Research Plan

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Title: Closing the hydro loop
Sub-title: Sinergy between decentralized urban water systems and constructions in the built-environment

Research domain: Make and Flow
Epistemes: Ecology (natural environment) and Morphology (shape, form)

Keywords: Hydrological cycle, Small Island Developing States (SIDS), circular economy, closed city, biomimicry, decentralized water management system

Glossary of key terms

The **hydrological cycle** crosses three environments: the geosphere, the biosphere, and the technosphere. In urban areas it consists of two systems, the natural water system and the water chain (Hooimeijer et al, 2019).

Small Island developing states (SIDS) are a distinct group of 38 UN Member States and 20 Non-UN Members/Associate Members of United Nations regional commissions that face unique social, economic and environmental vulnerabilities.

Circular economy, is based on three main principles: 1) designing out waste and pollution 2) keeping products and materials in use and 3) regenerating natural systems. It provides a framework for "*a new way to design, make, and use things within planetary boundaries*" (Ellen Macarthur Foundation, 2020).

Closed City is defined as "a city that does not have adverse effects on its surroundings, such as water depletion or emission of pollution" (Hooimeijer et al, 2019). This proposal is to improve the water storage and water purification capacity of cities, to store and recycle rainwater and sewage.

Biomimicry is "design inspired by the way functional challenges have been solved in biology" (Pawlyn and Safari, 2019)

Research fascination

''Architecture must serve the people.'' – (Pohl & Nachtigall, 2016)

Freshwater sustains human life and is vital for human health [plants harvest literature]. According to GSO (2017) only 1 percent of the water on earth is available as fresh surface and ground water, making this a scarce good. How to treat water properly is an urgent challenge that many Small Island Developing States (SIDS), such as Curaçao, face, especially if they are largely urbanized. I am interested in exploring how to respond to this challenge from the perspective of architecture. According to Pawlyn and Safari (2019) architecture and its conventional building structures have tended to draw down on natural capital, like the hydrological cycle, whereas ecosystem thinking and looking at nature as examples provide opportunities to do the opposite. Like the quote mentioned above from Pohl & Nachtigall (2016), architectural structures should not solely fulfil a functional purpose for human beings, but help regenerate the environment where they are built in. This is also in line with the idea of Pawlyn and Safari (2019) where they state that there is a need to change from the industrial age of thinking, where ecosystems are neglected, to an ecological age of human kind. If we increasingly shape the built environment with this in mind then (I believe), over the next few years, we can create spaces that are healthy and regenerative for their inhabitants and infrastructure that becomes integrated with natural systems.

The interest that has grown over time is to analyse how technical solutions in the built environment can help harvesting and reusing water in order to relieve the pressure on freshwater demand in semi-arid climates, like that of Curaçao. Water consumption by man continues to grow with the increasing population (Pohl & Nachtigall, 2016). The current supply of fresh water needs to be supplemented to meet the future needs. Solutions to these problems may come from learning how living nature deals with these same issues . According to Pawlyn and Safari (2019) architects, designers and engineers already design inspired by the way functional challenges have been solved in biology. This is called biomimicry. Because buildings contribute to these problems greatly, this research paper focuses on using sustainable water treatment techniques in the built-environment.

Problem statement and research questions

The problem statement is derived out of 3 components from more generic to site specific:

1. Fresh water treatment issue in urbanized regions in small island developing states
2. Water treatment issue in Curaçao
3. Urban periphery of Willemstad context

1) Fresh water treatment issue in urbanized regions and SIDS:
According to Gurera and Bhushan (2020) it is estimated that 2 billion people live in counties that are experiencing problems related to high water stress. These problems are often found in urbanized areas around the world. The increases in population and building density that occur in these progressively urbanised areas can have a far-reaching effect on the *hydrological cycle* and therefore on both the quantity and quality of water resources (Hall & Ellis, 1985). The hydrological cycle can be split into two elements; natural water system and water chain.

A trend to live in urbanized area has developed greatly in Curaçao. According to the Government of Curaçao et al (2019) 75% of the population on Curaçao lives in urbanized regions, that makes up of quarter of the total area of the island, which is classified as a highly urbanized countries. Looking at the hydrological cycle of Small Island Developing States (SIDS) numerous challenges occur due to their biophysical settings. SIDS are at the forefront of climate change and its consequences, particularly with regards to their freshwater resources, where 91% is threatened by water shortages (UNESCO, 2019). Also problems relating to the pollution of ground water and surface water due to

saline intrusion can be found on these types of islands. As stated in UNESCO (2019) ,SIDS are often surrounded by the ocean, making their ground prone to saline intrusion, causing 73% risking groundwater pollution.

