Integration of Living Machine and Biogas plant Case EVA Centre Lanxmeer, Culemborg

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ABSTRACT: This paper focuses on the spatial and architectural integration of a combined waste (or: wastewater)/energy system in the EVA Centre (Information Center on Sustainability with conference center, hotel, and Spa & Vitality center) in the deep green district 'Lanxmeer' in Culemborg (the Netherlands). The design of the district and the building is based on permaculture, Reggio Emilia and organic design principles. An innovative mixture of 'red and green' development is presented (urban agriculture), together with a concept of integrated decentralised technologies for wastewater and organic waste treatment with energy and nutrients recovery. The concept is called Sustainable Implant (S.I.). Principally, the concept is based on a small scale biogas installation (with treatment of blackwater and green waste/garden & park waste), Combined Heat Power (CHP) and accompanying closed glasshouse, designed as a four storey high double skin façade of the EVA Centre, with partial wastewater treatment based on the Living Machine concept. These compact 'hanging gardens', as they are called, are situated in a non-ventilated space with heat (and water) recovery, heat/cold storage (in an underlying aquifer) and with injection of the surplus CO_2 of the biogas plant. The S.I. will be realized as a part of the EVA Centre and has an interconnecting role between both district and EVA Centre, inhabitants and visitors. The system layout and the dimensioning backgrounds are explained in this paper. Additional emphasis is put on maintenance, conservation and administration of the integrated whole, and the possible consequences for the district and its inhabitants.

Keywords: self-sufficiency, interconnection wastewater treatment and energy generation, architectural integration, urban agriculture

1. INTRODUCTION

There is a need to compare sustainable concepts and accompanying structures as alternatives for conventional sanitation and energy generation with respect to a greater number of aspects than the ones being indicated by the existing paradigms and dominant actors in urban planning. This is the background for the present research. The basis is formed by urban planning that is based on 'interconnection', as well as waste management in general, and on closure of the essential cycles (energy and water) inside urban developments, or as close to them as possible. The research was commissioned by the Delft University of Technology (TUD) as part of the DOSIS (Sustainable Development of City & Infrastructures) project, which has recently been continued in the CD&E research (Climate Design & Environment). The aim of DOSIS is to investigate and develop decentralised sanitation, energy and reuse technologies. In addition to CORE International, Haskoning Nederland, Innogas and Thecogas Biogas B.V. are responsible for the Culemborg case related quantitative and qualitative process analysis (battery limits) and the economic implementation study. Atelier 2T Architects together with Hospitality Concepts, V&L Consultants and several other partners are responsible for the development and design of the EVA Centre in the deep green district Lanxmeer in Culemborg.

2. SUSTAINABLE IMPLANT (SI)

The project EVA (Education, Information and Advice; in Du.: 'Educatie, Voorlichting en Advies') Lanxmeer concerns an ecological settlement in the small-scale city of Culemborg [1].

Figure 1: Lanxmeer district with orchard, drinking water extraction area, retention ponds & helophytes.

The location of the EVA project is unique: near the central railway station of Culemborg, on 24 hectares of agricultural land and some orchards.

This was the first time in the Netherlands that permission was given to build in the vicinity of, and partially even within the protection zone of a drinking water extraction area. The regional government allowed building at this site only under the guarantee that it would carefully be built according to modern 'deep green' principles. Innovative is the integral participation of future residents and other relevant parties right from the moment of initiative. The project has been carried out in different phases and will consist of appr. 250 houses and apartments, (collective) permaculture gardens and ecological office buildings (40,000 m^2 gross floor space). In addition to special functions such as a biological city farm, the EVA Centre (an education, information & conference centre) is also situated in this district, along with a hotel and Sustainable Implant facilities.

Figure 2: Zooming in from the Lanxmeer district and surroundings towards the Sustainable Implant (SI); 1000x1000m; 300x300m; 100x100m and 30x30m [2].

At first the district's energy concept, developed by CORE International, had completely autarkic living as its main principle. Because of the concept of autarky and, consequently, the requirement for energy being available 'on demand', it was decided to use chemically bound energy, in the form of biogas. The production of gas from waste flows in the district has two positive effects at the same time: not only does gas become available, but also there will be no need for a connection to the public sewage system.

