FOOD PRODUCTION AND DECENTRALISED SANITATION IN THE LIVING ENVIRONMENT

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Abstract

As the housing shortage in the Netherlands is rapidly increasing, hence the need to develop more housing is as well. It is needed to make these new houses more sustainable to honour the Paris climate agreement. It is known how to make buildings energy neutral. To push further the development of a sustainable urban environment research is done by investigating shortening the transport into the urban environment to a minimum by implementing food production and black water sanitation on site.

Based on data provided by the Dutch nutrition centre (Voedingscentrum), the amount of food needed is calculated and divided in what could be feasible to produce within a neighbourhood and is translated to 36 m² per capita. Blackwater and organic waste are produced and digested on site. Biogas forms from organic waste and biosolids and can provide a potential energy of 626,1 kWh per capita. Ammonia and fertiliser can be harvested with a struvite reactor and has a potential of 20,5 kWh per capita, and the struvite harvested is 474,5g per capita per year. A total of 646,6 kWh per capita is gained.

Keywords: *Urban Farming, Decentralised Sanitation, Blackwater, Nightsoil, Biogas, Fertiliser, Sustainability.*

I. Introduction

The Netherlands is experiencing a housing shortage and in the coming decade 845 thousand new homes must be developed to prevent an additional increase of the housing shortage (Ministerie BZK, 2020a). The Netherlands currently has a shortage of 331 thousand homes, 4.2 percent of the total housing stock. It is expected that the Netherlands will have 18.8 million inhabitants by 2035, meaning that homes must be built, not only to make up for the current shortage, but also to meet the rising demand. The number of new homes built is expected to drop, largely due to problems surrounding sustainability issues such as nitrogen emissions, PFAS, and the lack of new construction sites (Ministerie BZK, 2020a). There is a need to be more sustainable to honour the Paris climate agreement.

In recent years strategies to develop more sustainable buildings, specifically energy neutral buildings have been extensively researched. Which for example is showing that the reduction of the carbon footprint of buildings can be managed by materials used in the built environment, however such interventions and solutions focus on the relative short-term results, when looking at the total lifespan of a building. Thus, the next step to develop more sustainable housing stock would be to research the use of the building during its lifespan. The use of the building has an impact on sustainability using electricity, heating and cooling to ensure a comfortable living environment. The resources to achieve comfort, among which energy, are transported from the outdoors into the house and go back as waste. Is it possible to shorten this transport to a minimum and by doing so, come closer to energy neutrality and self-sufficiency within the built environment?

1.1. Thematic Research Question

This paper explores the feasibility of shortening the transport of food and black water to contribute to sustainability of the built environment by implementing food production and decentralised sanitation installation on site. The problem statement led to the following main question:
How can the integration of food production contribute to the sustainability of the living environment?

The following sub questions can be derived from the main question:
- What interventions contribute to the sustainability of the living environment?
- What kinds of food production can be integrated in the living environment?
- How much space is needed in order to feed a person?
- How can black water contribute to plant growth?
- How much resources and energy can be retrieved from organic waste?

II. Methods

The first research method applied in this paper is a flow analysis of how food and blackwater relates to the built environment. Secondly, a literature study was performed to combine plants and blackwater as possible resources. In this phase also the term 'nightsoil' was adressed and this research was followed by where it originates from and how it is has been used. Simultaneously the daily food demand per capita was calculated as well as the selection of food types that could be fit in a neighbourhood and the yield these food types could generate per square meter. Lastly, a literature study of the process of black water sanitation was done providing information about the potential energy gain that could be retrieved from the neighbourhoods blackwater waste flow.

III. Results

3.1. Sustainability in the built environment

The built environment is responsible for 39% of the greenhouse gasses due to human activity (UN Environment & International Energy Agency, 2017). Therefore, it is evident that the building sector must be more sustainably improved. Within the built environment a distinction can be made between the different forms of sustainability wherein the common forms of sustainability are represented in materials and comfort of the indoor climate. As a result, from 2021 onwards, the Dutch standard of new developed buildings should be almost energy neutral (BENG) by law (Ministerie van BZK, 2020b), which means that the thermal energy needed for houses is 25 kWh per m^2. The figure (1) below shows the current situation of steps for sustainability in the built environment.

