Community food production version 2.0

Closing the waste cycle with urban farming.

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Abstract: In every society people will inevitably generate unwanted and useless material that is called waste. However, this term is very subjective and inaccurate because most of these materials still contain valuable resources like nutrients and moisture. This research focuses on growing vegetables using the organic waste material and waste water from a local community. The nutrients required for crops will be recovered through anaerobic digestion of organic waste. Before we can start ferment organic matter, an initial technique is required to process wastewater into sludge. To determine the area size for the anaerobic digester and the wastewater treatment facility an equation will be derived from case studies. The method to calculate the amount of nutrients, that can be recovered by anaerobic digestion, will be done according to case studies as well. Finally, the estimated nutrient will determine the amount of vegetables that can be grown along with the spatial requirements for the design. The outcome of this study will be can be used as design tools for an architect who is interested in building a facility that can recover nutrients from waste and produce vegetables with it.

Key words - *nutrients in waste streams, waste water treatment, growing vegetables, urban farming.*

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1. Introduction.

Every person produce waste water and organic waste every day. As the world population grows the waste production will increase as well and effect our environment. According to Tannahill (2012) the waste management sector contribute significantly to climate change due to the use of landfills. Fortunately, a shift from waste management to more resource management was noticeable in recent history (International Solid Waste Association [ISWA], 2007), which lead to the encouragement of waste diversion through alternative technologies (DEFRA, 2007; ISWA, 2009). Architects can play an important role in the increasing demand for environmentally acceptable waste management strategies (Hazra, 2009). For instance, a survey conducted by the Compendium (2013) group indicate that organic waste make up 35% of the total waste stream in the Netherlands. However, a metropolitan city like Amsterdam, that produces around 94.106 tons in the year 2011 alone, uses its waste stream to generate energy through incineration (Amsterdam Afval Energie Bedrijf, 2006). After this process, all that is left is an ash like material that is only useful for the asphalt industry. A proposed alternative is to use this organic waste to make biogas and bio fertilizers. Both of these products are a form of recovered energy and are renewable sources as well (Holdom and Winstrom-Olsen, 1980).

The purpose of this paper is to investigate how much vegetables can be grown with the use of recovered nutrients from waste streams. Because each kind of waste require a specific method of treatment and not all are suitable for farming this paper will focus on the use of organic waste and waste water generated from households. These two waste streams are rich in nutrient and readily available for use (Sabey, 1980). The method to recover these nutrients is to first remove organic matter from waste water before putting them with other organic waste into anaerobic digestion. In the field of waste water treatment there are different methods to purify water. Each method has its own organizational challenges that can be solved with architectural intervention (Hammer and Hammer jr., 2008a). The treated water can be discharged into recreational surface water while the sewage sludge, along with organic waste, can be used to make fertilizers. An experiment done by Vaneeckhaute (2013) show that anaerobic digestion offers the most efficient method to recover energy and nutrients without any useless byproducts. The subsequent aim of this paper is to investigate if these methods can be incorporated into a design tool for architects.

In the following paper we will start with an explanation on how anaerobic digestion and wastewater treatment facilities operate. This is then followed by arguments from researchers on the subject of using digestate as a bio-fertilizer and it is an improvement on our current agriculture. The next part of this paper then examines the appearance of a conventional wastewater treatment facility and a anaerobic digestion facility. The final section of this paper focuses on the interpretation of the existing literature as a design tool.

To estimate the required area for a new plant, a calculation method is also presented at the end. The strategy is to compare the area size of case studies in relation to the amount of waste each project can process and the amount of sludge they eventually produce. Data collected from surveys done by the municipality serve as input to determine the quantity of wastewater and organic waste that is available in any design location. To estimate the area needed for the growing of crops, the same method is applied in the calculation. Finally, at the end of this study is a conclusion on the use of domestic waste to grow food as a design tool for architects and the recommendations future researchers can follow on this topic.

2. How does anaerobic digestion work and how are organic matter recovered from waste water.

Anaerobic digestion is a process where micro organisms break down organic matter from waste water and organic waste into methane, carbon dioxide and a nutrient rich sludge (Spuhler, 2013a). In earlier studies done by Hobson and Wheatley (1993a) the results indicate that the process can only take place in an environment where oxygen is absent such as an airtight chamber. The study also found that the organisms responsible for the digestion are bacteria known as 'anaerobes', that can only live when oxygen is absent or even die if they come into contact with it. Perhaps the most important finding in their research is the discovery that these anaerobes thrive well a controlled environment. The benefit of a controlled environment is that no methane is emitted into the atmosphere thus it does not contribute to climate change (Hobson and Wheatley, 1993a). However, not all organic matter can be used for digestion in their original state. Solid waste has to be reduced to fine grain size while waste water needs to be treated in order to remove nutrients from their soluble state (Hammer and Hammer jr., 2008).

The first digesters were erected to process sewage sludge. These were large, completely-mixed and heated tanks mostly designed for liquid waste. In later plants the design shifted to the digestion of solid waste as well (Hobson and Wheatley, 1993b). Today, all systems are developed to facilitate the anaerobic digestion process which consists of four stages: hydrolyses, acidification, acetogenesis and methanogenesis (West-Vlaanderen, 2007). In the hydrolyses stage organic matter is broken into dissolvable components with the addition of water in the process. During the acidification stage these dissolvable components are transformed into fatty acid ethanol. The third stage is acetogenese where the dissolved material is turned into CO_2 and H_2. Methanogenese is the final stage where methane (CH_4) and CO_2 is created. Each stage requires different environmental conditions for the bacteria to function properly. Lab tests have confirmed that for the acidification stage the optimal environment needs to have a pH value of 5.5 - 6.5 while from acetogenese onwards the ph value has to be between 6.5 - 7.5 (Spuhler, 2013b). The pH value is a term used in chemistry to determine the nature of a liquid; with the value 7 being in a neutral state while any value beneath this is considered acidic and any value above 7 is considered alkaline. Luckily, the pH value is self regulating and does not need adjustments. Because of this, there are two types of anaerobic digesters: a single stage system with a 'dry' or 'wet' biomass and a two stage system with biomass retention or without biomass retention (Vandevivere, 1999). In the two stage systems hydrolyses and acidification is activated in the first stage while acetogenesis and methanogenesis proceeds to take place in the second-stage.

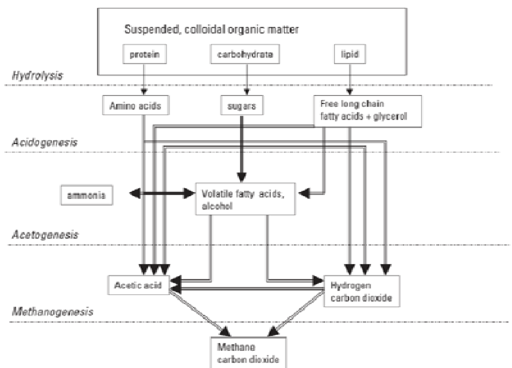

Figure 1: Simplified schematic of digestion process. Source: T.D.Z. Mes http://www.sswm.info/library/1058

Other parameters that are essential for digesters to function properly are the mixing mechanisms, the temperature inside the digester and the content of the Total

Solids (TS). The mixing of the biomass is essential in order to prevent inhibitor patches from forming. Depending the main inhibitors are substances such as ammonia, sulfide, heavy metals and organics (Chen et al., 2008). These inhibitor patches stop the fermentation process resulting in a low biogas yield. Mixing can be done either by mechanical stirring, gas circulation or displacement under gravity (Spuhler, 2013b). In the study by Chen et al. (2008) the researchers added the suggestion that co-digestion with other waste, adaptation of microorganisms to inhibitory substances, and the incorporation of methods to remove or counteract toxicants before anaerobic digestion can improve the waste treatment efficiency. According to Hobson and Wheatley (1993b) the temperature of the biomass is essential for bacteria to live inside a digester. Heating is especially important for a thermophilic process that is sensitive to environmental changes (De La Rubia et al. 2006a). The term thermophilic refers to the temperature range from 55 °C to 60 °C where anaerobic digestion can develop. Its counterpart is the mesophilic process that develops bacteria at 35°C. Currently, the thermophilic process is considered to give a faster reaction rate, higher gas production, and higher rates of the destruction of pathogens than mesophilic processes (Zabranska et al., 2000; De La Rubia et al. 2006a). The heating of digesters are done by an external motor that is usually run on biogas while new biomass is continuously fed through a shredder. This biomass can either be dry with a TS content above 20% or wet with the TS below 20%.

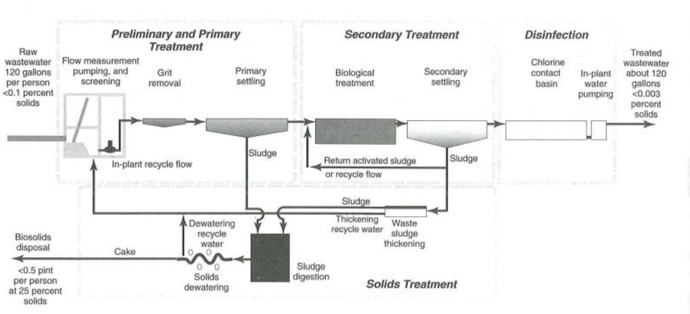

Figure 2: Schematic of a typical wastewater treatment plant. Here you can see the three stages along with the required elements. Source: Hammer and Hammer jr.

Hammer and Hammer jr. (2008a p.359) describes conventional mechanical wastewater treatment as '*a combination of physical and biological processes designed to remove organic matter and solids from solution*'. The process consist of three stages: primary treatment, secondary treatment and disinfection. Before starting the recycle process a preliminary treatment is done to remove solid material that would otherwise abrasive to mechanical gear. The cycle then continues with primary treatment, whose purpose is the removal of solids by sedimentation and scum that floats to the surface by a scraper. The remaining water continuous to the next treatment stage while collected sludge is processed in a separate tank. However, the effectiveness of primary sedimentation is very limited since more than half of the organic content is still present in the water. Straining water to remove solids has its limits so a secondary treatment is needed to improve the settleability of the wastes. The first methods for secondary treatment were done with the use of gravel beds where the wastewater would slowly pass through. In this process, also known as trickling filtration, a rapid reduction of organic matter and biochemical oxygen demand (BOD) can be registered. The authors Hammer and Hammer jr. (2008a) call this method biological bed because of microbial oxidation of organic matter by slimes that are attached to the rocks. Their review also mentioned that an alternative biological treatment is when biological solids, developed in polluted water, flocculated organic colloids. '*These masses of microorganisms, referred to as activated sludge, rapidly metabolized pollutants from* *solution and could be subsequently removed by gravity settling'* (Hammer and Hammer jr., 2008a p360). Conventional wastewater secondary treatment is subsequently divided into two groups according to the support medium for the biomass. The first group incorporate a fixed film on which biomass is attached to while it grows. In the second group biomass is grown in a suspended state in wastewater. Barnes (1995) stated that all of these methods have in common that they all aim to provide a suitable environment in which a diverse population of micro-organisms may be brought into contact with the wastewater long enough for it to remove the organic content, and use it for growth of new biomass, so reducing the effluent BOD to a low concentration. Examples of the first group or biological filtration techniques are flood irrigation, trickling filter, rotating biological filter. The second group is also called biological aeration and consists of activated sludge, aerated lagoon and waste stabilization pond.