As mentioned above there are many resident living in urbanized areas facing the issue of the quantity and quality of fresh water resources. Researchers like Pawlyn and Safari (2019) state that our standard approaches to water have an inherent technological laziness to them that has developed from the same assumptions of limitless supply that characterised our attitude to resources at the start of the Industrial Revolution. By introducing the hydrological cycle in our built environment, buildings could be seen as the connection between the water chain and its inhabitants.

2) Current water treatment and production in Curaçao:

On Curaçao the importance of freshwater is tangible (GSO, 2017). One of the main problems on the island is the lack that management and infrastructure of freshwater have in order to cope with the natural water system and water chains. This main problem can be divided into the following: 1) issues in the catching and managing of rainwater and groundwater, 2) issues in the harvesting of fresh water and 3) the lack of treating waste water.

Despite imminent shortages, Curaçao allows rainwater to drain unused into the sea (GSO, 2017), which not only effects the quantity of fresh water resources on land but also pollutes the ecosystems in the ocean. This inadequate management contributes to the pressure of harvesting enough freshwater for the inhabitants and tourists, but also for flora, fauna and agriculture, for example to produce food or renewable building materials.

To produce freshwater, a reverse osmoses production plant, named Aqualectra, was built on the island. This plant produces freshwater for 98% of the households (Central Bureau of Statistics, 2018). However, the production is a time and energy consuming process which makes the fresh water expensive. According to Wesselink (2015) the cost per cubic meter of fresh water in Curaçao is seven times more expensive than that of the Netherlands. In addition to this, Curaçao faces the pressure of producing enough freshwater for the inhabitants and tourists (Antilliaans Dagblad, 2019). Although the population growth on the island has flattened, there is still a big growth in tourists visiting it. According to Antilliaans Dagblad (2019), tourists drink up to 300% more water than inhabitants of the island. Another problem the plant faces is the loss of produced water, due to deteriorated pipe lines and illegal tapping of fresh water. It has been stated in the 2019 Annual Report of Aqualectra (2019) that 27% of the produced water of Aqualectra is lost in the process of distributing it to the people.

Another challenge facing Curaçao is the lack of infrastructure and treatment of waste water. At the moment only 18,6% of the households are connected to a sewage system, while 77,1% to a cesspool and 3,4% to septic tank or other means (Central Bureau of Statistics, 2018). This consequences lead to the illegal dumping of waste water back into the ecosystems. According to Hendriksen (2019) 1.6 million guilders was invested to build a new water waste treatment plant, specially designed to treat polluted water in order to dump it back in the ocean. Linear solutions like these are implemented even though 2% of the people on the island can’t afford their monthly water bill (Ministry of Economic Development, 2021). Currently, there are four different wastewater treatment plant on Curaçao built by the government, but these do not function well due to inadequate machinery and treatment techniques.

To conclude, there is a high freshwater demand which is currently provided by an expensive, energy consuming production method (reverse-osmoses desalination method), while much water is lost due to inadequate management. Wastewater, if collected properly by an infrastructure, could partly fulfil the high demand for water on the island.

3) Urban periphery of Willemstad context
The urban region of Curaçao is concentrated in Willemstad (centre and periphery) and is located in the centre district of the island. This part is in transition from a unsustainable developed urban area, that grew out of new neighbourhoods built for the labour class during the early days of the prosperous oil refinery and 20th century modernist suburban expansion (Ministry of Economic Development, 2021), into a green and healthy living environment. In the past, water reservoirs and greenery where depleted in order to build these scattered neighbourhoods and car infrastructures. Due to this depleting of natural environment, problems related to quality and quantity of water started increasing. Therefore, in the Objectives for the community-based vision 2030 of the New Urban Agenda, it is stated that the drainage system, wastewater collection and treatment system functions would be optimized and integrated in a sustainable water management cycle (Government of Curaçao et al., 2019).