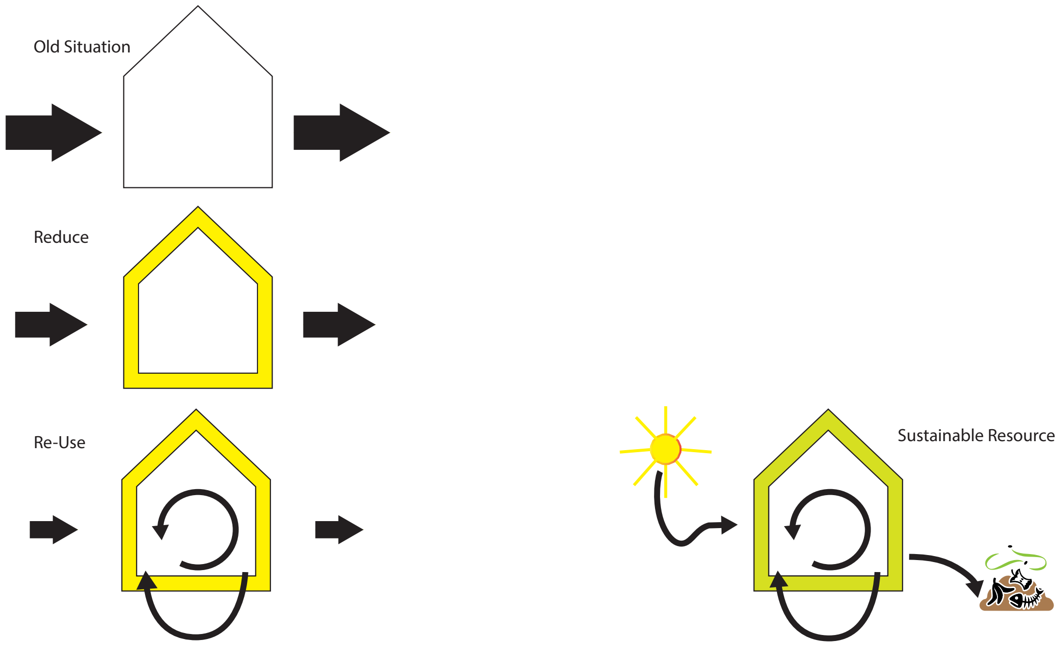

Figure 1. Steps according to 'de nieuwe stappenstrategie'.

3.2. Food flow

As cities become denser and are rapidly expanding, the amount of green space within them, including agricultural land, is decreasing. In fact, if the Netherlands produces the amount of food to meet its needs, more land is required than is available within the country's borders (Gerwen, Hoogervorst, Eggink, Brandes, & de Hollander, 2015). Moreover, the Netherlands is the second largest exporter of food. This has to do with two factors: a lot of food is imported in the harbour of Rotterdam from which it is further transported to the rest of the world, this is merely a transit port (AGF, 2019). Another is the vast amounts of greenhouses, that is Westland, where food is produced and mostly also exported.

The food that is produced in the country is stored in warehouses. These warehouses distribute it further to the supermarkets. The warehouses, supermarkets and transport vans are cooled to stretch the lifespan of the consumables. From the supermarkets, consumers transport their products to their homes. One could imagine that all this transport and cooling of the products is very energy intensive and not an efficient way of operating when simultaneously international goals have been set to tackle the issue of climate change.

An evident solution would be shortening the transport cycle from farm to plate, hence ideally food should be produced within the urban environment as close to consumers as possible. Bringing the farm into the city can be multi-functional: it greens the urban environment which in turn lowers the urban heat island effect, stores water, feeds people with local products and could increase mental and physical health (de Vries, Boone, de Rooij, & Keip, 2017).

