A REEDBED-BASED WATERCYCLE SYSTEM DESIGN FOR AN ISLAND NEIGHBORHOOD, STRANDEILAND

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ABSTRACT

The objective of this thesis is to make a local watercycle system design for a new neighborhood, Strandeiland, Amsterdam. Strandeiland is the 2nd phase of IJburg housing project and the construction is expected to start in 2020. Just like most conventional neighborhoods in the Netherlands that adopt linear economy, discharging all mixed effluent to the wastewater treatment plant is the main solution for wastewater management, which consumes a lot of energy and all the nutrients and heat embodied in wastewater is lost. Learning from the cases of Waterschoon and Eva-lanxmeer, a new reedbed-based watercycle system is proposed in Strandeiland. Saving water resources can be achieved in three ways: 1. reducing the consumption of drinking water, 2. collecting and using rainwater instead or 3. recycling the wastewater. Domestic rainwater harvesting system and vacuum toilets can effectively reduce the clean drinking water consumption, getting more concentrated blackwater for further recovery. By separating wastewater streams from the source, less-polluted wastewater can get purified with biofilters, which requires less energy and performs environmentally friendly. The treated water then can join the watercycle again to achieve 100% water self-sufficient with only rainwater supplemented. Further research is required into utilizing reed waste as building materials. Solutions based on integrated synergies can be supportive evidence for decision-making in the architectural and urban design process.

Keywords: *Wastewater, reedbed filter, circular, neighborhood*

I. INTRODUCTION

The water scarcity problem is one of the most serious risks facing the world because only 0.5% of surface water on the Earth is suitable for human consumption. As the world population keeps increasing and is estimated to reach 8.1 billion in 2025, people's daily activities require larger amounts of fresh water and produces polluted wastewater, which brings heavy burden to the earth. Regarding the influent, water has gone through an energy and carbon intensive process of filtration, chemical treatment, and pumping from miles away, just to flush down a toilet or water the lawn. When talking to the effluent, the main solution for most wastewater management in the Netherlands is to discharge all mixed effluent through sewer to the wastewater treatment plant, reflecting linear economy. Nutrients and heat embodied in wastewater is always lost. All too often, water mistakenly is considered a cheap resource - and wastewater is seen as disposable. This must change. Now is the time to explore circular water management solutions and prevent these valuable resources from being lost. An island neighborhood, acting as clusters where human's activities are happening within, is a good test ground for system-level interventions because of its clearly defined boundary.

IJburg is a housing project to be located in an artificial island raised from IJmeer, Amsterdam, which will be realized in 3 phases (see figure1). Strandeiland, also called IJburg 2, is a neighborhood of 8000 dwellings expected to start construction in 2020. *The Amstel, Gooi and Vecht Waterschap/Waternet* take the main credit for supplying drinking water and cleaning wastewater in North-Holland area, including IJburg. The drinking water is mainly pumped from the surface water in Amsterdam-Rijnkanaal and Bethune. The energy intensity of municipal water supplies on a whole system can range from 1,250 kWh/MG and 6,500 kWh/MG. The CO2 embedded in the nation's water represents 5% of all Dutch carbon emissions [1]. Thus a new sanitation system is required to replace the conventional one with large energy consumption, high emission and little recovery.

18 years after the first residents moved in IJburg 1, now it appears a good chance to evaluate the system performances and make improvements on IJburg 2. This research paper is embedded in an Architectural engineering graduation project, that aims to develop architectural and urban interventions that helps with the utilization of wasted resources and forming a circular neighborhood with strong local identity.