At the end of this stage is a final sedimentation tank, similar to the primary sedimentation tank, for the collection of sewage sludge. The remaining effluent enters the final stage of treatment where it is disinfected before being released into open streams and other bodies of water. The disinfection process is traditionally done by chlorination but more recent developments have introduce a new technique that uses ultraviolet radiation (Pilkington, 1995).

The sludge that was removed in the primary sedimentation is added with sludge from the secondary clarifier. This accumulated sludge is then processed into biogas in an anaerobic digester. The left over digestate from digesting the sludge is rich in nutrients and very suitable for the use as feritlizers. However, studies has shown that the presence of heavy metals restricts its use as a fertilizer (Pathak et al., 2009). According Pathak et al. (2009, p. 2344) *'Bioleaching process uses the catalytic effect produced by the metabolic activities of iron-oxidizing and sulfur-oxidizing microorganisms resulting in an acceleration of the chemical degradation of the sulfides. It is a low cost environment friendly technique which is 80% cheaper in terms of chemical consumption compared to the traditional chemical methods employed for metals leaching from the sludge and recovery of metals from the leachate.'* Peng et al. (2008) further added that when combining the bioleaching and electrokinetic remediation technology the results indicate that heavy metals are dissolved to dissociative or ionic fractions from the sludge. Under the condition of an electric field, the dissociative or ionic fractions of heavy metals can migrate directionally to the cathode zone and be deoxidized to the fraction of elements, and thus recycled to eliminate the danger of concentrated superficial liquid of heavy metals. This method is still in its pilot phase and still needs to tested on a larger scale. The alternative to this is to create separate sewage systems for grey-and black water. According to Teeuw and Luising (2005) the advantage of this approach is that methods used for the treatment of wastewater are also excellent tools the design of the landscape or buildings.

3. Benefits of anaerobic digestion as bio fertilizers.

The process of anaerobic digestion and application the digestate has been well known since the early 1920's but it is in the recent 20 years that researchers started to show interest in this technology. (Hobson and Wheatley, 1993c). It is interesting to know what the thoughts of contemporary researchers are on the use of digestate as bio fertilizers and wastewater treatment. Earlier experiments have confirmed that the use of anaerobic digestion is the solution to handling organic waste. But in addition the results also reveal that it has little adverse impact on the environment (Zupančič et al., 2008). For residential neighbourhoods, this means that the process could be placed inside their environment without having the fear that it would influence the liveability of the area. Further research by Cavinato et al. (2013 p.264) found the following:

- the thermophilic option can be considered as the best condition in a co-digestion process for the treatment of sludge or bio waste mixtures:

improvements in terms of biogas yields around 45 to 50% are proven;
- the energy balance of the thermophilic process, although demanding a higher heat capacity compared to a mesophilic process, can be easily supported even when treating only 50% of the biowaste produced in a given basin;
- digestate characteristics are adequate for the production of good quality compost using a simple aerobic post stabilisation step, considering a very short HRT due to the high biological stability already reached in the anaerobic step. Metal contents are within the more stringent limit used in Europe for high quality amendants.

With these positive findings the use of anaerobic digesters could possibily make a community become self sustaining in both energy and food production. However, the use of digestate itself does not have physical advantages on the soil itself. Bougnom et al. (20120 stated that the use of residue from renewable energy production does not affect soil physical and chemical parameters nor microbial biomass and activity compared to manure application. Vaneeckhaute et al. (2013) added that the use of digestate as bio fertilizer only has a small improvement on the physicochemical soil fertility and soil quality by one year application. Their research also indicate that bio fertilizers do increase the forage yield of their crops. In Vaneeckhaute's research, the harvested energy maize is slightly higher, and the economic and ecological benefits are significantly higher, when compared to artificial fertilizers and animal manure. Both studies need to be continued in order to validate what the impact is on soil quality in the longer term. According to Khalid et al. (2011 p.1742) *'the use of advanced molecular techniques can further enhance the efficiency of this system by identifying the microbial community structure and functional, and their ecological relationships in the bioreactor.'* It is possible that this system is able to integrate other technologies into itself and improve its functioning.

The main methods to recover organic matter from a soluble source are through a biological filtering process or a mechanical treatment. The choice for either is determined by the goal: for nutrient recovery a mechanical treatment is most efficient while biological filtering more variety as design tool. For the most sustainable method to treat waste water Muga and Mihelcic (2008 p.445) stated the following:

> 'traditional sustainability indicators for wastewater systems that have emphasized environmental stressors at the neglect of societal issues need to strive in the future to include current and intergenerational balanced impacts. In addition, the design of wastewater management systems that are better integrated into larger community needs could be considered. For example *the reuse of treated wastewater and management of solid residuals could be better integrated with local agriculture activities which would re-distribute and return nutrients back to the surrounding environment, instead of concentrating nutrient fluxes in one receiving water body. Ideally the use of onsite-treatment systems like septic tanks, constructed wetlands, and even composting latrines has potential in contributing to sustainability as they rely on non-energy and chemical intensive processes that return nutrients to the surrounding environment.'*

There is no clear water treatment system that is considered the most sustainable. Different factors have to be incorporated into the choice and design of a particular technique. The similarities are that the whole process has to form a contribute to a local water cycle.

4. Physical appearance of anaerobic digesters and a wastewater treatment facility.

Vandevivere (1999) stated that there is no consensus on the optimal design for a anaerobic reactor. The author also went on to add that the design of such a reactor is influenced by the perspective from a biological, technical, economical or environmental viewpoint. It is clear that conventional digesters are designed to facilitate the process only and that there is no attention given to the design of its appearance. However, there are basic elements that are noticeable from every digester. According to Hobson and Wheatly (1993b) the first digesters were built in concrete because of high capital costs and the intention of operation them for a period of fifty years. In later designs other materials such as enamelled steel and plastic are used for more lighter constructions. There shapes are almost always tall cylindrical with exceptions such as peer shape or flat cylindrical. The reason to use a cylindrical shape has to do with the efficiency to mix the contents of a reactor during digestion. Their placement can be on ground level, up to a quarter buried, half buried or three quarter buried in the ground (Polprasert, 1996). The form of gas holders have a more flexible design and placement. They can be shaped cylindrical like the reactors or completely rounded like a sphere. They can also be places on a platform or integrated on the top of a reactor.

One-stage 'wet' systems.

The advantages of a one-stage system in general is that they are similar to the demonstrated technology that has been in use for decades. Even the biomass is similar: bio solid matter that is pulped and diluted with water creating a slurry that consist of 15 % total solid contents(TS). The technical disadvantage of this system is its vulnerability to short-circuiting where a fraction of the biomass passes through the reactor without being fully processed. This leads to on one hand less biogas yield while on the other hand a digestate that contains a high concentration of pathogens. Other drawbacks include a complicated pre-treatment of waste. If this waste is not treated properly the heaviest particles will sink to the bottom of the reactor and damage the propellers through abrasion. From a biological viewpoint, these reactors have been known to experience shock loads when inhibitors spread in the reactor. Shock load is when the anaerobic digestion process of the bacteria is suddenly halted by an inhibitor such as ammonia and fatty acids. Fortunately, the addition of water help in diluting these inhibitors. In economical terms this type of digester always require the consumption of vast amounts of water and energy for heating. However, these cost are balanced by the use cheaper equipment such as pumps and piping to handle slurries. Important shapes for this system are cylindrical tubes. The circular surface area is obviously practical for biomass to be turned. Because of the low TS biomass content there is no need for an external shredder. They can be passed into the digester through pipes that are connected to a sludge tank.

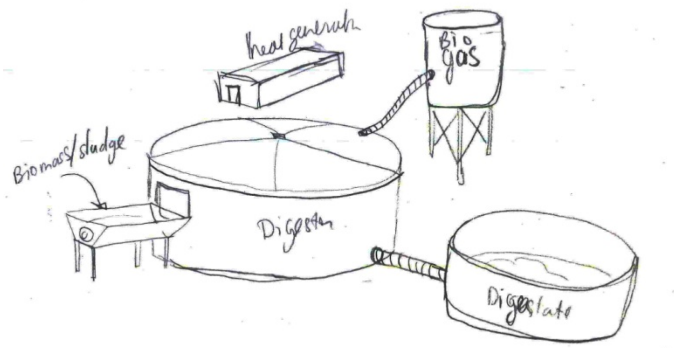

Figure 3: Sketch of the required elements in an anaerobic digester. Image by author, based on images from Provincie West-Vlaanderen, 2007.

One-stage 'dry' systems.

The content of dry systems comprise of 20 - 40% TS where only matter with a content higher than 50% is diluted with water. In technical terms this system has no risk of short circuiting because there no moving parts in the reactor. The biomass is turned by using plug flow in the form of impellers and biogas recirculation or rotating the reactor drum . This also means that robust material bigger than 40 mm can remain in the reactor without influencing the process. The only technical disadvantage is that wet waste with a TS smaller than 20% cannot be treated alone. From a biological viewpoint there are less volatile solids are lost in pre-treatment. A dry system can take a larger organic rate when compared to a wet system of the same size with the added advantage that the dispersion of inhibitors is limited. The disadvantage is having little possibility to dilute inhibitors with fresh water. From an economical perspective this system has smaller reactors and requires cheaper pre-treatment while the usage of water is significantly less when compared to wet systems. However, the waste handling equipment are robust in the form of conveyer belts and require a larger investment. The appearance of this system is similar to the 'wet' version with the addition of a shredder that can be rectangular.

Two-stage systems without biomass retention.