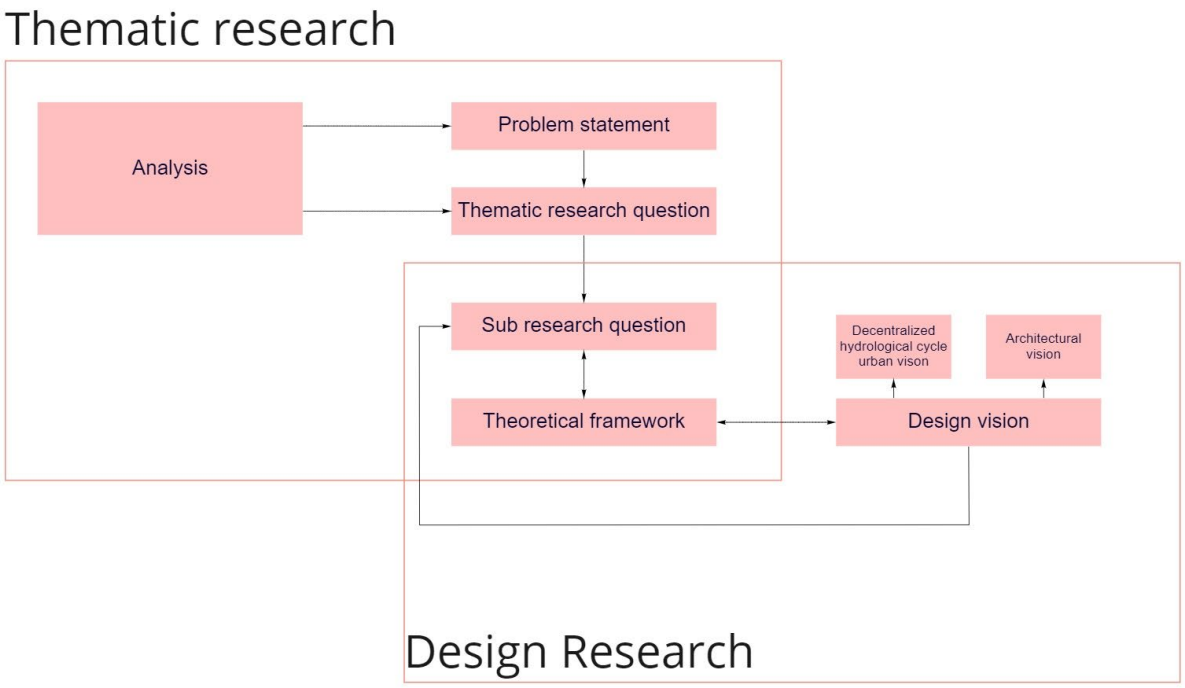
The above mentioned research fascination together with the problem statements, followed to the **Design question:**
How can a decentralized water management system (closed loop) on neighbourhood scale in Willemstad be connected to a public programme to increase the communal awareness of the finite resource of freshwater?

The thematic research focusses on the life cycle of water in the built environment. Harvesting and reusing of freshwater in the urban water cycle is seen as an essential part of a circular approach to this natural resource. Thus the following **Thematic research question:**
Which techniques exist for harvesting, treating and storing water as part of a decentral water management system (closed loop system) on neighbourhood scale which are beneficial for the local ecosystem and built-environment?

Developed further via **sub questions** (see appendix image 2):

- *What is the current situation of the freshwater treatment flow of Curaçao (in the context of the urban hydrological cycle)?*
- *What (biomimetic) techniques exist to harvest freshwater (water storage, capturing water with gravity, capturing water against gravity, water transport, managing excess water and minimising water loss) and treat wastewater? What are the challenges for these solution in arid or semi-arid climates?*
- *How can these techniques be integrated on neighbourhood scale?*

Image 1: Relation Design question and Thematic research question (own image)



Theoretical framework:

The theoretical framework for the project integrates the principals of decentralized water management systems, like the Closed City concept, explained by Hooimeijer et al (2019) and the principals of biomimicry (Pawlyn & Safari, 2019) which offers a more ecologically-oriented approach.

The 'Closed City' theory calls to reinvent the connection between urban space and water management and insist in designing decentralized water circulation systems. This proposal is to improve the water storage and water purification capacity of cities, to store and recycle rainwater and sewage (Hooimeijer et al, 2019). This is believed possible by creating a self-sustaining water circulation system that responds to water shortages and floods. Hooimeijer et al (2019) state also that 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.

In the opinion of Pawlyn and Safari (2019) buildings can be seen as the scale that connects the city and its urban water system to its inhabitants. Therefore, this research will focus on the role that architecture could play in the urban water system. According to Pawlyn and Safari (2019) biomimicry calls to reframe conventional design methods of architectural structures by recognizing that ecosystem thinking an looking at nature as example for designing could provide opportunities for architects in order to create architecture that could for example harvest, capture, store, transport and reuse water. Therefore, the principals of harvesting water with constructions in the built environment will be used as a tool to enhance this approach.

