil (Ligtvoet *et al.*, 2011) p.19. Water management is therefore an important part for being able to overcome these problems happening more often in the future. Water should be dealt with more efficiently and intelligent, and the main opportunities should be examined to help with the transition to a circular built environment. Great potential lies in water to be harvested for either using it as a medium for storing or generating kinetic, temperature or hydrogen energy or simply to be reused for household related purposes. It can also be used to grow urban vegetation to eventually enhance cooling capacities within cities or to temporarily be stored and used when needed in drier periods. Unfortunately, the water cycle is currently being neglected for the most part, yet the influence of it upon human life is more than present. Increasing temperatures result in the urban heat island effect and pose negative effects on the biodiversity of cities. The extensive implementation of green-blue grids in the urban environment are considered one of the structuring constituents that can largely alleviate the negative effects of climate change. Urban cycles can be closed by implementing a nature-based solution while at the same time contributing positively to socio-environmental challenges. (Pötz, 2016) p.33 It is estimated that about fifty-five percent of the world's population resides in cities. The current urbanisation continues to grow and is projected to reach about sixty-eight percent by 2050 as stated by the United Nations. (*un.org*, 2018) Due to strong urban densification currently happening worldwide, the implementation of the water cycle in the built environment is even more at risk. Higher urban densities are putting more pressure on existing grey systems and less room is left for making use of the subsurface. A more resilient design which takes soil dynamics and ecosystem services into account should be sought after within the domain of spatial planning. When bringing together climatic and urban systems, the above ground spatial planning should fully consider the subsurface accordingly (Hooimeijer *et al.*, 2020) p. 23 It will thus be necessary to work through the different layers that constitute the built environment and strive for a more interdisciplinary way of collaboration and urban development. Using a layered model for spatial planning is well established within the domain of urbanism. Often referred to as the Dutch layers model, this approach has undergone different transformations since 1998 to develop into several variations currently used throughout the profession. (van Schaick and Klaasen, 2011) Although the Layers Approach has become established in urban planning, this does not seem to be as evident within the domain of architectural design. Nevertheless, a Layers Approach can be recognized in the theories of John Habraken. Published as 'de dragers en de mensen, het einde van de massawoningbouw' (1961) the distinguishing between levels is elaborated by introducing the principal of the support and infill in architectural design. Therefore, the conception of time was now related to architectural design and a theoretical framework for Open Building was established. (Havik, Teerds and Habraken, 2011) Up till now, most dwellings have not been built for disassembly or built over-dimensioned and are therefore not resilient to cope with future challenges concerning climate change or demographic changes. Whereas architecture usually tends to appeal to the imagination of an independent object fixed on one layer in the layered model, green-blue infrastructure is more likely to be seen in relation to multiple layers.

As climate change is a problem affecting all the scales of the atmosphere (geosphere, biosphere, technosphere) BRON??, it consequently affects both the scale of architecture, the urban scale and the water cycle. In order to find out how green-blue infrastructure can be combined with Open Building it is important to get a clear understanding of the interrelation between the domains operating at the different layers. By examining the different layers through which the water cycle circulates and relating them to the layers of the Open Building concept, the similarities can be sought after to establish possible combinations in which green-blue infrastructure can be implemented.

Following the formulated problem statement, this research will focus on the implementation of Green-blue grids in a high-density mixed-use neighbourhood when applying the Open Building concept in order to create a 'net positive (circular) water cycle'. Research is being conducted by using the concept of Green-blue grids as the basis for climate proof (circular) neighbourhood development, a high-density mixed-use neighbourhood as urban setting and the Open Building typology as architectural component to sustain circular housing possibilities within future neighbourhood development. Aiming for the implementation of nature inclusive public spaces within the built environment, this leads to the following research question:

"How can GreenBlue infrastructure be integrated within the 'Open Building' concept to create/ contribute to a 'net positive (circular) (local) water cycle' which simultaneously achieves nature inclusive public space in a mixed use, high density neighbourhood?"