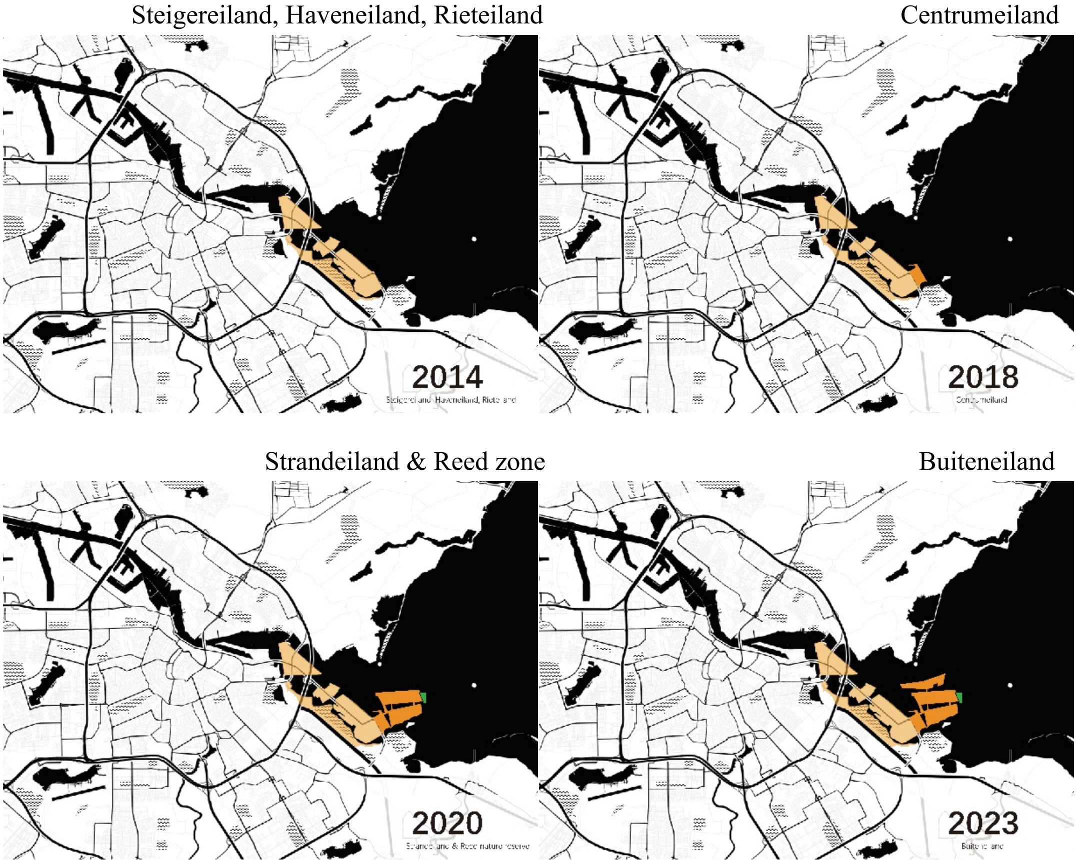

Figure 1. Different phases of IJburg housing project

II. RESEARCH METHOD

2.1. General scheme

For a complex research with more than one system involved, it is important to define the system boundary first. Considering that Strandeiland is an island neighborhood, the first system boundary of the coastline is clear. In order to demonstrate the detailed water-use with daily activities and how they flow, the second system boundary, per household, is also introduced (see figure 2). The general scheme is to compare the conventional sanitation system and the visionary sanitation system within these two system boundaries. When zooming out, it shows a comprehensive overview of the total watercycle in the neighborhood, showing the input and output and recycling process. When zooming in, detailed waterflow and consumption per household is illustrated.

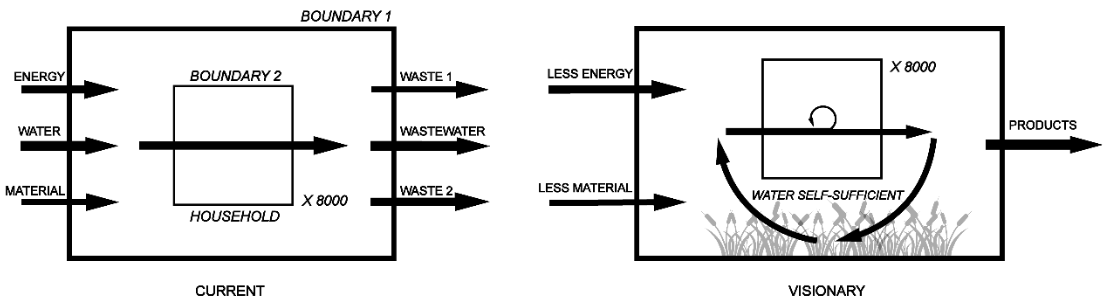

Figure 2. General scheme about two defined boundaries and flows happening within

2.2. Data collection

The main method used to collect data is by online resources, literature and field research. Existing pioneer cases in the Netherlands are taken into consideration for references. In this paper, the data related to helophyte filters and blackwater recovery are separately collected from Eva-lanxmeer and Waterschoon, both of which prove to perform well in system level. Additional assumption and conversion factors are also permitted. All the calculations and sources are listed in the appendix.

III. Research question

3.1. Main question

- How to build a circular water system with reedbed filters in Strandeiland?

3.2. Sub question

- What's the water-use and wastewater composition per household?

- How to recycle wastewater both in building level and neighborhood level?

- How to form the water cycle with reedbed filters?

IV. Content

4.1. Watercycle per household

The average daily water consumption of a Dutch person is 121.2 liters. The main uses of household drinking water are showering (43.9 %), the toilet (27.9 %) and the machine washing of laundry (13.0%). The data of water demand has already taken usage frequency into account, which is more scientific. The wastewater generated from toilets is called blackwater and in correspond to that, greywater is wastewater from any household source other than toilets. The conventional sanitation system discharges all mixed effluent (120.2 liters/per person/day) to the wastewater treatment plant. The treated water will end in draining into the surface water. This linear process of wastewater treatment has been proved to have large consumption, high effluent and almost zero recovery. Wastewater should be separated from the source, which is of vital importance to simplify the wastewater treatment process.