Methodological positioning

Overarching methodology:
For this project is *scenario planning*. Inspired by the 'Closed City concept' described by Hooimeijer et al (2019), scenarios are imagined relying on the ideas of decentralized water management system and circular economies. In order to formulate scenarios that will assist me in gaining knowledge for the research, as well as for the design, the theory of biomimicry in architectural design principles (Pawlyn & Safari, 2019) is also studied.

Defined scenario for the thematic research:
Where decentralized closed water systems are implemented as part of a advanced circular approach to relieve the pressure on freshwater availability in Curaçao. This scenario shifts the emphasis from current conventional centralized water management to technical and practical challenges of the transition into a decentralized closed water system where building construction are needed to be designed as part of an advanced regenerative circular economy. Allowing exploration in techniques of freshwater harvesting and wastewater treatment.

Research Methods

(See appendix image 3.)

Thematic research methods:

Literature review: academic literature and scientific articles providing an overview of existing knowledge on:

- Hydrological cycle: definition, flows, challenges.
- Closed City concept: definition, economic challenges, environmental and social benefits.
- Circular water systems: definition, economic challenges, environmental and social benefits.

- Biomimicry in architecture: definition, economic challenges, environmental and social benefits.
- Biomimetics in harvesting, capturing, storing, transporting and reusing water.
- Different plant species and there capacities of extracting, storing and transporting water in semi-arid or arid climates.
- Different biomimetic and non-biomimetic technical solutions in the built-environment which create smart ways of harvesting, capturing, storing, transporting and reusing water

Interviews:
- Stakeholder interviews that are in the business of creating and improving techniques of built structures in order to play a role in water harvesting.
- Stakeholder interviews in the business of reusing wastewater

Case studies: Case study analysis of different examples that show interventions and biomimetic solutions for storing, capturing, harvesting, transporting and reusing (waste)water.

Experimentation: This part is used to bridge the gap between the academic an practical work. I would like to do experimentation with creating forms to better understand the physical challenges in creating a space that both tackles social aspect and technical aspect of harvesting, capturing, storing transporting and reusing water.

Quantitative analysis: the hypothetical case of the decentralized water treatment plantation, placed in periphery of Willemstad, is tested further with a quantitative analysis of potential saving in energy and cost in the renewable used water.

Contextual-research methods:

This part will be done parallel to the thematic research in order to compliment the architectural programme that will be added on a plantation in the Periphery of Willemstad. The added program should boost the concept of decentralized circular water treatment in order to re-establish the hydrological cycle in the area.

Argument of relevance:

Disciplinary relevance:

Circular water treatment is one of the key elements in order to tackle the contemporary issue of climate change and consequent changing of the hydrological cycle in urban areas. In Curaçao water processing companies and wastewater treatment facilities have already made steps in order to down the pressure on freshwater resources, like desalination reverse osmoses plant and waste water treatment plants. However, there remains problems in the urban hydrological cycle in SIDS on how to collect and treat water properly and efficiently.

Allot of research is done on how to create closed water cycles that inspired by mimicking solutions found in nature. For the building level there has been allot of research done based on biomimetic approaches for freshwater treatment and waste water reuse.
Thus, based on the existing knowledge on decentralized closed water cycles and freshwater harvesting and wastewater treatment technologies, this research would try to get an insight into the feasibility of managing the natural water system and water chain on the scale of a neighbourhood.

Societal relevance:

This research is also of great societal relevance because currently, many residents of SIDS are not aware of the importance of creating closed urban water cycles. In order to realize the circular hydrological cycle in urban areas, community involvement and awareness can be a crucial part. A closed urban hydrological cycle is not only beneficial for the quantity and quality of fresh water resources but also beneficial for providing a healthy living environment for residents. Residents will

have more possibilities to work together with their communities on treating the freshwater from their neighbourhoods. This would enhance the cohesion in the sprawled neighbourhoods of Curaçao which is missing at this moment.