The following division of sub-questions is made to be able to answer the thematic research question:

- How are the constituents of the Open Building concept related to the constituents of the water cycle when aiming for a 'net positive' water cycle'?
- How can the Open Building concept contribute to a high-density neighbourhood and nature inclusive public space?
- What is the impact of densification on a 'net positive water cycle' and how can nature inclusive public space mitigate these effects?

1.1. Method

The research set about with a literature study into the different levels of decision making in Open Building and the different levels of the built environment in which the water cycle circulates, briefly described in the introduction. After these have been described in general, the water cycle and green-blue infrastructure will be examined more thoroughly in chapter two. In chapter three, a literature study is conducted which examines the research carried out by the Stichting Architecten Research (SAR) into the spatial properties of the typology of the in-between spaces. High-density and nature inclusive public space are defined within chapter four and chapter five will include the executed case studies. It is extended upon the conducted case studies to clarify how Open Building can contribute to a high-density neighbourhood and nature inclusive public space by means of research by design. Two case studies specifically concerning the principals of 'open building' are tested against the typology of the SAR and are conducted by means of analytical drawing. An addition of two case studies based on a selection of their green-blue characteristics has been made to put forward a comparable drawing analysis. The interdependency between the constituents of Open Building and green-blue infrastructure is discussed in chapter six. Lastly, the impact of densification on a net positive water cycle is explained and the possibilities of nature inclusive public space to mitigate these effects are given. By structuring the connection of Green-blue infrastructure with Open Building at different levels of abstraction, a better understanding of the interdependency within planning for urban renewal is put forward. In conclusion the outcome is analysed/ tested against the thematic research question.

II. THE WATER CYCLE

The dynamics of the water system at a regional level is determinant for the specifications of the corresponding area within the Netherlands. The ground-, rain-, and surface water combined with soft soil conditions are critical aspects to consider for the urbanisation and development of the Dutch polder. (Hooimeijer, 2011) p.11 Within the (natural) water cycle on, above and below the surface of the earth, water is in constant movement. (*usgs.gov*, no date) Although the water cycle is a naturally circular process on a global scale, it is constructed into a hybrid system of the natural and artificial within the smaller scale of the built environment. (Sugano and Lu, 2019)p4 Consequently, the process of water movement is more difficult to experience on an urban level due to a difference in scale and the distinguishing between the separate systems. The hybrid system within Dutch urban planning encompasses the water system and water chain. The natural cycle of water moving through the built environment as rainwater, surface water or groundwater is called the water system. The artificially constructed process called the water chain consists of the cycle which involves the extraction, treatment, usage and transport of water used for sustaining humans their lives. Taken together, they are part of the global water cycle. The process of the water chain includes the retrieval of water from the ground, rivers and lakes, and its treatment to make it safe for drinking or other uses. After usage, it flows down the drain or toilet and ends up in the sewer system where the waste water is transported to a treatment facility. After treatment has been done, the water gets discharged to the surface water. Therefore, the cycle of the water chain is complete. (*Waternet*, no date)

Urban Water Systems

The functioning of the hybrid system existing in the Netherlands can simultaneously be called into question with regard to its degree of circularity. Not only can the (natural) water system be understood as partly artificial by the pumping of polders, its combination into a hybrid system with the water chain also results in the inefficient use of rainwater as it is connected to the discharge of drinking- and sewer water. (Sugano and Lu, 2019)p.4 "*Traditionally, underground combined systems that collect both stormwater and wastewater have been used to protect urban environments from harmful effects, but in the last century they resulted to be not adequate and too rigid to face the climatic and demographic challenges.*" (Hooimeijer *et al.*, 2016) p.16 As more precipitation and a growing urbanisation over the past years is increasingly influencing the (natural) water system, it is thus putting pressure on the artificial system as well. Besides the benefits that a technological approach of combined systems brought society regarding improved hygienics, it has created an artificial water system that is unable to deal with increased rainfall and drought. (Hooimeijer, 2011)pp.103 & 286 The limited network capacity is prone to overflowing due to heavy rainstorms. Resulting in the sewers to discharge their surplus of mixed waste- and rain water into the surface water. Polluting the water quality as a consequence. Added to that, inconsequent quantities of water pose a negative effect on the efficiency of wastewater treatments. (Hooimeijer, 2011) p.302 & (Hooimeijer *et al.*, 2016)p.18