With examples of urban farming in mind, the issue is not whether it is possible, but the question is space related in terms of how it can be integrated in the neighbourhoods that will be developed in the future. Does this mean it is necessary to build less dense housing projects to ensure space remains available to implement the function of farming? Are all sorts of products produced within the build environment?

To establish the amount of space a person needs to sustain itself, an inventory is held on what a with a healthy diet person consumes. A healthy human diet consists of various products as shown in table 1 by the Netherlands Nutrition Centre (Brink, Postma-Smeets, Stafleu, & Wolvers, 2020).

Table 1. Advised daily intake by the Dutch Nutrition Centre (Voedingscentrum)

	1-3 jaar		4-8 jaar		9-13 jaar		14-18 jaar		19 -30 jaar		31-50 jaar		51-69 jaar		>70 jaar			
	Jongens	Meisjes	Jongens	Meisjes	Jongens	Meisjes	Jongens	Meisjes	Mannen	Vrouwen	Mannen	Vrouwen	Mannen	Vrouwen	Mannen	Vrouwen	Zwangere vrouwen	Vrouwen die borst-voeding geven
Groente	75	75	125	125	175	175	250	250	250	250	250	250	250	250	250	250	250	250
Fruit	150	150	150	150	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Brood	88	88	105	105	193	158	245	158	245	158	245	158	228	123	175	123	193	228
Graanproducten*	38	38	63	63	113	100	150	113	113	113	113	113	100	88	100	75	113	113
Aardappelen*	53	53	88	88	158	140	210	158	158	158	158	158	140	123	140	105	158	158
Vis en schaaldieren**	7	7	8	8	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Peulvruchten**	8	8	24	24	34	34	38	38	38	38	38	38	38	38	38	38	43	47
Wit vlees**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rood vlees**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ei**	18	18	25	25	25	25	25	25	25	25	25	25	25	25	25	25	32	32
Noten, pitten, zaden	19	19	19	19	32	32	32	32	32	32	32	32	32	19	19	19	32	50
Melk en melkproducten	300	300	300	300	450	450	600	450	375	375	375	375	450	525	600	600	375	375
Kaas	0	0	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40
Smeer- en bereidingsvetten	30	30	30	30	45	40	55	40	65	40	65	40	65	40	55	35	45	50
Dranken	650	650	850	850	1100	900	1300	1000	1500	1100	1500	1100	1400	950	1300	900	1500	1500

From this table a calculation can be made to establish the amount of space needed to produce each product in kg/m²/year by cross referencing the yield of the product per year. It is identified whether it is feasible to produce this product within the built environment, see figure 2. The product needs to develop itself and must be space efficient accordingly. Developing meat products in the built environment is not space efficient since, for example, cows need 50-60 kg of food a day (Veldverkenners, 2020), which comes down to 1 hectare of space that is reserved to produce livestock feed on the spot and not being consumed by residents. Also, the maturing of cattle is a factor; it takes time to grow but does produce dairy products and meat over time, same goes for poultry and other cattle farm animals.

In this paper bulky products such as grains and potatoes, which are earth bound, were considered not feasible to develop within the build environment, therefore it is recommended that these are produced outside neighbourhoods. To eleborate, the figure (3) below illustrates that grain products are space intensive as they require 130m² per capita. Potatoes are less space intensive but need arable land to be plowed which is not possible in hydroponic and aquaponic farming, since these types of farming use little to no soil.

By posing these restrictions, about 30% of the daily intake could be produced on site, which are mostly plant based, yet fish are implemented since aquaponic circumstances are fitting in the urban environment. Moreover, the aquaculture and plants work symbiotically, meaning organism work together in favour of each other, in this case, producing a higher yield than conventional and hydroponic farming (Goddek, 2017, p. 39).

Figure 2. The selection of food types to implement in the built environment.

3.3. Calculation of the food flow

Figure 3. Shows the type of products that need the amount of space to provide in daily intake of a person.