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APPENDIX (See next page)

Image 2: Relation between sub-questions

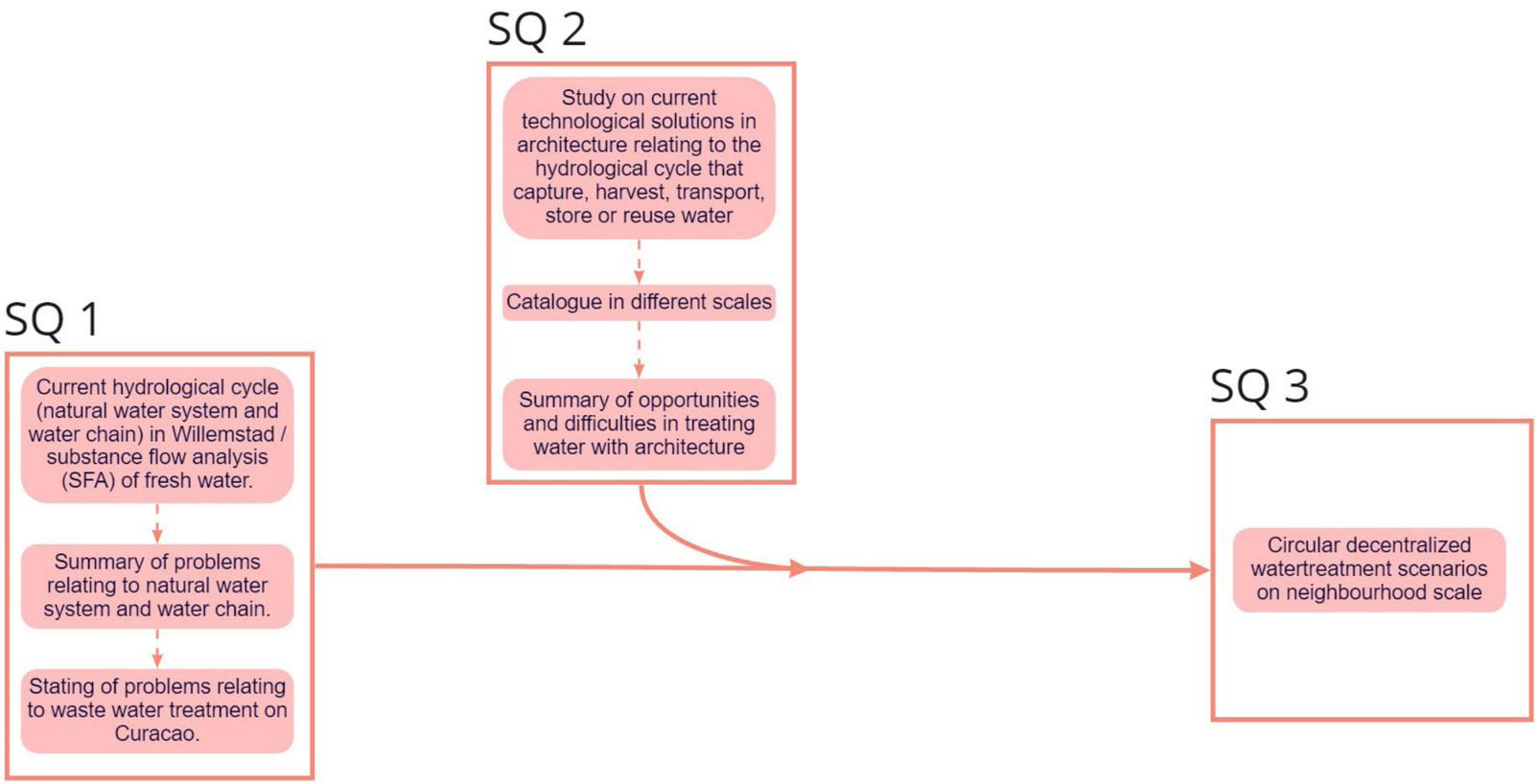

Image 3: Description research methods sub-questions

Sub questions:	Needed data:	How can this data be collected?	How will the data be analysed?	What will be the expected result?	How will this research inform your design?
o ***What is the current situation of the freshwater treatment and wastewater treatment flow of Curaçao?***	***Literature*** *on the following flows defined in the urban water systems of Curaçao:* • *General: current natural water cycle* • *General: current anthropogenic water chain* • *Specific: current freshwater treatment flow* ***Stakeholder interviews*** *that actively participate in:* • *Urban water systems of Curaçao* • *Wastewater treatment of Curaçao*	*Via internet and library* *Via interviews with different companies and initiatives like:* • *Aqualectra: Desalination plant on the island that is the main production line of fresh water for inhabitants* • *Public Works Curaçao: Company that manages the only four sewage treatment plants on Curaçao* • *Nos Bario :initiatives that aims for a watermanagement system in new neighborhoods so that waste water can be reused*	*Research will be done doing an Substance Flow Analysis (SFA) on the different water flows in the urban water cycle of Curaçao.* *Specifically the wastewater flows will be analysed by doing a SFA.* *Research will be done on the current methods wastewater is treated on the island.*	*Expected result will be:* • *The urban water cycle will be a linear process, especially the anthropogenic water chains.* • *Thewater streams of the natural water chain are insufficiently used and become wastewater that is disposed back into the ecology.* • *Current fresh water flows to the inhabitants are centralized, unsustainable, inefficient and costly.*	*Studying and analysing the different water flows in Curacao can inform me as a designer which streams could be potentially used in order to create a closed/ sustainable urban water cycle.* *It also gives an idea of the relevant bottlenecks in the urban water cycle, which I as an architect can interfere.*
o ***What biomimetic techniques exist to treat fresh water (water storage, capturing water with gravity, capturing water against gravity, water transport, managing excess water and minimising water loss)?*** *What are the challenges for these solution in arid or semi-arid climates?*	***Literature*** *on different biomimetic techniques in the built-environment, derived from plants and animals living in arid or semi-arid climates that survive by smart ways of water storage, capturing water (with gravity), capturing water (against gravity), water transport, managing excess water and minimising water loss in these dry climates.* ***Interviews*** *with people in the business of biomimetic interventions in urban water cycles.* ***Case study analysis*** *of different design projects that show biomimetic interventions and solutions in the built-environment.*	*Via the internet or library.* *Via interviews with different companies and initiatives like:* • *Botanic Garden in Delft: Interview with the director of the Botanic Garden, Bob Ursem.* • *Leo Gommans: Works at the Faculty of (department of Architecture Architectural Engineering) and specializes in climate design and sustainability* *Case study analysis:* • *Andrew Parker & QinetiQ: Produce a type of plastic with the same combination of hydrophilic and hydrophobic surfaces to enhance condensation.