"Although some separated systems have been implemented in the Netherlands to separate domestic wastewater from rainwater, the majority of the installations stay as combined systems."
(Hooimeijer *et al.*, 2016)p.18

Another problem with combined systems is that they are currently reliant on grey infrastructure which is put primarily underground. Over the past centuries efforts have focused on water management, which has led to a decrease in the resiliency of systems. Water management often turns out to lead to a vicious circle in which additional measures have to be taken repeatedly (Remmelzwaal and Vroon, 2000). Moreover, there are a number of challenges in the subsurface that need to be considered. These include aspects such as subsidence, pollution, infrastructural damage and a lack of space for the implementation of new technological systems. Subsidence can cause entrances to dwellings to be inaccessible and sewer pipes can possibly shift in relation to the dwellings, which is likely to result in damage. It also has a negative impact on the water system because the ground level water rises relatively. This puts pressure on both the natural and artificial system.(Hooimeijer *et al.*, 2016) p22&23

The available space for expansion is limited (underground) here and costs for maintenance and/ or replacement of sewerage pipes are high. (Hooimeijer *et al.*, 2016) p18 This should therefore be considered when shifting towards the implementation of separate systems as a possible solution to climatic challenges. As stated by (Hooimeijer *et al.*, 2016) p22, *"the subsurface is also housing the natural system that is crucial for a stable, green, healthy and liveable city."*.

Hence, alternative solutions should be sought after which minimise the impact on the limited underground space and are less dependent on grey infrastructure. Alternatives that combine grey infrastructure with green-blue infrastructure in an urban context are likely to be the greatest effective strategy to mitigate flooding hazards and enhance system resilience. (Alves, 2020)p.4&5 An important characteristic of resilient water systems is that there is a certain amount of space reserved for the natural dynamics of water. Restoring the resiliency of water systems fits in with the change in thinking about water management that is currently taking place (Remmelzwaal and Vroon, 2000). Hooimeijer et al., (2016) p24 elaborates on this aspect by stating that within today's urban planning the focus is a reconnection with landscape and ecology. Opportunities will come to the forth by better organising the subsurface space. Flooding can be coped with and green structures will be provided, resulting in the decrease of heat stress. (Hooimeijer *et al.*, 2020) p.23 A resilient system recovers after a disturbance. The faster recovery or adjustment takes place, the more resilient the system becomes. Reinforcing the resiliency of water systems requires a change in thinking on a number of points, taking account of natural dynamics, which is not entirely predictable. It means that water is more than just a tool or obstacle to economic gain. Resilient water systems therefore require adjustments on the part of the people dealing with the system. This is giving water an increasingly important place in spatial planning (Remmelzwaal and Vroon, 2000). By means of green-blue infrastructure to achieve resilient water management, there are a number of types of water in the urban environment that need to be taken into consideration. These types of water are defined by high variables of flows of water quantity, quality and solids content. (Hooimeijer et al., 2016) p16

3.1. Net positive water cycle

A distinction in the urban water system is made between drinking water, waste water, rainwater, surface water and groundwater. The drinking water used in urban areas is extracted from purified surface water or groundwater. Mainly via the sewer system, the used drinking water is subsequently transported to a wastewater treatment system. This is where it is purified and discharged into surface water. By means of filtration, evaporation and discharge of storm water into the surface water and drainage system (the sewer system), the drainage of rainwater is regulated. (Hooimeijer, 2011) p302 states that in an average urban tissue, the balance between filtration, evaporation and discharge is respectively c.a. 40%, c.a. 37% and c.a. 23%. However, the conditions and choice of the surface material and its relation to green structures and the retention of rainwater in and on buildings are of great significance for water management when intervening in the urban tissue. As this is partly determining the balance between infiltration, evaporation and discharge, it is important to consider while striving for a solid water system. (Hooimeijer, 2011)p302 To achieve a circular water cycle in the built environment, possibilities for intervening in either the water system or water chain will be examined. The different types of water and their characteristics are further explained in appendix I.