The Dutch nutrition centre prescribes the amount of edible portions a person needs. The space to grow the whole product is calculated, which is the edible part and the wasted part since that is non-edible of which is daily 605 gram per capita produced. Taking the average of the table, the amount of needed space comes down to 36m2 per capita to be partly self-sufficient for food production. The rest of the advised daily intake is produced elsewhere and imported.

3.4. Blackwater flow

In the western developed world, it became the standard to build enormous infrastructures to transport our human organic waste through underground sewage, in order to keep it far away from the people. This principle dates back from the Mesopotamian Empire who developed the primal structures of drains in streets, while the Minoan civilisation developped the principle further by designing and constructing a well organised sewerage and drainage system to protect their population and agricultural land. The Hellenic and Roman civilisations developed these technologies further with the help of hydraulics, and by doing so, greatly increased the scale and implementation of the system (De Feo et al., 2014).

Other cultures handled their unwanted waste in a different manner; in many diffrent areas around the world where the soil condition was poor, fertiliser was needed to provide the agricultural land with nutrients. Cattle manure only is often not sufficient to provide enough nutrients for the plants, therefore human stool was collected and used to fertilise the fields (Julius, Gunnerson, & Shuval, 1981, p. 11). The collection of the stool happened during the night, so the term of this fertiliser became ‘nightsoil’. Nowadays, nightsoil is still used as biofertiliser in Subsaharan Africa since artificial fertiliser is more expensive (Oinam, 2008, p. 25).

However, why would the blackwater flow be a sustainable solution within the built environment? The Netherlands has always been proud of their drinkable tap water and would like to keep it that way. the country has vast sewage installations to purify blackwater into drinkable tap water, yet these installations are very costly in terms of energy and resources when built centralised (Hophmayer Tokich, 2006, p. 27). Apart from the water reclamation, black water contains effluents which in turn contain valuable resources, which could for example be used to fertilise the lands to grow crops.

3.5. Health hazard

The use of nightsoil is restricted in the Western world. In the European Union the restrictions of manure use stretch that when applied, harvest cannot take place for the following 10 months (Hudcová, Vymazal, & Rozkošný, 2019, p. 113; Inglezakis et al., 2014, p. 638). The reason behind this contingency is the fear of pathogen outbreaks. The Western world is keen on keeping their world sanitised, since it had different fatal diseases in the past which found their origin in unsanitary practices. The orofecal-route transmitted diseases, in relation to nightsoil are: Hepatitis A, Hepatitis E, Typhoid fever, Polio (Poliomyelitis), amoebic and/or bacillary dysentery, Ascaris and Hookworm (Cross & Strauss, 1985; Carr & Strauss, 2001, p. 98).

3.6. The process of blackwater flow

Domestic blackwater is generally a composition of water, faeces and urine. In a sewage installation blackwater is split into water and sludge, whereas most of water is filtered and the wet sludge is stored in a biodigester where organisms turn the sludge into methane and carbon dioxide: these compounds form biogas and are in the ratio of ~65% methane (CH_4), ~34% carbon dioxide (CO_2) and <1% impurities. When the wet sludge comes out of the biodigester it still contains resources such as metals and organic compounds. These resources can be harvested and turned into fertiliser. During this process firstly, the wet sludge needs to be dewatered, as a result, this reject water contains the minerals needed to make fertiliser. The dewatered sludge still contains organic matter in the form of unprocessed fibres and fill matter. This dewatered sludge needs to be heated to eliminate pathogens before it can be used as fertiliser. Reject water goes through the process of reversed osmosis wherein water and salts are separated, these salts contain the aimed minerals. In order to harvest the minerals, the salts go through the struvite reactor wherein struvite-MAP ($Mg(NH_4)PO_4 \cdot 6H_2O$), commonly known as bladder stones, is formed. This is one of the minerals that can be used as fertiliser as it contains magnesium (Mg^{2+}) and a scarce resource phosphate (PO_4^{3-}) (STOWA, 2012).

Phosphorus (P) is an element that is conventionally mined and used in artificial fertiliser, but it is rapidly becoming a scarce resource: at the current rate of use the world stock of phosphorus will be depleted within 80 years (MIT, 2016). It is just as important for plants like CO_2 since they cannot grow without it.