* • *Sahara Forest Project: translated biological forms of water harvesting into building proposals, principally those of a fog-basking beetle.* • *The Seawater Greenhouse: an invention by Charlie Paton that uses the evaporation of seawater to achieve factor-8 savings in irrigation.* • *The Las Palmas Water Theatre: proposed for Gran Canaria in the Canary Islands by Grimshaw demonstrates how the challenges of water shortages can be transformed into creative solutions.*	*Research will be done in analysing biomimetic techniques, divided into 5 categories:* • *water storage* • *capturing water (with gravity)* • *capturing water (against gravity)* • *water transport* • *managing excess water* • *minimising water loss*	*Expected result will be that each category will have different biomimetic techniques based from specific specie (cacti, trees, plants, animals etc.).* *These different means and strategies will be mapped out and catalogued into a toolbox which will be informative for the design phases.*	*Studying adaptations in biology can reveal solutions to some of the most intractable problems, like harvesting water in dry arid or semi-arid climates. These different biological forms of dealing with water can inform building principles.*
o ***What biomimetic techniques exist to reuse wastewater?*** *What are the challenges for these solution in arid or semi-arid climates?*	***Literature*** *on different biomimetic solutions in the built-environment which create smart ways of recycling and reusing wastewater.* ***Case study analysis*** *of different projects that show interventions, derived from biomimicry, in wastewater treatment.*	*Via internet and library* *Case studies on the following projects on wastewater treatment:* • *Berlin Water Competence Centre* • *Bauer Nimr LLC, Muscat: (Constructed wetlands vertical flow)*	*Research will be done on analysing the different technical innovations, derived from nature, in the wastewater treatment.* *The different wastewater treatment systems will be analysed on their different methods and capacities.*	*Expected result will be that there are different solutions to treating different types of wastewater. Each system will also be influenced by the climate it is situated in and its function in the context.* *These different wastewater treatment systems and strategies will be mapped out and catalogued into a toolbox which will be informative for the design phases.*	*Studying different strategies, biomimetic solutions and looking at existing case-studies can enrich the potential use of such systems and the way they are designed. These different findings on how it is built, why it is built and for whom it is built can inform me as a designer.*
o ***How can these techniques be integrated on neighbourhood scale?***	*Data required from the above mentioned sub-questions* *Quantitative testing of potential water accumulation* *Design testing of different of different functional forms*	*Via answering the above mentioned sub questions* *Quantitative analysis* *Experimentation*		*Expected result will be that substantial surfaces are needed to implement a decentralized water treatment facility on neighbourhood scale.* *The elements to harvest and treat water are expected to be functional and therefore it is interesting to see how the experience can be boosted, while also being informative.*	Studying how different technical volumes, found in earlier sub-questions, can interplay with each other could inform the composition of my design