Drinking water is increasingly becoming a scarce commodity. It is important to avoid wasting it. This involves not only reducing the amount of tap water, but also the usage of self-generated water (groundwater) and surface water. This also affects the drying up of the soil. In addition to saving on total water consumption, it is also important to replace good (and scarce) water with less good quality water wherever possible. Initiatives are ongoing in various parts of Europe to develop new concepts for waste water collection and treatment. These concepts are based on the separate collection and treatment of flows from households. The ultimate aim of these initiatives is to develop a more efficient system for waste water collection and treatment. The alternative must meet the objectives and preconditions of the current system while at the same time generating solutions to current bottlenecks. (Mels, 2005) There is a growing need for sustainable urban planning. One response to this is the growing popularity of ecologically inspired neighbourhoods or eco-neighbourhoods in the Netherlands and abroad

(Moentjens and Lüdtke, 2013). The idea of efficient water drainage through grey infrastructure has changed by now, and should be designed in a flexible manner that adapts to climate change while the usage of water for energy storage alleviates its impact on the water system. Based on the natural system and partly on the balance between water and land, coherence between the hydrological system, the soil, the subsurface and urban development can efficiently be accomplished. (Hooimeijer, 2011) p.311

"A new principle based on the perspective of the natural system can efficiently create, coherence between the hydrological system, the soil and subsurface (the natural system) and urban development" (Hooimeijer, 2011) p.311

Within the water system, a distinction can be made between reuse of water of the same quality, cascading and upcycling. Cascading means re-use of water in another function for which water of lower-quality can be used. Upcycling is the re-use of the water after, as an intermediate step, improving the quality of the water. Such quality improvement often takes place in a municipal water treatment plant (central water treatment plants or infiltration areas in dunes) but can also take place in the neighbourhood or near buildings (helophyte fields, lagoons, algae purification). Applications in the district or near buildings in particular can make an important contribution to the quality of the living environment by providing more greenery and water in the district and also provide water storage in the event of high-intensity precipitation. In order to make the step towards re-use, cascading and upcycling it is important (in addition to improving the living environment) to emphasize the products released during purification processes. In conclusion, to achieve a sustainable and hygienic water system in the near future, circular thinking is required. In addition to saving water and the use of renewable sources such as rainwater, attention must be paid to reuse (without loss of quality), cascading and sustainable upcycling. With such use of residual flows, it is important to distinguish between various water quality levels (drinking water, grey water and black water). Because many of these techniques also require energy and materials, the efficiency of these systems remains an important precondition; however, effectiveness is just as important. Effectiveness is also about emphasizing the desired products in water purification. (Tenpierik *et al.*, 2016) At the neighbourhood level, a circular water cycle can be integrated by converting grey and black water into usable raw materials and the water does not have to be drained the length of the sewage treatment plant. (Haan, 2018) The report 'Amsterdam Circulair' (Circle Economy, TNO and FABRIC, 2015) describes the ideal circular future within the organic value chain when the residual flows are delivered to consumers in the form of food or water of a high possible quality. This can be achieved by recovering organic residues in a high-quality manner and stimulating reuse in innovative applications (Circle Economy, TNO and FABRIC, 2015) p. 47 Decentralised management of waste water can be beneficial in areas with excessive water flow, such as densely populated urban areas. Further investment in waste water cascading and process technologies can bring major improvements. More energy, water and nutrients can be recycled. In the next paragraph the notion of green-blue infrastructure is examined. Its qualities, possibilities and implications as a possible solution for coherence between the hydrological system, soil and subsurface are discussed.