Reactors consisting of two-stage systems were briefly explained in the previous chapter. Their main advantage is that they enable the optimization of the hydrolyses and acidification in the first stage while optimizing the process of acetogenesis and methanogenesis afterwards. Eventually, this could lead to a higher reaction rate and a higher biogas yield. From a technical point of view, the design of a two-stage system allows freedom in the design of the process: they can be a combination in series of two plug-flow reactors, either in the 'wet-wet' or 'dry-dry'mode. The disadvantage is that this process is very complex. This system has a greater biological stability for rapidly degradable wastes. The disadvantage is that in cases when solids are not methanogenized the biogas yield decreases. Economically this system requires a large investment but less heavy metal is left in the compost when solids are not methanogenized.

Two-stage systems with biomass retention.

The advantages of this type are similar to the one without retention. The difference is that, with the retention of methanogens in the second stage, shock loads are reduced while the amount inhibiting substances are also limited. Both types of two-stage systems use cylindrical shapes for their digesters. They are only distinguishable from the single-stage systems because they have an extra digester.

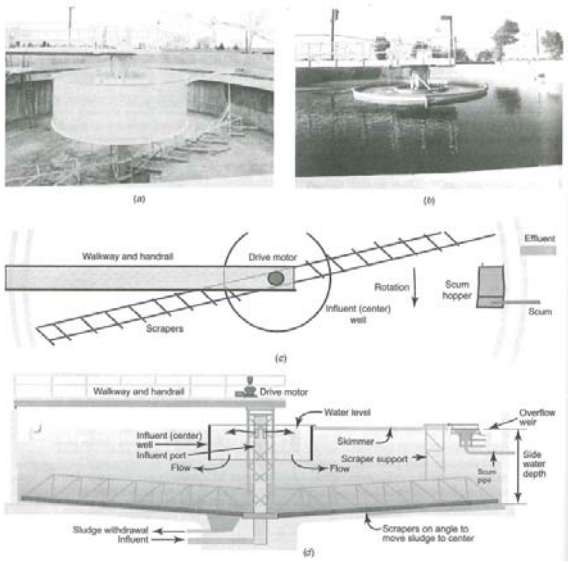

Figure 4: A sedimentation tank. On the top left is an empty tank. Top right when it is in use. In the middle are the rotating axis. Bottom is a section of the tank. Source: Hammer and Hammer jr.2008a.

For the treatment of wastewater the first step is preliminary removal of solid matter. This is usually done with the use of screens, fines screens and shredders located in a rectangular shaped building. Inside this building are also located the influent pumps that help transport the water to the primary settlements. Primary clarifiers can either be rectangular with sizes of 3m by 9m to 6m by 18m or circular shaped with size ranging from 9m to 46m in diameter. However, in water treatment plants for small communities, such as villages and towns, the primary sedimentation stage are popularly discarded in the design (Hammer and Hammer jr., 2008a).

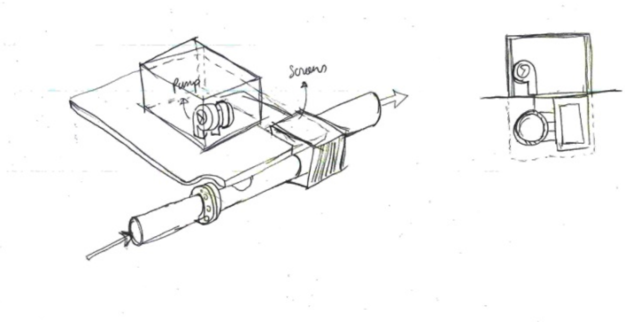

Figure 5: Sketch a pumpstation. Image by author.

The second step of wastewater treatment can either be done with biological filtration or biological aeration. According the Barnes (1995 p.95) the biological aeration treatment has the advantage that that nutrients can be removed from the process. *'In general the advantage of activated sludge process is that it is adaptable for nitrification, denitrification and even biological phosphorus removal by manipulation of a sequence of anaerobic, anoxic and aerobic zones within the reactor, and by manipulating the feed pattern and characteristics as well as the environmental conditions.'* In his research he also added that biological filtration systems produce a good but variable effluent quality.

Stone-Media tricking filters.

A trickling filter bed build in the shape of a circle. The depth of this bed varied between 15 cm to 21 cm. Deeper depths do not mean improve the removal of BOD. The key elements are a rotary distributor that is connected to the center of the circle, a underdrain system and filter media. The most common material for the filter media crushed rocks ranging from 6 cm to 10 cm.

Biological towers.

The shape of this system is also in the form of a circle but other forms may be possible. The workings are similar to stone-media filter with the exception that the filter elements are manufactured with plastic. The main advantage of this media is the high vertical surface which allows more substantial slime to attach on to. Additionally, due to the uniform media, liquid is better distributed allow for the construction of deeper filters that in turn offer the ability to treat high-strength wastewaters.

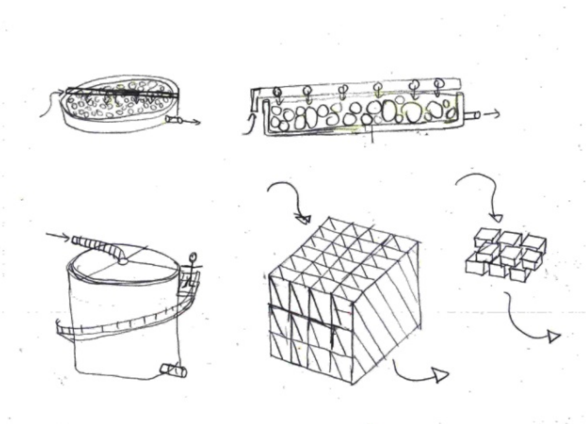

Figure 6: The top sketch is a trickling filter with section. Bottom is a biological tower with zoomed in view of a filter medium and the configuration of such elements. Image by author based on Hammer and Hammer jr. , 2008a.

Conventional and step aeration.

The shape of the construction is a long rectangular tank with plug-flow compartments in between the walls. The compartments form an oscillating biological growth pattern. In the bottom of the tank are air diffusers that serve for oxygenation and mixing. In conventional basins the air supply is tapered along the length of the tank. The former prove a better deep mixing and adequate oxygen transfer.

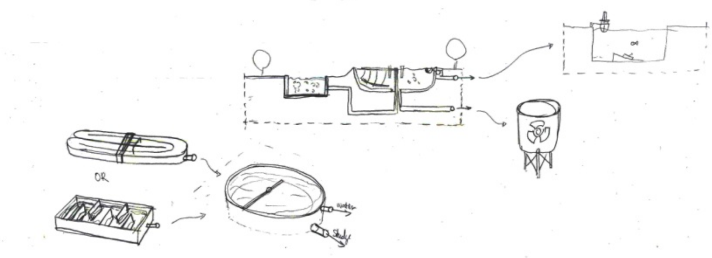

Figure 7: Sketch of an extended aeration tank or a step aeration tank connected to a sedimentation tank. Image by author based on information from Hammer and Hammer jr.2008a.

Extended aeration.

These are the most common systems for small flows from schools, subdivisions and villages. The construction consists of an elongated oval basin of 120 cm to 3 m depth. Here, the aeration diffusers are also placed in the bottom of the basins to allow a better oxygenation and mixing. The biological process is very stable in this system.

Combined filtration and aeration process.

These a combination of biological towers with a second-stage aeration to improve treatment from high-strength industrial or seasonal waste. They are constructed to operate the biological filter and the aeration sequentially.

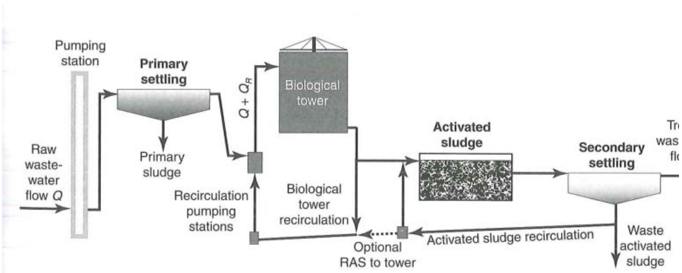

Figure 8: Schematic of a combination of filtration and aeration tank. Source: Hammer and Hammer jr.2008a.

Membrane filter

Membrane filters are used to provide an increased degree of treatment for industrial applications, water reuse, and reclamation (Hammer and Hammer jr., 2008b). The categories of pore sizes are: microfiltration, ultrafiltration, nanofiltration and reverse osmosis. This technology can either be used to improve the efficiency of older existing treatment plants or they can function autonomously on their own. An example of this is the RWZI Heenvliet. (Maccormich, 1995; STOWA, 2009) The membrane filters are compact in size and are commonly located in rectangular buildings alongside pump stations.

Constructed wetlands.

An effective method to filter treatment water is to use constructed wetlands in combination with helophyte vegetation (Teeuw and Luising, 2005). The technique can produce high quality of treated water but has the disadvantage that nutrients cannot be recovered. For water highly contaminated water sources this technique would be an ideal solution. A manual issued U.S. Environmental Protection Agency (1988) stated that these filter systems can be built almost everywhere.

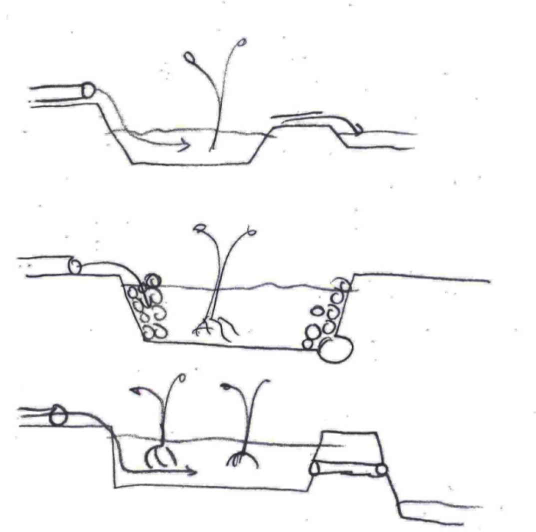

Figure 9: Sketches of plants in an constructed wetland. The effluent filtrated by these ponds are very clean. Source: Teeuw and Luising, 2005.

5. Research strategy.

The aim of the previous chapter was to gain an overall impression on the forms that can be generated from the elements in an anaerobic digester and a wastewater treatment facility. In order to design a building it is important to know how much space is required to built it. Case studies have in common that their sizes are influenced by the amount of wastewater or organic waste that is available in its context. The following is the description on how both the area for the wastewater treatment facility and the anaerobic digester can be estimated.