When the struvite-MAP is formed, it is heated to 60-70°C in the oven. The ammonia (NH_4^+) in struvite loses its bounds to the crystal and leaves hydrogen (H^+) which fills the gap back in the struvite crystal. The now formed struvite-MHP ($MgHPO_4 \cdot 6H_2O$) can be applied on land as fertiliser, whereas the ammonia (NH_3) can be further processed (STOWA, 2012).

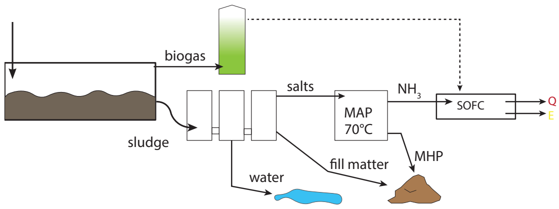

Figure 4. The proces of forming biogas and fertiliser.

3.7. Ammonia and Fuel Cell

Applying Ammonia (NH_3/NH_4^+) directly as fertiliser can disturb ecosystems as bacteria need to process Ammonia in the soil to form NO_2^- and NO_3^- so plants can take up the nutrients and grow (Plaza, Szatkowska, Löwén, Gut, & Trela, 2003, p. 78). Over fertilising means there is too much ammonia to be processed and changes the pH of the soil which is harmful for flora and fauna. Therefore, this paper suggests using the ammonia from the sewage process to produce energy by feeding it to a fuel cell. Conventionally energy is produced by means of the Carnot cyclus. Typically, it starts from turning chemical energy into heat, which is converted into mechanical energy and later into electrical energy. Finally, the yield of energy is around 35% due to its many conversions, there is a great loss. A fuel cell converts chemical energy directly into energy and heat and has a greater yield.

A fuel cell is mostly used as a device to convert the chemical energy of hydrogen (H_2) into energy (National Geographic, 2019). However, as ammonia (NH_3) and methane (CH_4) are merely carriers of H^+, these compounds can be fed to the fuel cell as well, posing higher yields in the production of energy.

3.8. Black water flow calculation

In the figure (4) below, human excreta are faeces and urine and flow from toilet to the digester. 77% of the solid organic matter from faeces can be turned into biogas. Organic waste such as kitchen- and food waste is fed to the digester as well and 40% of its total mass can be turned into biogas (Deublein & Steinhauser, 2010, pp. 49-56). Other organic waste such as leaves and branches as a result of autumn and pruning are not taken into the equation.