3.2. GreenBlue infrastructure

Increased exposure to prolonged periods of drought and heat waves, but also an increase in the frequency and intensity of peak floods and rainfall are among the expected features of climate change (Majoor, 2013). The urban area will be particularly vulnerable to the increasing risk of flooding and heat stress, as there are many paved areas and buildings in the urban area which prevent rainwater from escaping in the event of heavy rainfall (Jacobs et al., 2007). Whether the climate effects cause damage or nuisance is largely determined by the properties and density of the buildings, the presence of public green spaces and trees, available water features and the state of the sewer system (Ligtvoet et al., 2011). A possible solution to overcome the inability of a merely artificial urban drainage system to achieve adaptation to the effects of climate change is green-blue infrastructure. Based on its capability to simultaneously deliver environmental, social and economic benefits it is able to provide for a resilient alternative. (Alves, 2020) p.4 The interconnection of *"green (land) and blue (water) spaces can improve environmental conditions and therefore citizens' health and quality of life."* Together it will form a green-blue network of landscape elements which provide several ecosystem services such as biodiversity, water purification and regulation, air quality, space for recreation and climate mitigation and adaptation. (ec.europa.eu, no date) & (Opdam, 2009). Green-blue networks are additionally providing an iconic feature in urban areas and are able to support its cultural-historical identity in the long run. Functional coherence is an important aspect within this context, as it makes for a stronger network by combining its separate entities (Opdam, 2009). New possibilities to construct the organisation of the human and natural environment for the future transformation of the built environment are developed by utilising green-blue open spaces (Bacchin et al., 2014). Combining green and grey measures into a 'hybrid' is currently proposed as an alternative to conventional approaches. Green-blue infrastructure has the capability to complement current grey infrastructure due to their difference in advantages and objectives. (Alves, 2020) p. V Whereas grey infrastructure is mainly put in the limited space of the subsurface, will green-blue infrastructure manifest itself mainly at surface level. Its spatial impact will therefore pose implications on the design and implementation into urban areas. Within low-density areas, retention ponds and other centralised options will be preferred, whereas high-density areas prefer measures with less spatial impact. When space is limited, green roofs and rain gardens or other decentralised options will be the choice of preference. (Alves, 2020) p.28 As a spatial concept, green-blue infrastructure helps to balance and integrate ecological, economic and social values. Almost all the functions to which value is attached can be linked to the network. Private interests are linked to public interests. Users assign value to these functions and attach importance to them. The development of these values is in the interest of various parties, at various levels of scale, now and later. Different spatial scales and different time scales are also connected via green-blue networks. Therefore, green-blue infrastructure helps with e.g. sustainable area development.

SUSTAINABLE FUNCTIONING – LOCAL STEWARDSHIP
CO-BENEFITS (appendix?)
PUBLIC SPACE
DESIGN EXAMPLES + DESIGN IMPLICATIONS

III. OPEN BUILDING

Since the 1960s, Professor of Architecture John Habraken has conducted practical research into the relationship between change and the built environment. In this design approach (Habraken, 1976, 1961), he made a connection between the type of influence, the type of parties involved and the time (in use). In the first place, he concluded that the process with all the parties involved (development, realisation and management) had to be organised differently. Secondly, you also have to organise all the physical components and systems of the built environment differently. Habraken argues in favour of what is known as 'Open Building'. People who value their living environment will take better care of it and thus increase safety. So, it is important to design and manage buildings in such a way that they feel responsible for them. This can be achieved by designing them according to the wishes and needs of the users. This creates a working method that organises connections between the various levels of scale: city, neighbourhood, building, carrier, 'skin', service, installations, spaces, interior and the parties involved. Once the connections have been defined, one can organise the responsibility for them. This has consequences for the building process. Firstly, it requires a different way of organising decisions and responsibilities. In this context, Open Building separates a number of levels: land use, urban tissue, support and installation. The different levels require the input of different parties involved (professionals and non-professionals) and different methods and techniques for design, realisation and management. In addition, each level has a different lifespan, which can be predicted and determined. The second consequence is that you have to organise the physical component of the mentioned levels in a different way: development, production and management.