Converting context specific elements into generic research parameters.

The equation to estimate the required area for each treatment plant is based on the relationship between the total floor area and the amount of waste it process. By dividing the amount of organic waste to the average area from the case studies we get a proportionate number. To calculate size of any treatment facility for a design, divide the amount of waste water or organic waste from a site to the corresponding version of this number. Note that in order for the estimation to resemble the reality as closely as possible, the assumption is that people produce organic waste with similar contents everywhere. The relationship between digester, treatment plant and crop growing beds is further expanded upon with the ratio 1 to 2,7 to 45. The number of inhabitants and the amount of waste they produce can be obtained from surveys conducted by local governments. An example of the extensive calculation can be consulted in the appendix. The equations to determine a wastewater treatment facility and anaerobic digester are:

$$A_{\text{Wastewater}} = \frac{1}{422{,}59 \times 10^{3}} \times \text{amount of wastewater in liters}$$

$$A_{\text{digester}} = \frac{1}{8{,}53} \times \text{amount of biomass in tons}$$

Researchers from the province of Western-Flanders (West-Vlaanderen, 2007) has conducted an experiment to produce biogas and digestate from different organic material including waste. The results of their research will serve as tools to estimate the amount of digestate from organic waste and sludge digestion as well as the amount of nutrients contained in them. The ratio is 40,6 kilogram of digestate from every ton of biomass. However, it is important to mention that in their study the contents of their biomass is made up with 80% vegetables and fruit (GFT) and 20% of another organic waste. The specific nutrients plants require are nitrate (N), Phosphate (P) and Potassium (K). Their amounts differ depending on the crops that people want to grow (Infonu.nl, 2011; Labosky and Peters, 2006). Locating a suitable site to grow crops in the city is very challenging. That is why Lanarc-Golder (2012) has conducted a study in British Columbia that serve as a guideline for urban farming. The selected locations are all depended on the density of the town or city. Among the possibilities are empty lots, rooftops, city parks or even balconies. After obtaining the amount of crops that can be produced and the required area to grow them we can compare this to results conducted by other researchers. We can divide the total area to the number of inhabitants to determine how much space is need for producing food for one person. Using the results from a research by Symvoulidou (2012) we can confirm if our own calculations meet the space requirements for one individual. In this case the maximum agriculture production area size for a person living on vegetables only is 39 m^2.

At this point it is possible to generate design tools from the obtained knowledge on the process of converting waste into nutrients and their physical requirements. These design tools are meant to be integrated with each other to form a preliminary design. It is up to the designer to update this preliminary according to the space requir*emen*ts of any context. In the follow are a few selected examples of the design tools:

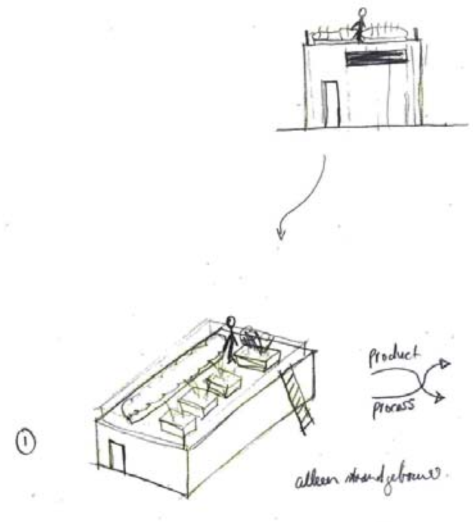

Figure 10: The pump station building cannot house people in its interior. The building also contain the screening bars and ultraviolet disinfectation equipment. Here the roof of the pump station can be used to grow vegetables. Image by author.

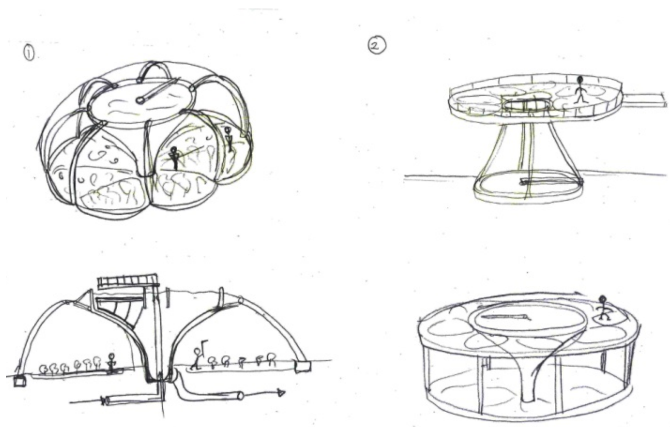

Figure 12: Two design variants of the sedimentation tank. The images on the left depicts it as the centre of a dome structure. The top right depicts the tank supporting a platform on top of it. The bottom right image depicts the sedimentation tank being lifted up. Image by author.

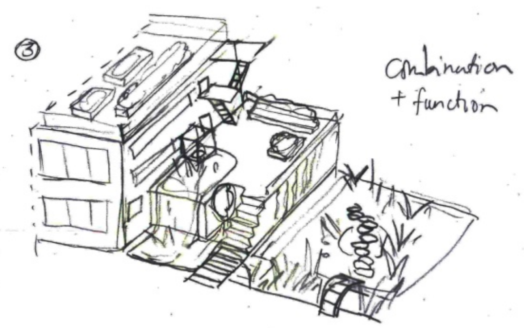

Figure 11: Third version where both a constructed wetland and crop beds are placed on the roof. The building itself is connected to an adjacent building. Image by author.

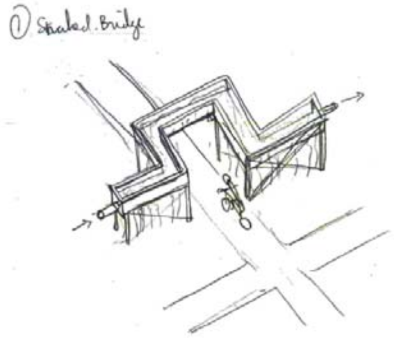

Figure 13: The aeration tanks can be supported on columns like a sky bridge. They can span over other structures or infrastructure. Image by author.

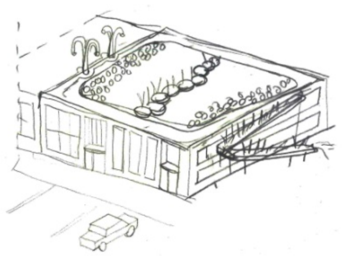

Figure 14: Constructed wetland design on the roof. Image by author.

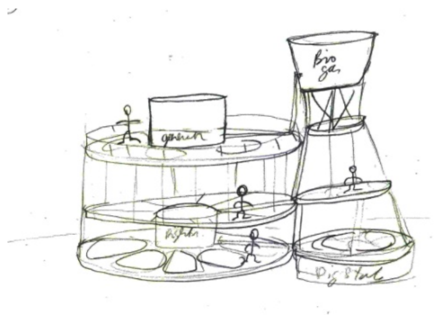

Figure 15: Anaerobic digester 2. The biogas tank is placed on top of a tower. The digester is placed on top of a platform next to it with underneath it on the ground floor the digestate repository. Image by author.

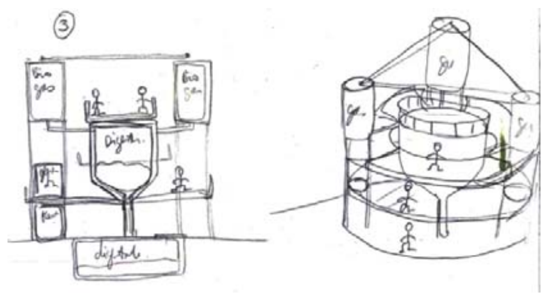

Figure 16: Anaerobic digester 3. In this design all elements are placed on top of a platform. Image by author.

The design tools from figure 10 and 11, propose to use the exterior of these buildings for the purpose of growing crops or as a platform for the biological filtration. The use of constructed wetlands as filtration system does not needs to be limited to the ground level as indicated on figure 14. In order to allow human interaction with the sedimentation tanks, the design tool form figure 12 suggest that it could be used as a supporting structure. In the first example the tanks is constructed as the centre of a dome construction. Its additional purpose is to function as a cooling device. The circulating water is a great medium to transfer heat away from this space enclosed by the dome. In an alternative design tool, the tank is constructed as a mushroom shape column while the same climate principle applies hear. The pie shape spaces placed around the tank can be used for a different array of functions. The aeration tanks have the least interaction value for people to use them. One method is to place them over head in the just like aqueducts. The plug-flow shape of the canals can be uncoiled into a zigzag line and still retain its function.

The design tool in figure 16 suggest that the biogas tanks can be integrated on the top of supporting structures. This design also indicate that the digester can function as the main support column, very much like the sedimentation tank in figure 12. In the design tool from figure 15, a more holist approach is applied to these elements. Here the main supporting structure in this figure is ring shape steel structure. Both digester and repository are located in the centres of the rings, one on the ground floor the other in the roof, while the biogas containment tank is on top of the tower. The purpose of the former is to deflect tension while the latter serve as attachment point for the under lying floors. Because digesters require heating and biogas can be generated into heat, these elements are also used as climate installations for the building.

6. Conclusion.

The aim of this research is to integrate waste treatment systems and crop production into a building or built environment. The methods selected to recover nutrients from waste offer interesting challenges for the designer to modify them for domestic use. Anaerobic digesters and wastewater treatment facilities are built to house a process that can potentially endanger the public safety when errors occur. It is because of this reason that most facilities are not designed as a gathering spot for large crowds of people. However, these restrictions can be overcome and even used to our advantage by incorporating them into the design. All the design tools in the previous chapter have in common that their physical form facilitate more than one function. The criteria for the second function is that it should allow more than one person to use the space. In addition this function must not restrict the primary use of the facility to function properly. And finally, the elements that are considered a nuisance or danger such as odour and combustion will be re-directed way from the users or placed into a containment zone.