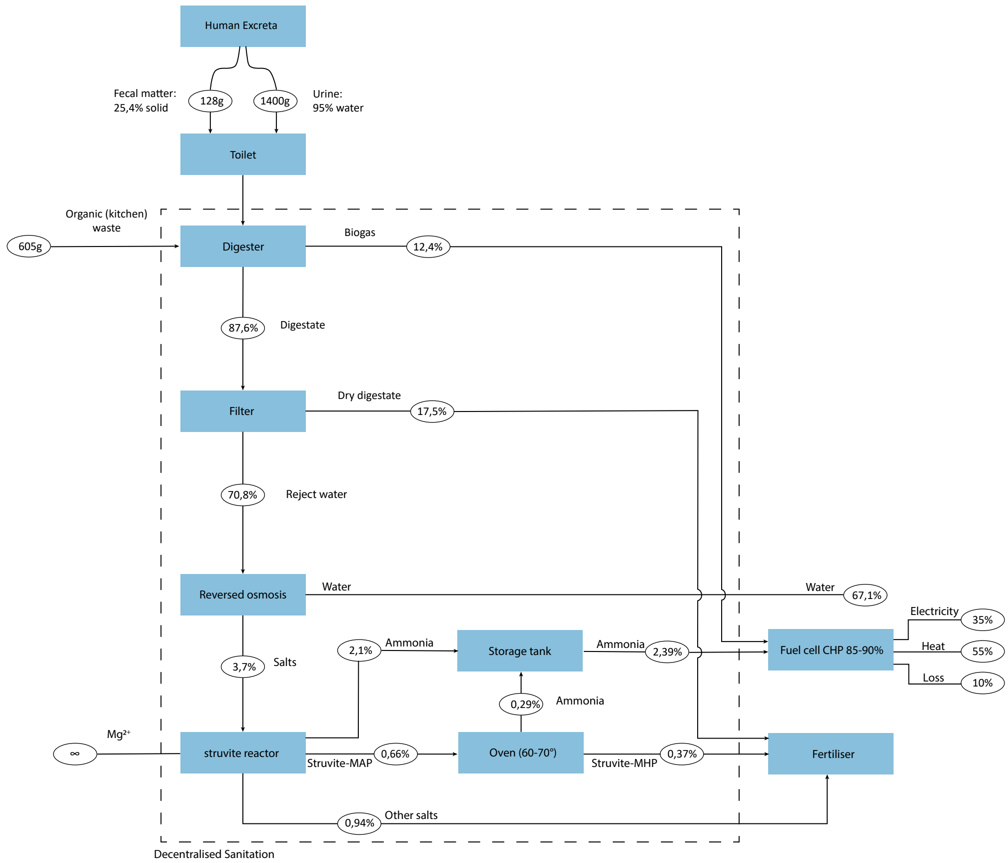

Figure 5. Flow of sanitation and resource reclamation of black water and organic waste, expressed in % of the total mass.

Calculations by Banks (2009) show that the 65% formed methane is divided by 16mole and multiplied by 22,4L to express methane in cubic meters (m^3). Methane has an energy value of 36MJ/m^3, divided by 3,6 to express in kWh. The energy from biogas formed from faecal matter is 79,83kWh per capita per year, whereas biogas from organic waste accounts for 546,3kWh per capita per year. The ammonia calculated has its origin from urine and fecal matter, both have 9 and 1,75 gram nitrogen compounds respectively (STOWA, 2005). Ammonia (NH^3) has an energy value of 18,8MJ/kg, divided by 3,6 to express it in kWh makes 20,5kWh per capita per year. The amounts of phosphate in faecal and urine waste are 0,5 and 0,8 gram. When harvested a yearly gain of 474,5gram phosphate is retrieved.