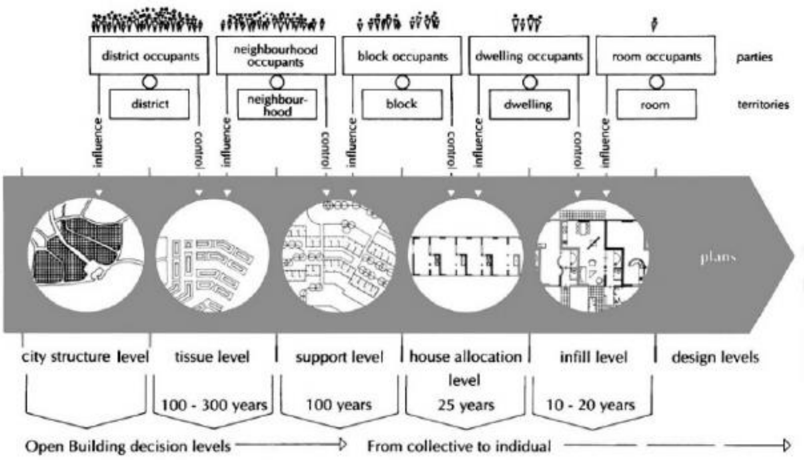

Figure 1. Levels of decision making (Habraken, 1961)

The SAR developed a building concept in which support and installation were combined. The installation can vary, adapt and expand according to the resident's wishes. The SAR method imposes a number of agreements and preconditions as guidelines to achieve good homes. In which people who value their living environment take better care of this. Therefore, in this context, open building separates a number of levels: land use, urban tissue, support and installation. In addition, they determine the location of the spaces on the basis of alpha, beta, gamma and delta zones according to their external boundaries. In this way, their function is considered, on the one hand, and their public or non-public character, on the other. (van der Werf, 1993)

http://urbanspringtime.blogspot.com/2018/03/the-open-city.html
http://uj-unit2.co.za/open-building-versus-architecture-or-open-building-as-architecture/
https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html -- WORLD POPULATION

2.1.1. Urban tissue

2.1.2. Support

2.1.3. Infill

IV. High Density and Nature Inclusive Public Space

Density is an important factor in the current spatial planning of the Netherlands. Policy is increasingly focused on infill within existing urban structures in order to preserve and guarantee green structures (Harbers *et al.*, 2019) pp. 1-4. Density is used in the literature to describe the relationship between a given area and the number of entities in that area. These entities can be people, services, homes or floor areas. These entities cause confusion within the literature. Density is reflected in differences in units of measurement and measurement methods. For example, a distinction can be made between plot density, volume density, net and gross housing density, general density and community density (Berghauser Pont and Haupt, 2007). Urbanisation has had a significant role in the modern history of urbanism and urban planning. From the Middle Ages onwards, urban structures have emerged, as they did in the Netherlands. With the advent of the industrial revolution around the 19th century, cities began to grow and people began to live around the industrial companies where they worked. As a result, urban structures with higher building densities were created. A study by (Nabielek *et al.*, 2012) p.8 into urban living and working shows that densification, restructuring and transformation within the existing urban area can contribute to achieving government objectives in the areas of accessibility, economy and the quality of the living environment. Densification could strengthen the attractiveness and liveability of urban areas. In addition, compaction around access roads and stations would optimise accessibility. In this manner, the urban economy could be strengthened by increasing the benefits of conurbation. An advantage of building with a high building density is that space remains elsewhere and thus the physical use of space in the open landscape is not affected (Lörzing, Harbers and Breedijk, 2007) p. 7. (Cheng, 2010) emphasizes that land is always a scarce resource within urban development. High building density, through the construction of tall buildings, can create more undeveloped space in other locations. High building density therefore helps to reduce the pressure on open space and frees up more land for communal facilities and services to improve the quality of urban living. (Uytenhaak, Melet and Mensink, 2008)pp. 14-15 elaborates on the issue and indicates that density ensures proximity to urban activities, greater urban dynamism and more efficient land use. Attractive locations can be created for residents, which can also give a qualitative boost to their immediate surroundings. As a consequence, the quality of life and urban dynamics can be enhanced. Support for urban activities would also be increased and distances to amenities would be reduced. This would enable more efficient use of existing infrastructure (Nabielek *et al.*, 2012) pp. 9-11. However, building with a high building density can also be disadvantageous. Too high building density can lead to a feeling of tightness. Too high building density can have adverse effects on the perceived density. In order to achieve high building density, large volumes of buildings are unavoidable and these structures, placed on a small surface area, can result in little open space and an overburdened cityscape (Bâldea and Dumitrescu, 2013);(Cheng, 2010);(Mitrany, 2005). (Nabielek *et al.*, 2012)p. 27 state that compaction on a local scale can lead to a reduction in the quality of the living environment. Causes may be increased traffic congestion due to pressure on the road network and the displacement of open space and green functions. The accumulation of congestion, noise and air pollution can be a downside of building with a high building density (Mitrany, 2005);(PBL, 2017). This also affects health and sustainability. Pressure causes functions to be displaced and, together with congestion and air pollution, affects sustainability. In addition, high building density can reduce the space for trees and shrubs, which purify the air and cool urban areas (Cheng, 2010)