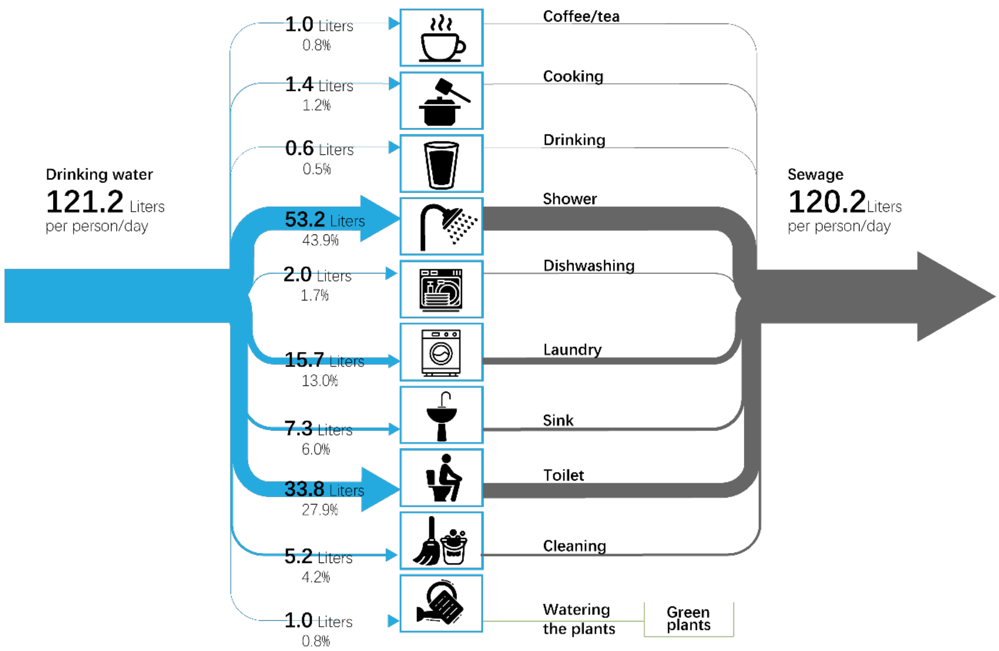

Figure 3. Conventional household water-use [*Watergebruik thuis 2016-Vewin]*

Saving water resources can be achieved in three ways: 1. reducing the consumption of drinking water, 2. collecting and using rainwater instead or 3. recycling the wastewater. For example, by using a vacuum toilet, per person can reduce the water-use by 22% and reduce the outflow of highly contaminated blackwater by 77.7%. The vacuum toilet only uses 1 liter per flush compared to 13.6L for a normal. The contamination in the remaining 7.5 liters of blackwater is then far more concentrated and makes it therefore suitable for fermentation. Except that, we found that part of the grey water can be self-recycled inside the house, like collecting sink water to flush the toilets. If do so, 7.3 liters/person/day water from sink is collected to flush the vacuum toilets, only 0.2 liters/person/day water is extra needed. A rainwater harvesting system can, typically, reduce main water use by around 30%. Otherwise rainwater would flow down gutters into the drain and cause stormwater runoff when heavy raining. The uses for rainwater are toilets (0.2 liters/person/day, 0.2% water use), washing machines (15.7 liters/person/day, 13.9%), outside cleaning use (5.2 liters/person/day, 4.6% water use), garden (this figure can grow greatly for keen gardeners). Other uses are not allowed. Now we can notice that 79.1 liters/person/day grey water and 7.5 liters/person/day black water (solid included) are produced. If we can reuse these parts of water, then it's possible to achieve water self-sufficient with no wastewater outflow.