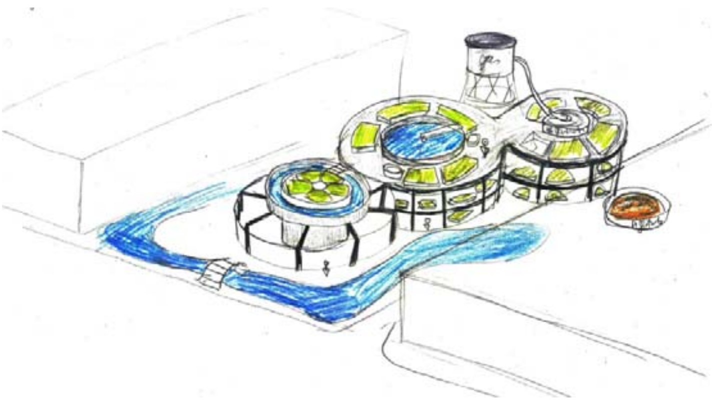

Figure 17: Preliminary design of the whole plant. Image by author

In the case of wastewater treatment facilities the challenge is the size of the elements and the odour that inhibits them from being placed inside buildings. A sedimentation tank for example has a minimal diameter of 9 meters which means that it will have an enormous weight, making it very difficult to place them on to rooftops of existing buildings. In stark contrast to this are the small equipment such as the pump stations and ultraviolet disinfection gear, that have to be grouped together to fill up a storage shack.

Anaerobic digesters are designed to facilitate efficiency rather than appearance. Their shape and placement are constructed to fulfil a specific set of requirements in order for the process to function. The placement of biogas tanks in the vicinity of the digester is important. However, case studies has shown that these two can even be integrated into one object.

The study in this research seems to indicate that the design tools are limited for use as structural elements and climate design tools. The elements with a mechanical efficiency offer little possibility for direct human interaction without the risk of danger. However, the biologically based solutions of have a greater potential to improve human experience. As design tools they offer a greater freedom integration.

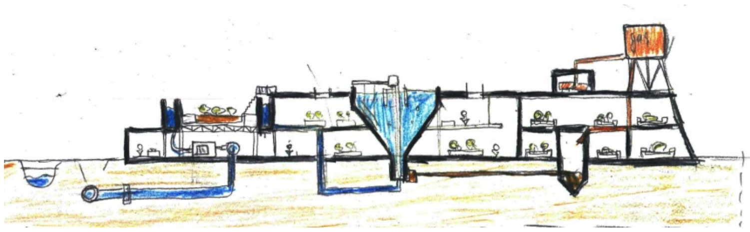

Figure 18: Section of the preliminary design of the whole plant. Image by author.

7. Recommendations.

The research conducted in this study focused on the recovery of nutrient from organic waste in buildings. The methods were largely based on mechanical solutions. The research did not take into account the efficiency of natural based solutions. For the contribution to a sustainably built environment, it is recommended that future researchers should focus on the natural systems. If the researcher should choose to continue studying the methods from this research, the recommendation investigate the possibilities to integrate mechanical and natural systems into a hybrid solution.

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Appendix A : Calculation method

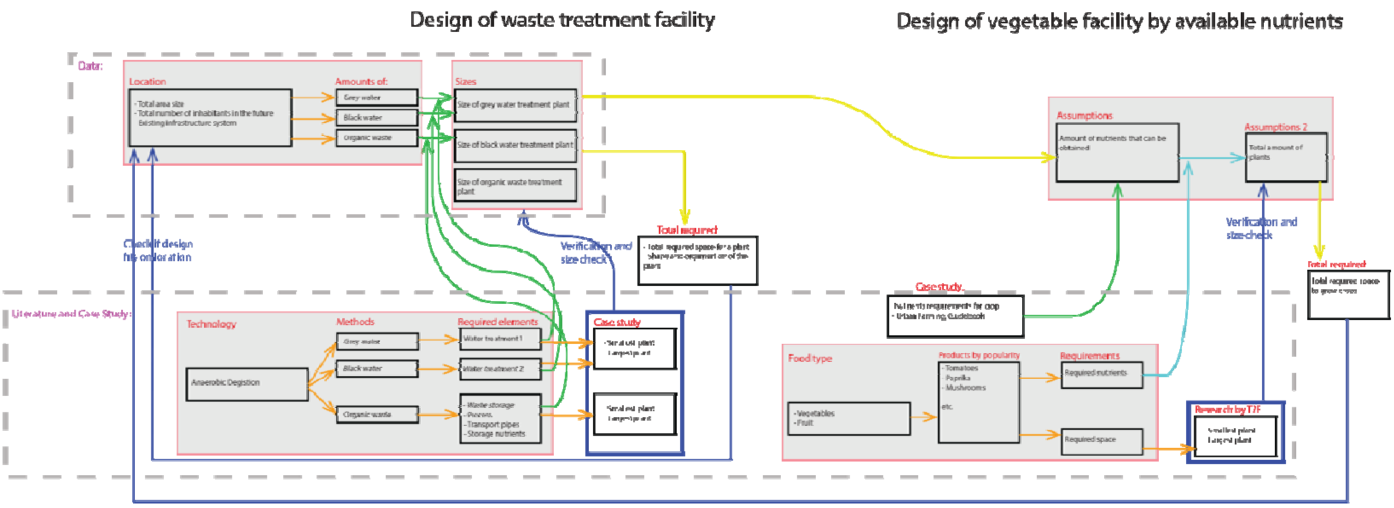

Figure 19: The research strategy in schematic overview. Image by author.

Case studies.

Complementing case studies are required in order to study the organization of the different elements in practice as well as to estimate the size of existing plants. Important parameters to formulate an equation are the relation between the capacity of each case study and the total area requirements for the facility, the area required for of each stage and the area required for each of the elements. It is there important to analyze each project for their elements and the capacity in which they run.

Waste water treatment facilities.

The two examples used in this study are RWZI Heenvliet and RWZI Hellevoetsluis on the outskirts of Rotterdam. The former is one of the first plants to incorporate a hybrid system of membrane filters while the latter's capacity is ideal for the comparison to a medium size community.

Table 1: Area sizes and treatment capacity for RWZI Heenvliet. This table was derived from the information provided by Waterschap Hollandse Delta

Heenvliet

	floor size (m2) per stage	floor size (m2) element
Primary	253	
Pump station		100
Screen bars		153
Secondary	1352,5	
Aeration tank		721,5
Secondary Sedimentation		568
Sludge retour		63
Disinfection	118	
Effluent pump station		70
Disinfection gutter		48
MBR	209	
Total:	1932,5	

Inhabitants: 8.266	Wastewater (l/year):	373520000

The total area of RWZI Heenvliet plant is 1.660 m^2, the town itself has a population of 8.266 people with an average water usage of 123,8 liter per day (Teeuw and Luising, 2005). This means that plant has to be able to process 373,53x10^6 liters of wastewater a year. The treatment facility contains basic elements with the inclusion of a Membrane filter facility (MBR) and a sludge lagoon. This facility also does not have a primary clarifier, but according to Hammer and Hammer jr. (2008a) this is common practice in some villages and towns with a small population.

Figure 20: Aerial photo of Heenvliet with the MBR building on the top left corner. Source:http://www.waterforum-archief.net/index.asp?url=/template_d3.asp&que=paginanr=1923

Table 2: Area sizes and treatment capacity for RWZI Hellevoetsluis. This table was derived from the information provided by Waterschap Hollandse Delta

Hellevoetsluis

	floor size (m2) per stage	floor size (m2) element
Primary	4166	
Pump station		105
Screen bars		363
Selectors		1782
Primary Sedimentation		1916
Secondary	7697,5	
Aeration tank		2750
Secondary Sedimentation (3tanks)		5748
Denitrification tank		1155
Nitrification tank		2145
Sludge retour		50
Disinfection	210	
Effluent pump station		85,71
Ultraviolet Disinfection		124,29
Total:	12073,5	

Inhabitants: 68.985	Wastewater (l/year):	3117000000

Total area minimal required elements:	9176,00

RWZI Hellevoetsluis has an area of 5.025 m^2. The town from where it collects its wastewater has a population of 68.985 people with a total capacity of $3{,}117 \times 10^9$ liters of wastewater a year. This treatment facility does have a primary clarifier along with three secondary sedimentation tanks. Other important features are the denitrification tank, the nitratification tank and an oval shaped aeration tank.

Case study anaerobic digesters.

Germany is renowned as one of the leaders in biogas production. The case studies conducted in this research are from factories located in the Niedersachsen region of this country. The data from these case studies help to indicate what elements are required for the design and how much area element take up.

Biolandhof in Puggen, Ebeling can digest 5.300 tons of biomass in a year. Here, they use a two-stage system where gas is collected at the top of the digesters. The total area of the plant is 2.145m^2. Similary, Biogas facility in Betzendorf alos utilizes a two-stage process. The area for this plant is 2.230m^2 but with a much larger capacity of 10.300 tons of biomass per year. Our last case study is biogas facility in Fluttenkamp, Blekendorf. This facility uses a single-stage system with an area size of 1150m^2 . Its capacity is 16.500 tons of biomass in a year.

Figure 21: Aerial photo of Betzendorf. Here the two digesters are visible. Source: Google earth.

Table 3: Total area size and floor size of every element of two digesters. Source:Biogasanlagen in Niedersachsen, Sachsen-Anhalt und Schleswig-Holstein.

Case study	Puggen, Ebeling	Betzendorf
Capacity (tons/year)	5.300	10.300
	area size (m2)	area size (m2)
Digester 1	260,16	543,25
Digester 2	260,16	543,25
Heat generator	78	411,84
Digestate repository	176,71	452,39
Feeder	28,05	286
Total size	803,08	2236,73

For the graduation studio Architectural Engineering the assignment is to design a building in the Sloterdijk area of Amsterdam. One available site is the Minervahaven area along with the future residential area Houthaven. The Minverva site contains only business and in order to increase the amount of waste the connecting residential areas of Spaarndammer and Zeeheldenbuurt are added. The Spaarndammer en Zeehelden neighborhood in Amsterdam is expected to have a total of 12476 inhabitants. According to Teeuw and Luising (2005) the average Dutch person uses around 123,8 liters of water a day. The total amount of water usage will be 563.753.012 liters a year. According to a publication from Waterschap Hollandse Dela (2010) this correspond to an amount of 2400 tons of sludge production per year. However, according to Teeuw and Luising (2005) water containing feces and urine have high concentrations of nutrients. This type of water is also called 'black' water by popular sources. In their research they also mentioned that when wastewater and rainwater mixed together, the extracted sludge also contains toxic residues. This makes nutrient recover very difficult. A solution is to collect grey-and black water separately for treatment. Since black water contains the most nutrients, the calculations of this research will focus on this source. The average person uses 35,8 liters a day to flush toilets; the total amount per year will be $163x10^6$ liters with a sludge production of 756,32 tons. Additional reports published by the municipality show that an average produces average 2kg of organic waste (the groente-, fruit-en tuin afval [gft]in Dutch) per year. The total amount of organic waste calculated from this is 37,428 tons per year. Adding these to outcomes together we have 793,75 tons of biomass for digestion.