V. CASE STUDIES

Case studies were selected on the basis of the conclusions of the (theoretical) research into the concepts of open building and green-blue infrastructure. The case studies were selected on the basis of selection criteria. These selection criteria are related to the characteristics and aspects found in open building and green-blue infrastructure. Lunetten, EVA-Lanxmeer, Hammarby and Buiksloterham are the selected case studies. Using an Excel table consisting of different water systems and features on the one hand and the different SAR spaces on the other hand, the case studies have been expanded. They examined which features are related to the water cycle and in what type of SAR-spaces they are present.

5.1. Impact

5.2. Solutions

5.3. Water processing systems + green-blue infrastructure applicable in open building neighbourhood

https://publicwiki.deltares.nl/display/SEES/Background

VI. DISCUSSION:

In the further process of my research design it is important to design in a way in which future residents feel responsibility for the building and their living environment. By designing the building in an adaptive and flexible way, the wishes of residents can be considered and adapted in the future. This creates relationships between the different scale levels of the city, neighbourhood, building, carrier, skin, service, installations, spaces, interior and the involved parties.

SUBQUESTION:
How are the constituents of the Open Building concept related to (the constituents of) the water cycle when aiming for a 'net positive (circular) water cycle'?

Open building
Water cycle
Net positive water cycle

SUBQUESTION:
How can the Open Building concept contribute to a high-density neighbourhood and nature inclusive public space?

Open Building
High-density neighbourhood
Nature inclusive public space

SUBQUESTION:
What is the impact of densification on a 'net positive water cycle' and how can nature inclusive public space mitigate these effects?

High-density
Net positive water cycle
Nature inclusive public space

VII. CONCLUSIONS. OPEN BUILDING & WATER SYSTEM IN HIGH-DENSITY NEIGHBOURHOOD

To examine how to create a net positive water cycle in a high-density neighbourhood by combining open building features with green blue infrastructure features research into the water cycle is carried out. In relation to the water cycle, various themes have been examined. Themes related to the water system, water chain, urban water systems and net positive water cycle in terms of the different present types of water and what is required for potential circularity. It was concluded that there are different ways for water to enter a city and different ways to handle water to create a circular system. The different types of water cited in the study are surface water, groundwater, rainwater, wastewater and drinking water. These conclusions will be considered in further research and design to develop new ways to optimise the collection and treatment of waste water in a high-density neighbourhood. These concepts will be based on the separate collection and treatment of water flows from households. A challenge here is that current water systems must be considered, but a different scope must also be provided for new developments. At the neighbourhood level, the water cycle could therefore be implemented by converting grey water and black water to raw materials, without having to drain the water along the entire length of any sewage treatment plant. Subsequently, the concept of open building was further researched. Themes such as urban tissue, support, infill and SAR methods were addressed. John Habraken's theories came to the fore in the research. He made a relationship between the type of influence, the type of party involved and the (used) time. In the first instance, it was concluded from this that the process with all parties involved (development, realisation and management) had to be organised in different ways. Secondly, it was concluded that the physical components and systems should also be organised in different ways in the built environment. Habraken argues in favour of an alternative housing concept in which the individual is given the opportunity to give form to the house himself within a collectively organised carrier. The SAR developed a building concept in which support and installation were combined. The installation can vary, adapt and expand according to the resident's wishes. The SAR method imposes a number of agreements and preconditions as guidelines to achieve good homes. In which people who value their living environment take better care of this. Therefore, in this context, open building separates a number of levels: land use, urban tissue, support and installation. In addition, they determine the location of the spaces on the basis of alpha, beta, gamma and delta zones according to their external boundaries. In this way, their function is considered, on the one hand, and their public or non-public character, on the other. No unambiguous conclusion could be drawn on the basis of the case study research. Different water systems and features were found in different SAR rooms and makes the conclusion broad in nature. This gives a wide range of scope and possibilities for further (design) research.