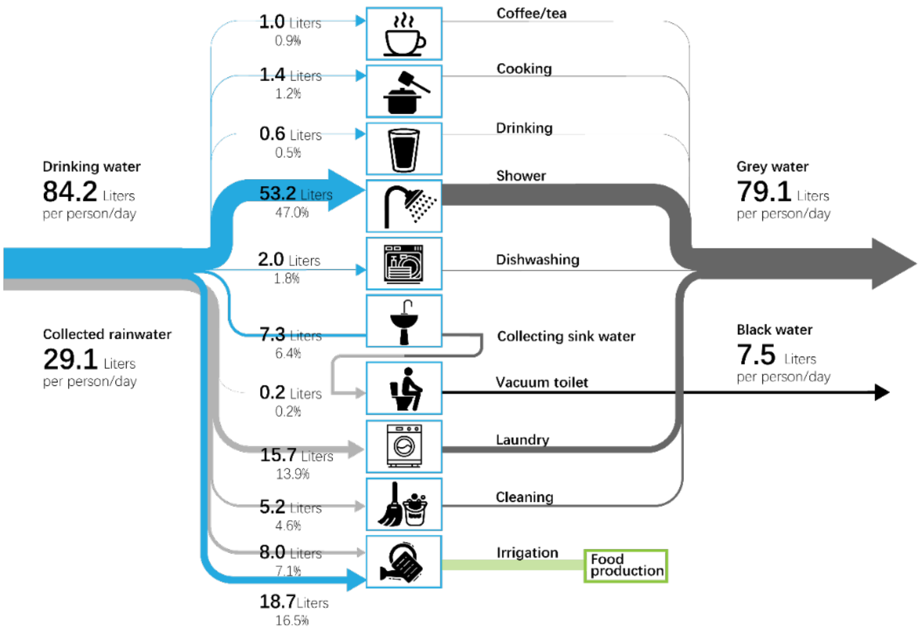

Figure 4. Proposed household water-use

4.2. Water purification

All the greywater (79.1 liters/person/day), combined with the rainwater from the rainwater sewer (6.0 liters/person/day, the actual rainwater collected from the sewer should be 44,165,000 liters/year, for intuitive comparison it divided by population and 365 days) and fermentation residue liquid, will first comes together in the grease trap and then flows through a reedbed filter system to get purified. The treated water is collected in a pond, acting as a combination of buffering, purification and infiltration. It could be a natural water storage and interact with the natural water body. Because of evaporation some water (4.4 liters/person/day, the actual evaporation should be 32,339,000 liters/year, the reason is as above) gets lost. The remaining treated water (84.2 liters/person/day) is discharged into a water building (to be built in the future according to the booklet *Urban development plan Strandeiland*) for further purification. Then it becomes clean drinking water and join the water cycle again.

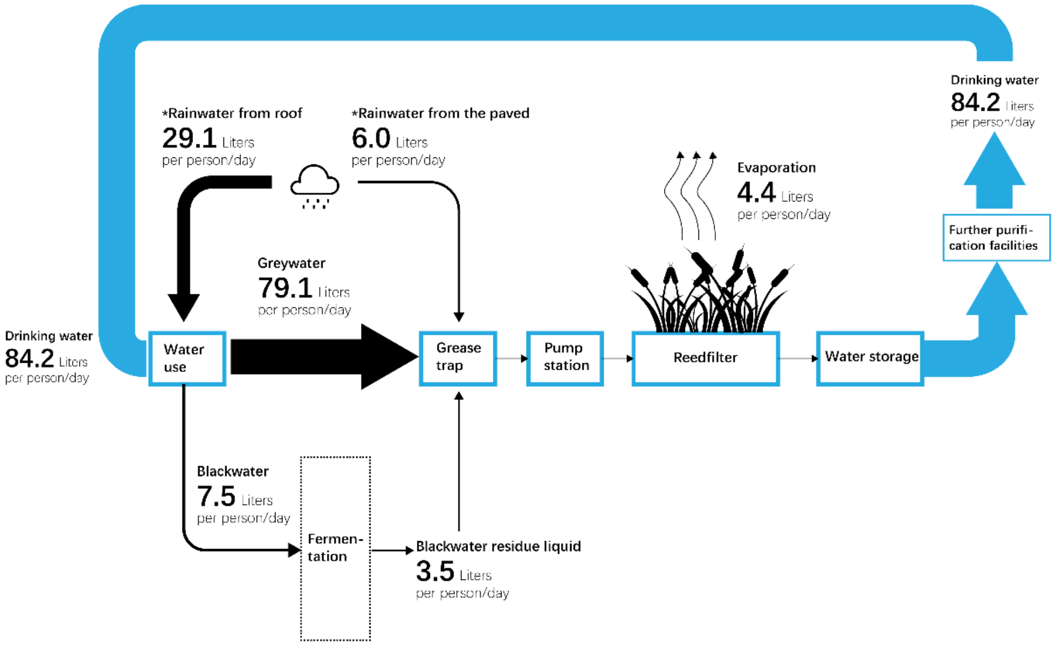

Figure 5. Watercycle with reed purification system

4.3. Fermentation

The fermentation plant uses different biomass to produce biogas: blackwater from vacuum toilets, food waste from kitchen and other organic waste such as garden waste. The fermentation process will happen in a centralized biogas plant (to be built in the future according to the booklet *Urban development plan Strandeiland 2018*). First the mixture of organic waste and blackwater will get fermented in the biogas digestor. This step will produce 12.2 m3/person/year biogas, which equals to 7% of daily cooking demand per person (assuming 1.5 warm meals per day). The heat generated during the process will be collected to heat the neighborhood. Part of the water is lost during the fermentation. After treating in the septic tank, 3.5 liters/person/day blackwater residue liquid will come together with the greywater and be purified in the reedbeds. Both the digestor and septic tank will remain some sludge, which can be used as fertilizer for plant growth.