Table 4: Information of the design location. Table by author.

Total size site (m2):	241360
Expected inhabitants 2020:	12476
Average waste production (kg/y):	3
Wastewater Amsterdam 2011 (l):	20300000000
Sewage sludge per year (tons):	94106
Ratio Water-Sludge:	0,00000
Average black water (liters/day):	35,8
Organic waster per year (tons):	37,43
Wastewater location per year (l):	163023892
Estimated amount of sludge (t) :	755,74
Total sludge (tons)	791,54

Table 5: Statistics on the waste sources and amounts in Amsterdam. Source: CBS statline

10.1.3 Huishoudelijk afval (kg/inwoner), 2007-2011

	2007	2008	2009	2010	2011
huishoudelijk restafval	328	323	304	293	294
grof huishoudelijk restafval	67	72	78	79	79
verbouwingsrestafval	19	20	16	15	15
groente-, fruit- en tuinafval	2	1	1	0	0
oud papier en karton	33	33	30	30	29
verpakkingsglas	22	22	21	21	21
textiel	2	2	2	2	2
klein chemisch afval	1	1	1	1	1
wit- en bruingoed	4	4	3	3	3
grof tuinafval	5	7	5	4	3
metalen	1	1	1	1	1
overige afvalstoffen	-	-	2	1	-
totaal huishoudelijk afval	482	488	464	450	448

bron: CBS

Table 6: The amount of waste water production in Amsterdam. Source: Waternet

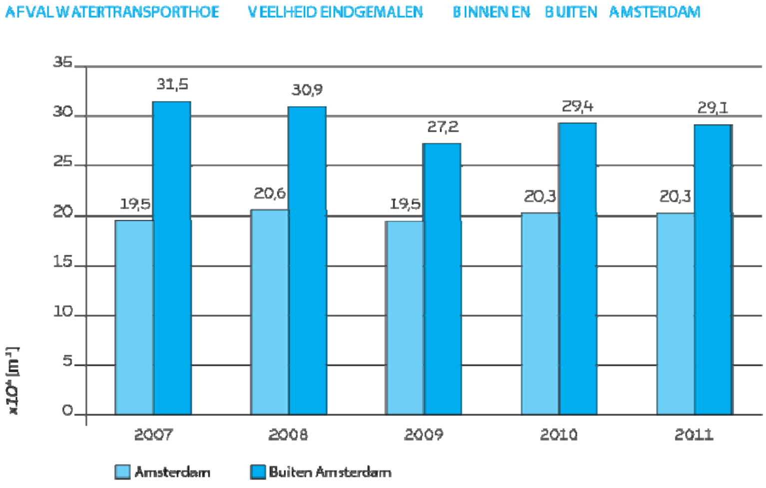

Table 7: Indication of amount of sludge production per year. Source: Waternet.

ONT WATERD SLI B		
Jaar	**Productie ton slib/jaar**	**Productie % droge stof**
2007	102068	22,4
2008	102289	21,4
2009	94453	22,4
2010	96135	22,2
2011	94106	22,0

Overzicht ontwaterd slib productie slibontwateringen Waternet

Table 8: Prediction of the number of inhabitants in the year 2020. Source: DRO/O+S

_E13

Tabel 6 Prognose buurtcombinaties 2012: E13 Spaarndammer- en Zeeheldenbuurt

	2013		2015		2020		2025		2030	
leeftijd	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%
0-4	643	6,0	622	5,8	587	5,6	552	5,2	511	4,9
5-9	428	4,0	458	4,3	443	4,2	422	4,0	388	3,7
10-14	363	3,4	355	3,3	370	3,5	367	3,5	338	3,3
15-19	414	3,9	374	3,5	347	3,3	360	3,4	350	3,4
20-24	663	6,2	678	6,3	663	6,3	589	5,6	579	5,6
25-29	1015	9,5	1008	9,4	879	8,4	847	8,0	842	8,1
30-34	1280	12,0	1238	11,6	1109	10,6	1047	9,9	1004	9,7
35-39	997	9,4	1049	9,8	1054	10,0	979	9,3	911	8,8
40-44	924	8,7	914	8,5	912	8,7	916	8,7	845	8,2
45-49	845	7,9	835	7,8	816	7,8	811	7,7	798	7,7
50-54	780	7,3	792	7,4	768	7,3	754	7,1	731	7,1
55-59	651	6,1	658	6,2	722	6,9	704	6,7	685	6,6
60-64	552	5,2	580	5,4	608	5,8	662	6,3	644	6,2
65-69	408	3,8	452	4,2	493	4,7	528	5,0	570	5,5
70-74	251	2,4	281	2,6	388	3,7	419	4,0	448	4,3
75-79	190	1,8	181	1,7	224	2,1	311	2,9	332	3,2
80-84	121	1,1	110	1,0	130	1,2	161	1,5	231	2,2
85 e.o.	122	1,1	111	1,0	111	1,1	120	1,1	162	1,6
totaal	10645	100	10697	100	10510	100	10549	100	10355	100
0-3	526	4,9	508	4,7	482	4,6	459	4,3	420	4,1
4-7	402	3,8	414	3,9	383	3,6	365	3,5	333	3,2
8-12	365	3,4	366	3,4	397	3,8	377	3,6	349	3,4
13-17	361	3,4	352	3,3	334	3,2	356	3,4	332	3,2
18-24	867	8,1	848	7,9	704	6,7	737	7,0	730	7,0
25-29	1015	9,5	1008	9,4	879	8,4	847	8,0	842	8,1
30-39	2277	21,4	2288	21,4	2163	20,6	2026	19,2	1915	18,5
40-49	1769	16,6	1749	16,4	1739	16,5	1727	16,4	1641	15,8
50-64	1983	18,6	2031	19,0	2094	19,9	2120	20,1	2060	19,9
65 e.o.	1090	10,2	1135	10,6	1344	12,8	1539	14,6	1733	16,7
totaal	10645	100	10697	100	10510	100	10549	100	10355	100

bron: DRO/O+S

Page 1

Calculation equation.

The equation to estimate the required area for each treatment plant is based on the relationship between the total floor area and the amount of waste it process. By dividing the amount of organic waste to the average area from the case studies we get a proportionate number. To calculate size of any treatment facility for a design, divide the amount of waste water or organic waste from a site to the corresponding version of this ratio. For example: the total area of the plant in Puggen is 803,08 m^2 with a capacity of 5300 tons of biomass per year. This has a ratio of $\frac{5300}{803{,}08} = 6{,}6$. For the plant in Betzendorf the ratio is 4,61. The average of these two is 5,6. In the equation this would be:

$$A_{\text{Digestion plant size}} = \frac{1}{5{,}6} \times \text{amount of biomass on the site}$$

The design location is estimated to produce 791,54 tons of biomass which will result in a digestion plant of 141,68 m^2. This procedure has to be repeated for the wastewater treatment plant to calculate the size. To calculate the required elements this method can also be applied to estimate their sizes. The following tables are the results from using this method to calculate.

Wastewater treatment facility:

Table 9: The calculated ratio between capacity and area of whole plant, the three stages and each individual element. Table by author.

Ratio total size 1	339.690,50
Ratio total size 2	224944,29
Average ratio	282317,3954

Primary ratio 1	6.660.256,41
Primary ratio 2	1476363,64
Average ratio	4068310,02

Secondary ratio 1	366.792,19
Secondary ratio 2	289662,66
Average ratio	328227,42

Disinfection ratio 1	14.842.857,14
Disinfection ratio 2	3165423,73
Average ratio	9004140,44

Pump station ratio 1	29.685.714,29
Pump station ratio 2	3735200,00
Average ratio	16710457,14

Screen bars ratio 1	8.586.776,86
Screen bars ratio 2	10,85
Average ratio	4293393,86

Primary sedimentation ratio 1	1.626.826,72
Primary sedimentation ratio 2	517699,24
Average ratio	1072262,98

Aeration tank ratio 1	1.133.454,55
Aeration tank ratio 2	517699,24
Average ratio	825576,89

Effluent pump 1	36.365.000,00
Effluent pump 2	5336000,00
Average ratio	20850500,00

Disinfection ratio 1	25.079.310,34
Disinfection ratio 2	7781666,67
Average ratio	16430488,51

Table 10: Calculated size of the water treatment facility for the design. Table by author.

	floor size (m2) per stage	floor size (m2) element
Primary	40,07	
Pump station		9,76
Screen bars		37,97
Secondary	496,68	
Aeration tank		197,47
Secondary Sedimentation		152,04
Disinfection	18,11	
Effluent pump station		7,82
Disinfection gutter		9,92
MBR		
Total:	554,86	
Inhabitants: 12.476	Wastewater (l/year):	163023892
Black water per person(l/day):		35,8

Anaerobic digesters.

Table 11:The calculated ratio between capacity and area of whole plant, the three stages and each individual element. Table by author.

Total size ratio1 Total size ratio2	6,60 4,60
Average ratio	5,60

Digester 1 ratio1 Digester 1 ratio2	20,37 18,96 0,00
Average ratio	13,11

Digester 2 ratio1 Digester 2 ratio2	20,37 18,96
Average ratio	13,11

Heat generator ratio1 Heat generator ratio2	67,95 25,01
Average ratio	30,99

Repository ratio1 Repository ratio2	29,99 22,77
Average ratio	17,59

Feeder ratio1 Feeder ratio2	188,95 36,01
Average ratio	74,99

Table 12: The calculated size of an anaerobic digester. Table by author.

	area size (m2)
Digester 1	60,54
Digester 2	60,54
Heat generator	25,62
Digestate repository	45,13
Feeder	10,59
Total size	141,68

Calculating the amount of nutrients.

From data obtained by the province of West-Flanders (Provincie West-Vlaanderen, 2007) we can estimate that for 794,51 tons of sludge we are able to obtain 95,19 kg of Nitrate and 21,49 kg of Phosphor. From the a survey done by Borgdorff (2012) we can see what crops are most consumed and thus divide the nutrients according to this.