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(Hooimeijer and LaFleur, 2018)
(Harteveld, 2014)

VIII. APPENDIX I

WATERCHAIN

Drinking water

Drinking water is vital. In the major part of the Netherlands, drinking water is prepared from groundwater. Groundwater in the west of the Netherlands is not suitable for the production of drinking water because it is too saline. Water from the Rijn and Maas is mainly used for this purpose. Climate change will increasingly affect the business operations of water companies. Measures are needed to ensure sufficient and safe drinking water in the future. These include the following measures:
- Comprehensive water treatment by drinking water companies.
- Comprehensive wastewater treatment by wastewater treatment plants.
- Aligning the granting of discharge permits with low river discharge.
- Adapt authorization policy for substances and take climate change impacts into account.
- supplying additional water so that discharges of waste water into the river are better diluted.

(Ondersteijn, 2014) p.6

Waste water

The protection of the living environment, soil, groundwater and surface water requires adequate treatment of waste water generated in homes, businesses and many other objects.
Prior to 1970, the policy in this regard was already aimed at the collection and relocation of waste water by means of municipal sewage systems. What is needed and what may be needed is decentralized wastewater treatment plants.

Greywater

Grey water from the shower and bath, and rainwater can be (re)used as domestic water, for example for toilet flushing or washing machines. This leads to less low-value use of drinking water, re-use of waste water, less waste water to be purified and recovery of rainwater. This promotes sustainability in the water chain. The design of these systems is complicated because many daily variations occur in the supply, rainfall is seasonal and there are dynamic differences in the use of showers and baths, depending on the family composition and the mains water system. There are also daily variations in use and water demand of toilet and washing machine. The supply of grey water and rainwater often does not match demand over time: storage tanks are therefore required in order to match supply to demand (Pieterse-quirijns *et al.*, 2012) p.39. Due to the relatively high investments in local wastewater treatment systems and additional pipelines, greywater and rainwater systems are considerably more expensive than the conventional single network. (van den Burg, van Buuren and van Vliet, 1999)

Blackwater

In households, concentrated and less concentrated wastewater flows are generated. A distinction is generally made between black water (urine and faeces) and grey water from baths, showers, washing machines and kitchens. In the current collection system, these wastewater flows are discharged mixed. Usually, rainwater is also discharged via the sewer system. Further dilution takes place by mixing with inflowing surface water, leaking water and source water. (Mels, 2005)

WATER SYSTEM

Rainwater

Rainwater can almost always be discharged directly into surface water or infiltrated into the soil. Only when rainwater comes from (intensively used) roads it should be treated as wastewater, because of the possible contamination with PAH, mineral oil and/or heavy metals. Rainwater is quite easy for private individuals to transform into use water. Before storage (usually underground) a simple sand filtration is sufficient (due to possible bacterial growth). Various techniques are already on the market for this purpose. The water is then suitable for all purposes, except as drinking and bath/shower water (Bentvelzen, 2008) p.7.

Surfacewater

The greywater that is emitted in the bathroom, from washbasins and from the washing machine is treated on a local scale and, together with rainwater, infiltrated or discharged into local surface water. Waste water from the dishwasher in the kitchen can also be fed into this greywater treatment, but could be introduced into the blackwater drain together with organic waste given its relatively high concentration (Mels, 2005) p.15.

Groundwater

Important secondary functions of sewerage systems in many urban areas are, in addition to the disposal of wastewater, the drainage of rainwater and excess groundwater. In municipalities with a high groundwater level, groundwater infiltrates the sewer system through deliberate or unconscious leaks. Recent research shows that in some places this causes up to 80% extra water to be discharged through the system over and above the discharge of the combined flow of urban wastewater and rainwater (Mels, 2005) p.3.