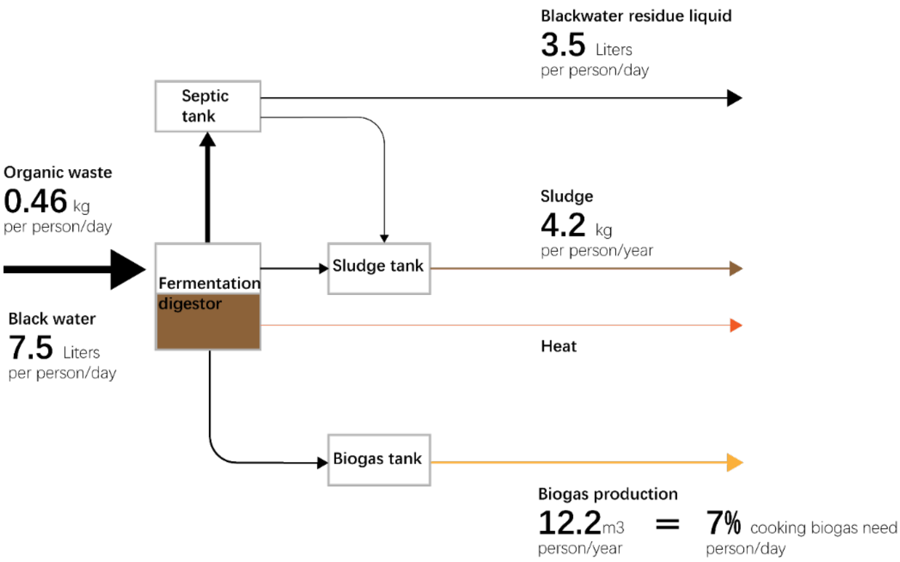

Figure 6. Fermentation with blackwater and organic waste

4.4. Rooftop garden and vegetables production

According to the calculation, the clean drinking water output (84.2liters/person/day) from reedbed are more than the daily activities water-use demands (because of rainwater harvesting system, only 65.5 liters/person/day drinking water are needed). So, for the extra input water, I would suggest expanding the rooftop garden area to 18.5 m2/house or other forms of urban farm, like tower garden and façade vegetables, which is more flexible and efficient. Although calculations in the appendix is about normal rooftop garden, it doesn't mean other technologies can't work.

4.5. Total wastewater cycle overview

The total wastewater cycle combined the water purification, fermentation and food production. The new sanitation system recycles greywater and blackwater separately, adopts vacuum toilets technology for less-diluted biomass, implements rainwater harvesting system with more green roof and reedbed filter system. The green roof can produce 8% of the daily food demand for the vegetables per person, cooling the surrounding area through evaporation at the same time. It proves the urban heat island effect can be reduced by 2°C if half of the roofs are green. Regarding water, it proves to be 100% self-sufficient in water use with only extra rainwater supply. Almost all the rainfall in Strandeiland are collected for different uses, which prevents stormwater runoff and pollution to the surface water. There will be no wastewater outflow with the help of reedbed filter system and bio-filtration process will no longer be energy and carbon intensive, which is much more sustainable and environmentally friendly. The local and on-site treatment also avoids long-distance transportations and water loss. Regarding energy, fermentation of human feces and organic waste produces 7% of daily cooking demand per person, as well as regain heat and minerals out of the wastewater.

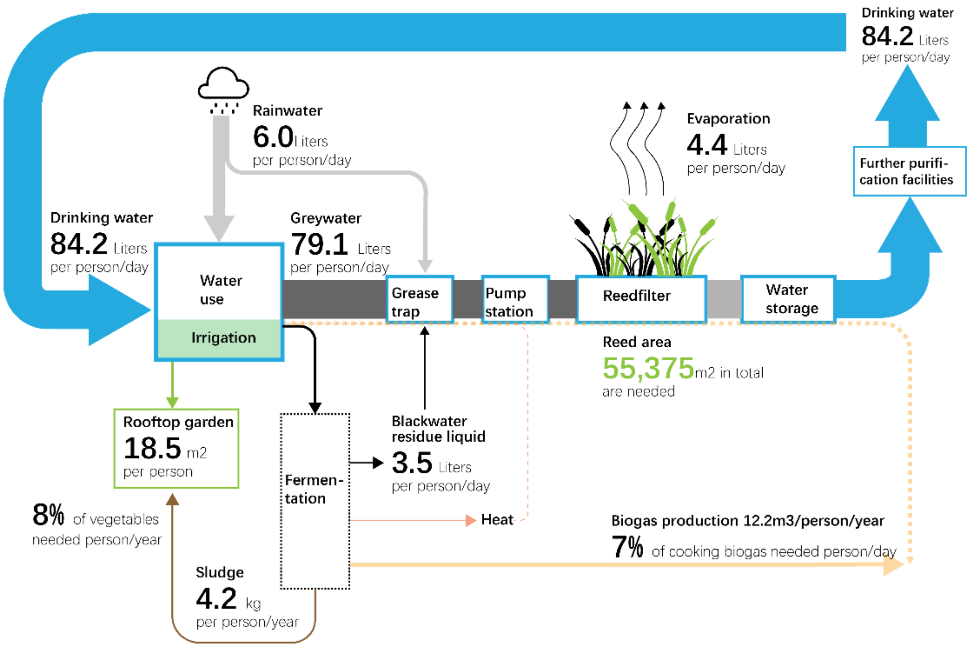

Figure 7. Total wastewater cycle

V. IMPLICATIONS FOR THE DESIGN

5.1. Reed road system

According to the calculations, total 55,375m2 reed area are required to purify all wastewater, which calls for expanded reed zone. It adds special flavor to the identity of the island. The main shining points that Strandeiland can present in the future will be its willingness to recover the natural versatility, biodiversity and resilience, given the very attractive qualities of the island. Instead of making the reed area centralized as a natural reserve, there can be other options like distributing reedbed along the coastline of the island or inside the island to bring as much as added value as possible to the neighborhood. Such as the reed road system(Figure 7), it prohibits vehicles and broaden the public spaces between two buildings.