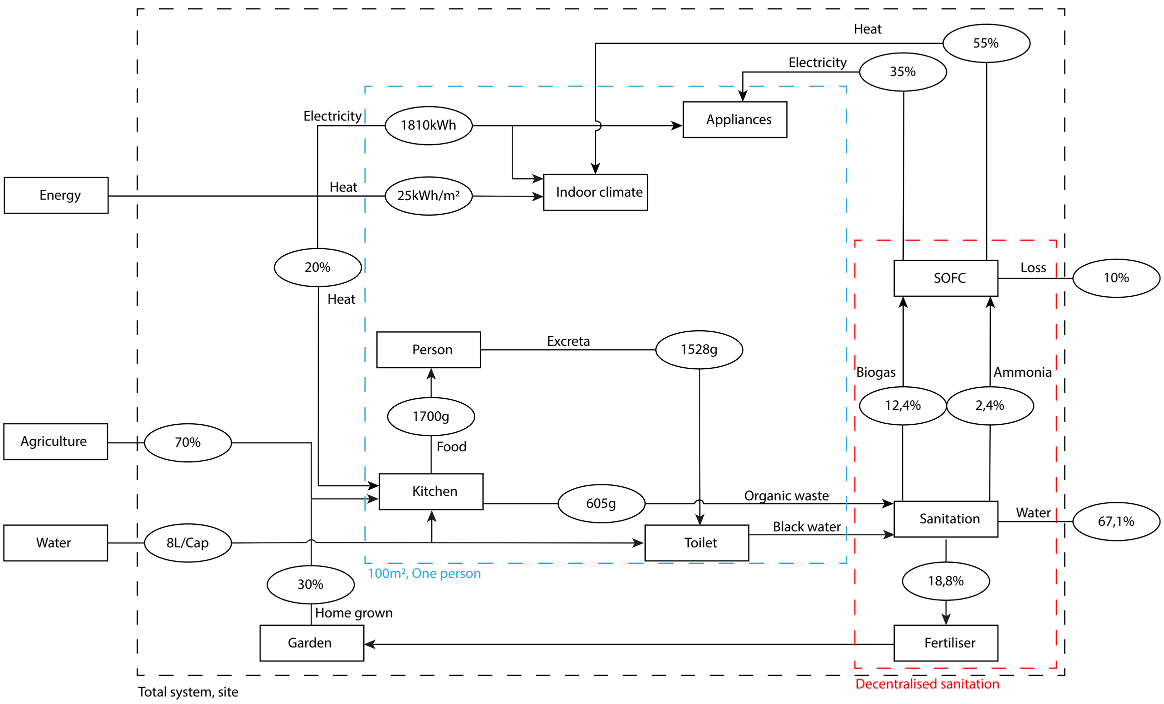

Figure 6. New situation wherein locally food is produced and blackwater is processed.

IV. Conclusions

How can the integration of food production contribute to the sustainability of the living environment?

By moving the farm into the city, food is produced locally resulting in less transport. Not all products are feasible to produce within the urban environment. Therefore, only a part of the plant-based foods of the daily intake as well as fish are implemented. This selection accounts for 30% of the daily intake, wherein fruits and vegetables are 100% and proteins 39% accounted for. The rest of the food is produced elsewhere and needs to be imported. Implementation of the selected foods require the space of 36 m^2 per person. Side effects of producing food locally are less transport, a greener environment, less urban heat island effect and water storage.

As sustainable food production also requires sustainable fertiliser, this was also addressed, and it was found that decentralising sanitation and sanitising locally gives the opportunity to win biogas locally which can be converted into energy that can be fed to the local buildings. Consequently, less energy needs to be imported into the neighbourhood. The sewage sludge is turned into valuable resources that can be harvested and used as fertiliser, which can be fed to the farm to provide nutrients to produce plants. The amount of struvite-MHP that can be produced is 474,5 gram per year per capita. However, more can be gained from sustainable fertiliser, as the organic waste can also partly be converted to energy. The amount of energy produced from organic waste is calculated in this paper wherein human faeces and food waste can be converted into biogas and have the potential energy of 79,8 kWh per year per capita and 546,3 kWh per year per capita.

The ammonia retrieved from the sewage flow can be fed to a fuel cell and produce in an efficient way electricity and heat. The amount of potential energy from the retrieved ammonia is 20,5 kWh per year per capita and the total potential energy gained is 646,6 kWh per year per capita. With the implementation of BENG in which new developed houses have an thermal energy demand of 25 kWh per m^2, 25,9 m^2 per capita can be heated by biogas and ammonia. This means less alternative energy sources need to be integrated in a design.

Figure 7. The new situation, interpreted from 'de nieuwe stappenstrategie'.

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Figures:

1. Current course of ‘de nieuwe stappenstrategie’, own material. Inspired by Yanovshtchinsky, V. et al., Architectuur als klimaatmachine.

2. Food selection, own material. Made with Miro

3. Food type space calculation, own material. Made with Miro

4. Making biogas and fertiliser, own material.

5. Black water flows, own material. Made with Miro

6. New situation, schematised, own material. Made with Miro

7. New situation as step 3b/4 in ‘de nieuwe stappenstrategie’, own material. Inspired by Yanovshtchinsky, V. et al., Architectuur als klimaatmachine.

Table 1:
Brink, L., Postma-Smeets, A., Stafleu, A., & Wolvers, D. (2020, February). Richtlijnen Schijf van Vijf (6e druk).P.66, table 4.5. Stichting Voedingscentrum Nederland, Den Haag. Retrieved from https://www.voedingscentrum.nl/professionals/schijf-van-vijf/richtlijnen-schijf-van-vijf.aspx