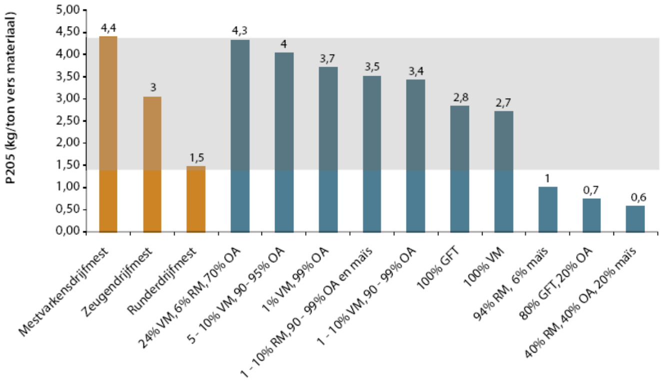

Figure 22: Graphic that indicates how much phosphor can be obtained from digestate. Source: Provincie West-Vlaanderen, 2007

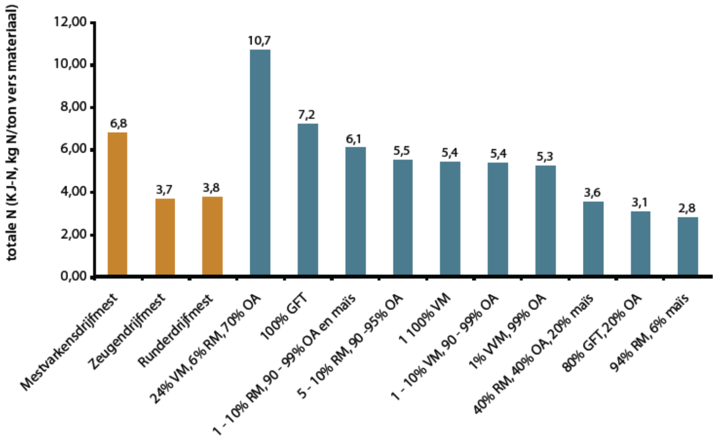

Figure 23: Graphic that indicates how much nitrate can be obtained from digestate. Source: Provincie West-Vlaanderen, 2007

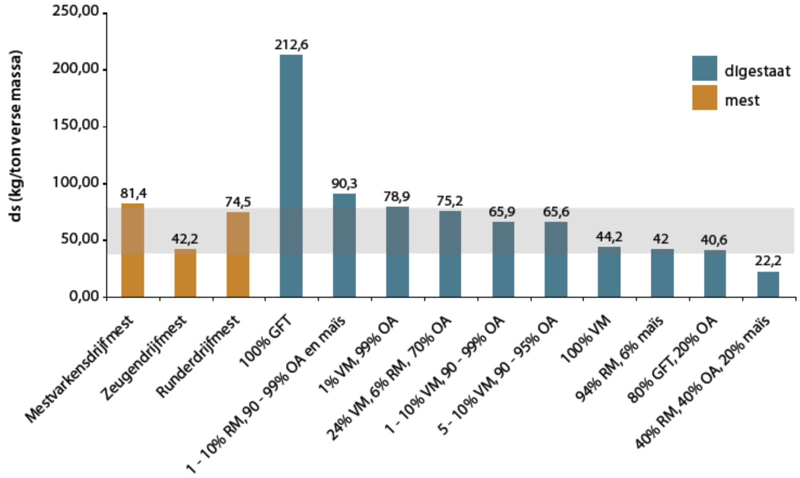

Figure 24: Graphic that indicates how much digestate can be obtained from biomass. Source: Provincie West-Vlaanderen, 2007

Table 13: Amounts of nutrients needed and the required space that can be calculated. Image by author according to information from Laboski and Symvoulidou.

Crop name:	Yield/area (kg/m2)	Nitrate needed (kg/m2)	Phospor needed (kg/m2)
Onions	6,7	0,013	0,007
Tomatos	6,18	0,0056	0,0044
Carrots	7,41	0,0044	0,005
Lettuce	4,9	0,0044	0,0044
Cucumbers	2,47	0,0033	0,0011
Brocolli	1,48	0,00278	0,0011
Cauliflower	1,98	0,0044	0,0022
Potatos	3,9	0,007	0,0072

amount of availabe Nitrate(kg)	amount of availabe Phosphor (kg)	Required space (m2)
9	2	285,71
8	1,8	409,09
6,1	1,1	220,00
6	1	227,27
5	1	909,09
4	1	909,09
4	1	454,55
53	12	1666,67
	Total:	5081,47
	Square meter per person:	0,41

The results indicate that the available amount of food is almost 100 times less the required amount of 39m^2 per person.

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Appendix B: Design tools.

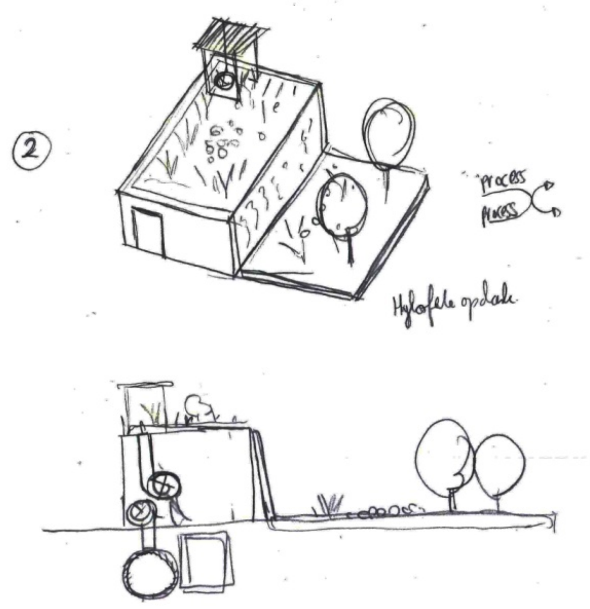

Figure 25: Another alternative is to place a constructed wetland on the roof. Image by author.

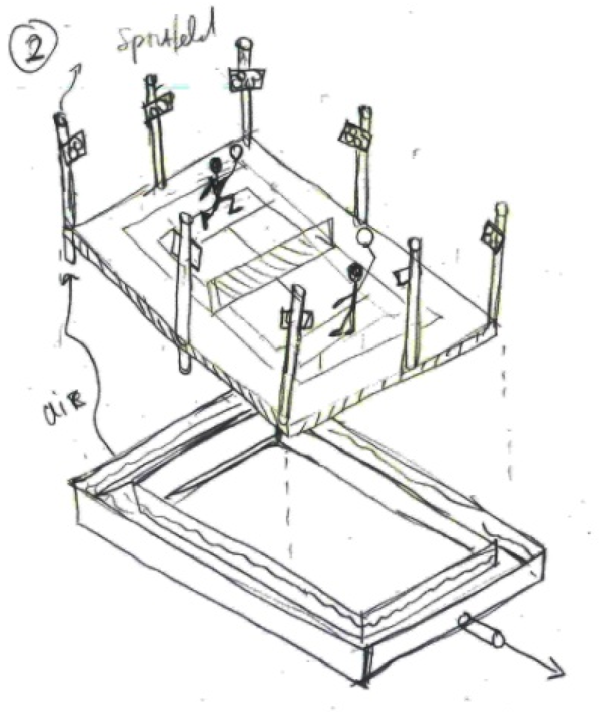

Figure 26: The aeration tank is placed beneath a tennis court. The light posts of the court also function as exhaust pipes. Image by author.

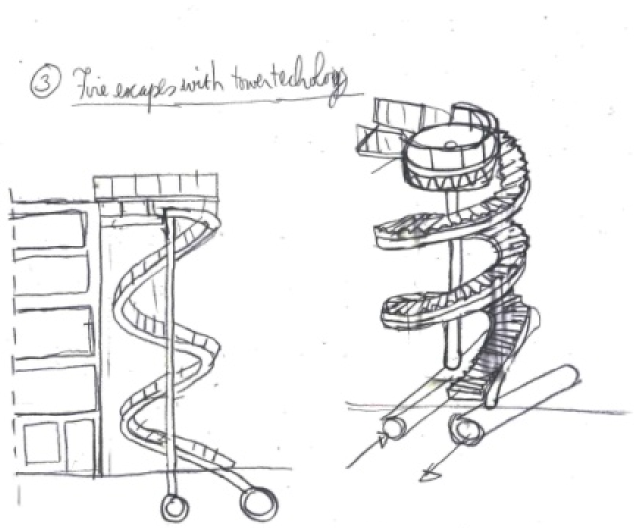

Figure 27: A biological tower integrated in a spiralling stair. Image by author.

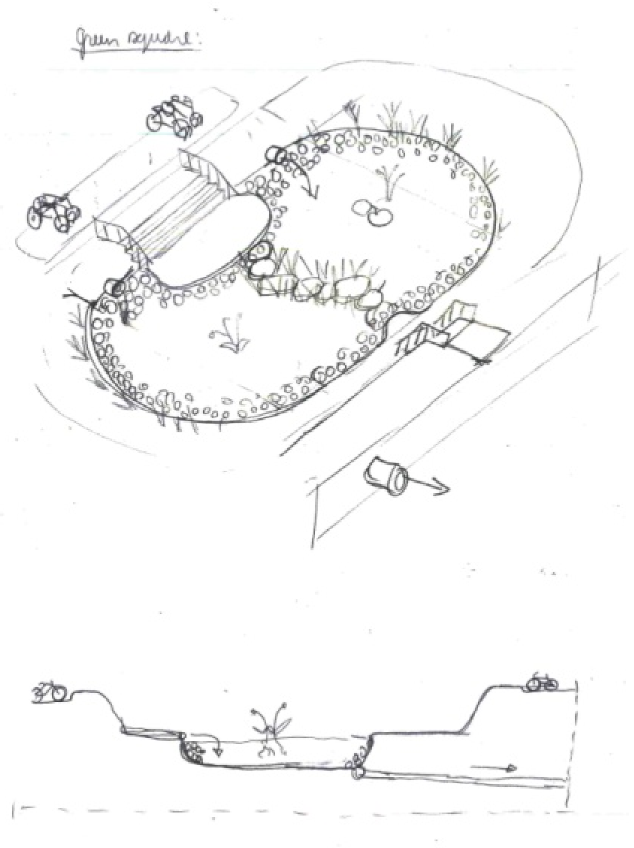

Figure 28: Constructed wetland design. Here the pool is used as a 'green' square. Image by author.