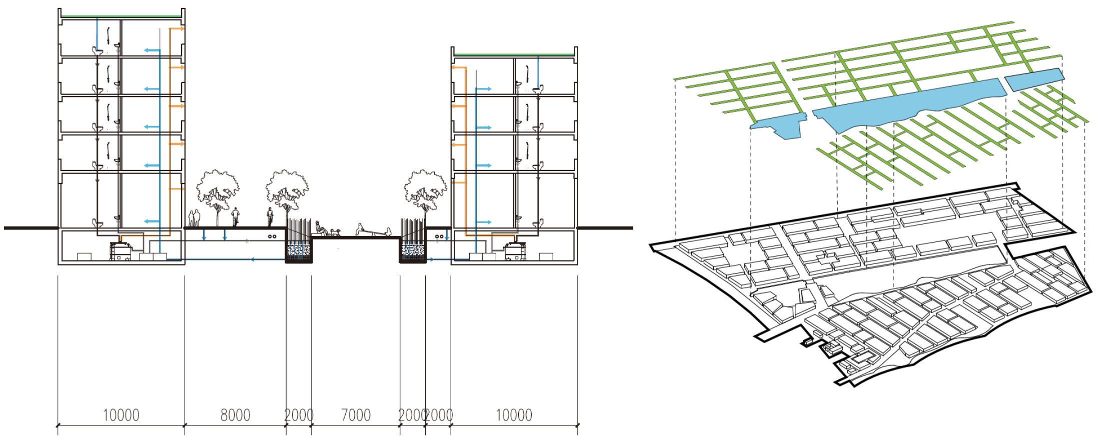

Figure 7. Reed road system

5.2. Rainwater sewer system

Based on the designed system, rainwater falling on the rooftop will be harvested to meet the part need of household water use. At the same time, rainwater from the pavement, roads, playgrounds and parking lots is also designed to participate in the watercycle. The rough amount of rainwater from the paved in Strandeiland is 44,165m3/year. It requires an independent rainwater sewer system in future Strandeiland.

5.3. Reed waste utilization

In most areas and for most applications, reed is harvested in winter. Reed cutting is traditionally undertaken to slow or reverse the natural succession to scrub and woodland and at the same time stimulating the production of new reed. According to the calculations, 27 tons of reed will be harvested once the watercycle system start functioning, which equals to 5,500 bundles of reed. Harvested reed per year can be used to cover 550m2 thatch roof or façade, or 2115m2 reed panels that could be used as screens, insulation mat, plaster base and interior design. Take average roof area 60m2 for example, the reed production can accommodate the maintenance usage of thatched layers for 9.2 houses per year. The leftover short straw can be compressed and glued to make granulate panels. Except the consumption of materials to maintenance the reed buildings in Strandeiland, the reed products can be exported to make profits. For example, Buiteneiland, the final part of IJburg project, will be connected to the Strandeiland and provide a large amount of public green area and waterfronts for all Amsterdam residents. The reed materials manufactured in Strandeiland can be exported for the construction of Buiteneiland, which is much more convenient and environmentally friendly. The general manufacturing process can be seen in figure 8.

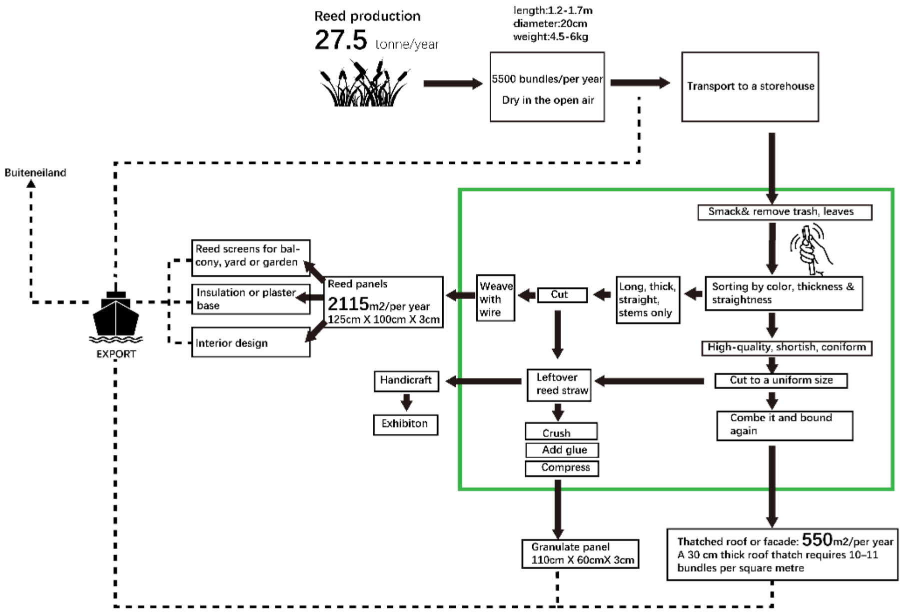

Figure 8: Manufacturing process

5.4. Reed factory & Water energy building

This innovation reedbed filter system working in combination with reed waste collection will minimize the waste output and pollution by reducing, recycling and reusing. Self-sufficiency will make Strandeiland healthier and more climate resilient. In order to function the designed wastewater system well, there are lots of facilities and factors needing to be taken consideration into. The figure 9 shows the synergies between each element and reveals how they work in coherence with each other. Besides the basic infrastructure and dwellings, we can notice that a water-energy building with fermentation and further purification processes within and a reed factory are required to be implemented to complete the whole water-reed cycle. The reed industry produces local rooted reed products and provides work opportunities for people. Considering the excellent performances of reed as building materials and its highly corresponded identity with the concept of a natural reed island, the further design will adopt the programme: Reed tower, a water-energy building that combines reed manufacturing, education and experience center, etc.

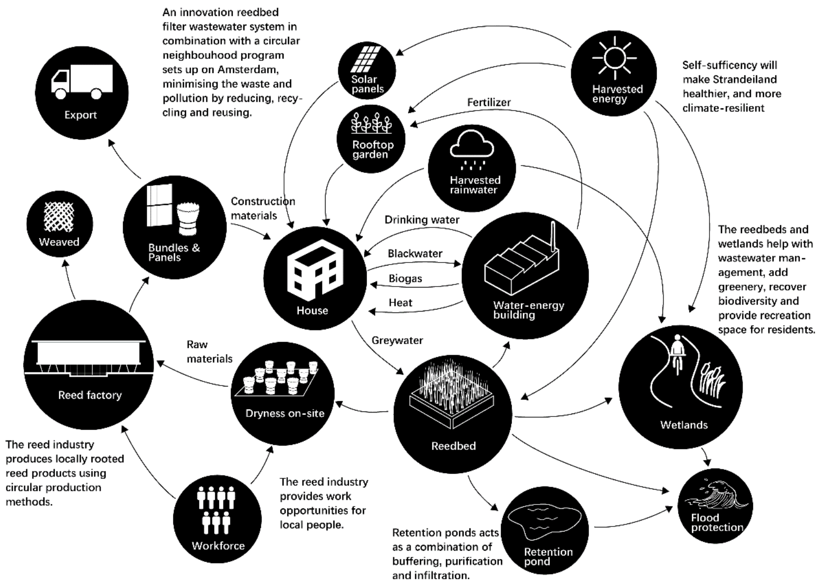

Figure 9: Facilities and values

APPENDIX

1. Household water-use

Table 1. A Breakdown of household water use with conventional flushing toilet.

Activity	Demand liters/ per person/day	Greywater	Blackwater
Shower/bath	53.2	Y	N
Cleaning	5.2	Y	N
Laundry	15.7	Y	N
Dishwashing machine	2	Y	N
Sink	7.3	Y	N
Toilet flushing conventional	33.8	N	Y
Drinking/cooking	2	Y	N
Coffee/tea	1	Y	N
Watering	1	-	-
Total	121.2	86.4	33.8

Table 2. A Breakdown of household water use with vacuum toilet and collecting water from sink.

Activity	Demand liters/ per person/day	Greywater	Blackwater
Shower/bath	53.2	Y	N
Cleaning	5.2	Y	N
Laundry	15.7	Y	N
Dishwashing machine	2	Y	N
Sink	7.3	Y	N
Vacuum toilet flushing	0.2	N	Y
Drinking/cooking	2	Y	N
Coffee/tea	1	Y	N
Watering /irrigation	27.1	-	-
Total	113.3 (84.2from drinking water, 29.1 from rainwater)	79.1	7.5

**Source 1: Watergebruik thuis 2016.*

2. Rainwater collected from rooftop

Average rooftop area	60	m2/ house	**Source2*
Rainfall rate (average NL)	2.2	mm/day	**Source3*
Evaporation rate	45%		**Source4*
Inhabitants	2.5		**Source5*

Rainwater collected from rooftop 29.1 Liters/person/day

**Source2: https://www.zonnepanelen-weetjes.nl/blog/afmetingen-van-zonnepanelen/*

**Source3: The average annual rainfall in Amsterdam is 805 mm, which equals to 2.2mm per day.*

**Source4: Green roofs further considered (in Dutch), K. Broks, et al., STOWA en RIONED (2015)*

**Source5：The average number of inhabitants per household in Amsterdam is 2.5 (CBS, Trends in the Netherlands, 2018). So, the total number of inhabitants of 8000 homes in Strandeiland is estimated to be 20,000.*

3. Rainwater collected from pavement/roads/playgrounds/parking lots

Paved surface (except rooftop)	100,000	m2	**Source6*
Rainfall rate (average NL)	2.2	mm/day	
Evaporation rate	45%		
Inhabitants	2.5		
House	8000		
Rainwater collected from the paved	6.0	Liters/person/day	

**Source6: Stedenbouwkundig plan Strandeiland concept*

4. Reed system

Although the maximum allowable hydraulic loading rate for V-SSF helophyte filters in the Netherlands is 60 l/m2/d (VROM and KIWA, 1998), the actual hydraulic loading rate in Lanxmeer is 32 l/m2/d.