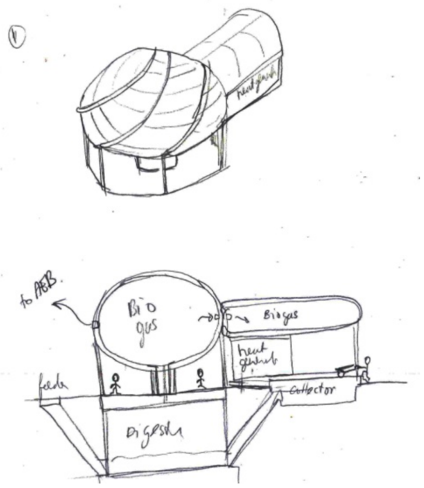

Figure 29: Anaerobic digester. Here the biogas tank function as a roof while the digester is placed underground.

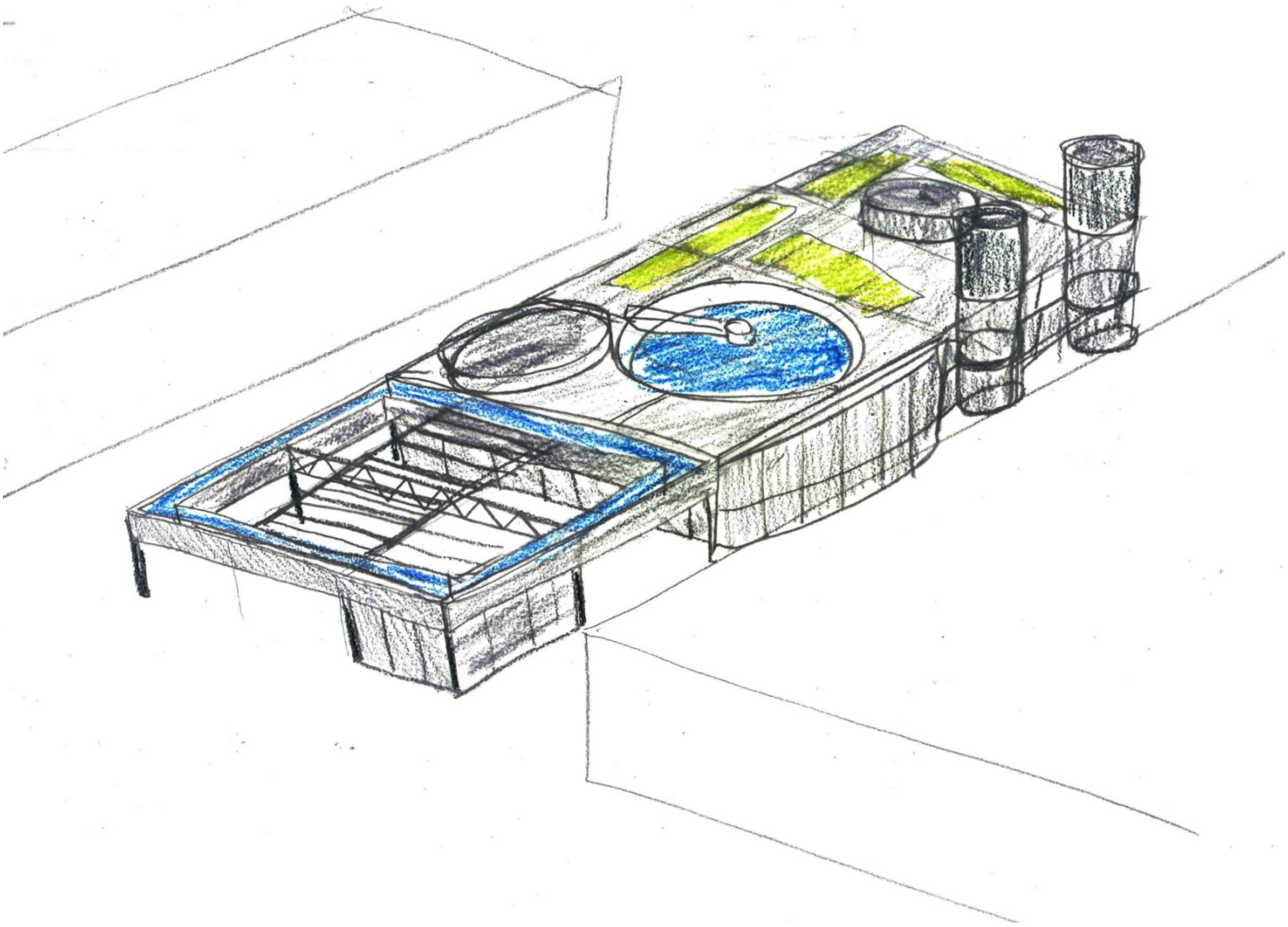

Figure 30: Preliminary design where the design is placed in an existing warehouse. Here the load bearing structure of the warehouse is adjusted to support the new function. Image by author.

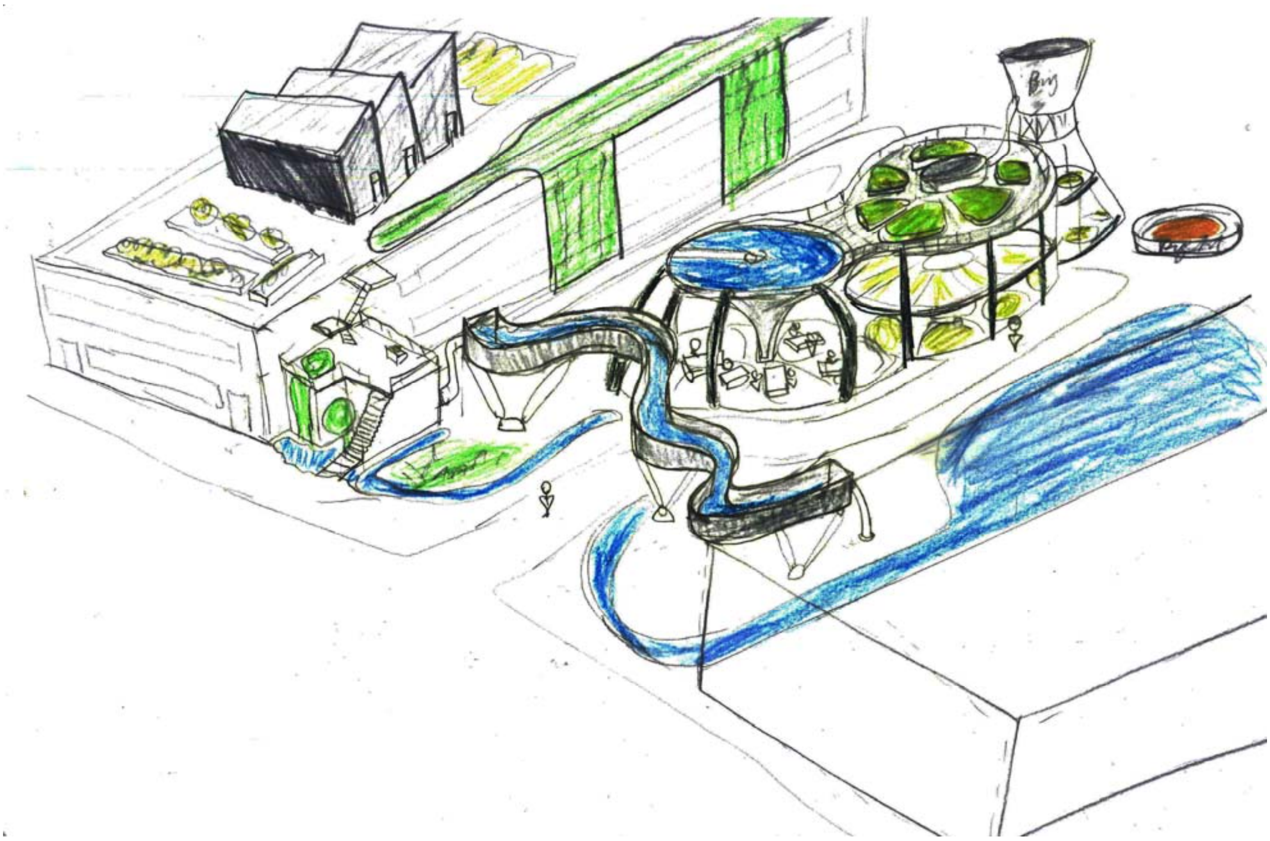

Figure 31: Preliminary design with sedimentation tank integrated a dome. Here the main elements are designed in a rounded shape to enhance the flowing movement of nature. Image by author.

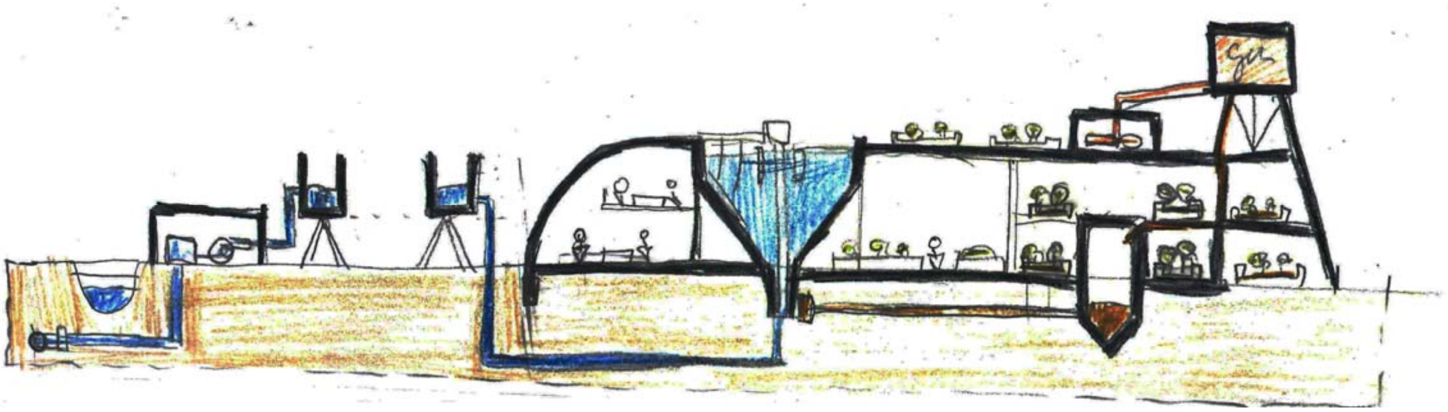

Figure 32: Section preliminary design from figure 31. Here you the different functions are visible. Notice that the space covered by the dome is used as a restaurant. Image by author.