Table 3. V-SSF helophyte filters performance in Eva-Lanxmeer.

V-SSF helophyte filters placed site	**Number of beds**	**Surface area**	**Service group**	**Effluent to**	**Greywater amount (L/day)**	**Function rate**
Station	3	each 300m2	houses	surface water body	28,800	100%
School	1	1500m2	secondary school	canal	24,000	50% of its capacity
Unie	1	1500m2	school and some offices	canal	24,000	50% of its capacity

Water needs to be treated	88.6	Liters/person/day
Filter loading rate	32	Liters/m^2/day
Person	20,000	/

Reedbed area required	55,375	m^2

5. Evaporation reedbed

Evaporation rate (average NL)	1.6	mm/day	*Source7
Area of reedbed	55,375	m^2	
Person	20,000	/	
Evaporation reedbed	4.4	Liters/person/day	

**Source7: The rough evaporation rate in Netherlands is 600 mm/year, which is about 1.6 mm per day.*

Sjauw En Wa, A. S. F. "Ecogreen Sports & Recreation Complex Rotterdam." (2010).

6. Rooftop garden area

Irrigation water (except daily use)	18.7	Liters/person/day	
Extra rainwater collected from rooftop	8	Liters/person/day	
Water needed for garden	3.6	Liters/m2/day	*Source 8
Inhabitants	2.5		
Rooftop garden area	18.5	m2/house	

**Source 8: https://www.theguardian.com/lifeandstyle/2014/aug/22/six-ways-to-save-water-in-your-garden.*

7. Food production

Average vegetables production	2	kg/m2	*Source 9
Rooftop garden area	18.5	m2/house	
Inhabitants	2.5		
Vegetables needed	0.5	kg/person/day	

8% of the vegetables need can be meet from the production of the rooftop garden.

**Source 9: Rooftop Impact Model, Rovers et al. (2016)*

8. Fermentation

- The purification efficiency for organic matter is 97%. During fermentation, 78% of the organic matter is converted to biogas and 7% to sludge. The system produces 12.2 m3 of methane per inhabitant per year, which is twice as the reference, because vegetable and fruit waste are also fermented.

- The sludge production of the system amounts to 4.2 kg ds per inhabitant per year.

**Source 10: STOWA NIEUWE SANITATIE Noorderhoek, Sneek*

- The biogas consumption for cooking lies between 300 and 900 litres per person per day (assuming two warm meals per day).

**Source 11: https://www.humanpowerplant.be/2017/07/biogas-production.html*

9. Reed waste

Thatching reed biomass is usually measured in bundles. The length of a standard bundle is 1.2–1.7 m, its circumference is (60–)62–64 cm (BRGA, n.d.), its diameter is 20 cm, and it weighs 4.5–6 kg. Depending on moisture content, one ton of reed is equivalent to 160–220 bundles. Depending on yield and size of bundles, 750–1000 bundles per hectare can be harvested.

Reedbed area required	55,375	m2
Hectares	5.5	hectares
Bundles	5,500	bundles
Weight	27,500	kg

**Source 12: The utilisation of reed (Phragmites australis): a review.*

10. Utilization

Reed is a wetland plant genus that has been utilized by man since ancient times. Due to its world-wide dominance, it is often cheap and readily available as a raw material. and the stems have traditionally been harvested in winter as a raw material for crafts and for construction materials including roofing. The table below catalogues other potential uses of reed as construction materials.

**Source 13: Natural and Plant Construction Materials: Raw Materials - Building Physics*

Table 4. A review of reed utilization as building materials.

Roof thatching for all house types, minimum roof slope 45°	Winter	High quality, long, straight, flexible, annually moved, moisture content <18% (dry)	Leaves etc. removed by combing, Stems packed in uniform-length bundles, dried if necessary	40 cm thick = 20 bundles/ m^2 1 m^2 needs 1–1.2 ton of reed	Reed €2.5 per bundle (UK), thatching €32–80 m^{-2} (Europe)
Construction and gardening Walls, panels, mats, fence plaster base, Insulation	Winter	Long, thick, straight stems only	Compressed and knitted in a weaving loom, fixed to the wall and covered with clay	λ= 0,055 W m^{-1} K^{-1} Size 1.25 m x 1.0/2.0 m 1 m^2 panel = 20 kg (5 cm thick) or 13 kg (3 cm thick) of reed, 0.6-0.8 kg wire	6–10 €/m^2 (Austria), 0.45 €/m^2 (China)
Granulate panel		Chips or clippings for granulate panels, also leftover	Chopping and mixing with glue	Size 110 cm x 60 cm	19 €/m^2 (Austria)

Bundles	5,500	bundles/year	
Thatched	10	bundles/m2	**Source 13*
Thatched façade	550	m2	
Average facade	60	m2/ house	**Source2*
Thatched house	9.2	houses/year	

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