For the production processes it is of importance that the percentage of solid substance in the fermenter is as high as possible: the energy content of blackwater is determined by the solid mass. Therefore, it is of importance to decrease the quantity of flushing water as much as possible.

The municipality – in its role as project developer – chose the booster option to achieve this. Since green waste is also included in the process, the need for refuse collection has been reduced. The combination of blackwater and green waste offers advantages. Firstly, the amount of biomass available will be higher and therefore the gas proceeds will be larger; secondly, the 'fresh blackwater' implies a constant supply of fermenting biomass, which is good for the stability of the fermentation process.

The fermentation of waste is not the end of the process. Other integral parts of the process include improving the gas to a usable quality, purifying the effluent of the fermenter to a level that it can be discharged into the surface water without major problems, and processing the sludge without odour nuisance. Because of the E for Education in EVA, a Living Machine [3] is taken as a starting point for purifying the effluent.

A Living Machine is a greenhouse with a cascade of tanks containing water plants that are carefully selected for their ability to absorb specified substances from the water [4].

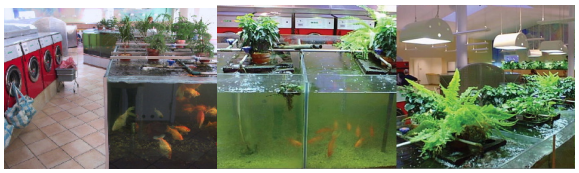

Figure 3: Water based (Living Machine like) waste-water treatment integrated in café/laundry room (Dk).

With respect to the necessary exploitation of the system it has been decided to add two extra decentralised concepts, viz. a facility for further separating various waste fractions ('Retourette' or 'Recycle Shop'), and the possibility for joint e-commerce supply ('E- Fulfilment').

The total system is called the Sustainable Implant or SI. The SI has been planned on the transition of the district into the surrounding (urban) areas, in the same lot as where the Eva Centre and the hotel are to be built [5]. The technical installations will be integrated in a architectural solution, in such a manner that they will take up as little space as possible.

2.1 Process steps, component and battery limits.

The process of producing biogas (energy generation) and wastewater treatment can be divided into various sub processes: (1) gathering blackwater on the one hand and green waste on the other, and leading them into the system; (2) the fermentation process, with biogas, effluent and sludge as its output; (3) purifying and improving the gas into natural fossil gas equivalent; (4) purifying the effluent until it has surface water quality; (5) composting sludge into usable garden compost.

Advantages of the biogas installation include getting rid of the inconvenience and cost of the (individual) green rubbish bins. This, however, can only be accomplished if the green waste is collected with a much higher frequency than the current once every fortnight. In Lanxmeer this will be an important role for the 'urban farmer' of the city farm 'Caetshage', who will also perform the management tasks for the installations [6].

The fermentation process takes place with a temperature of approximately 30 degrees Celsius, fully automatically; its stability is guaranteed by sufficient organic waste being fed into the system and as long as bactericides are avoided. Therefore, there is a risk that residents want to disinfect their toilets in case of illnesses and use cleaning products for that (bleach, lysol etc.) that do not harmonise with the fermentation process. Unwanted objects (in the green waste) can also damage the installation.

On the whole, the green kitchen waste is fermented quite well. However, woody materials are worse, since decomposing the lignin chains takes relatively much time, so that the fermenter can get

obstructed. That is why the materials are 'chopped up' first so that the contact surface of the resulting smaller fraction is as big as possible for the fermentation process .

The biogas is a mixture of 65% methane, 34% CO_2 and some remaining gases (with a maximum of 1%), e.g. sulphur hydrogen. Especially the sulphur compounds are highly harmful, and, furthermore, they produce a very disagreeable odour. Therefore, the clarification of the gas is an important aspect of the installation. The desulphurising process largely takes place in a biocatalytic way in the fermenter by adding predetermined amounts of oxygen on the threshold of gas/fluid. The CO_2 content determines the incineration characteristics of the gas, as a function of the Wobbe index and the calorific value. For application in home appliances it is necessary to adjust the CO_2 content in such a way that the improved gas will be natural fossil gas equivalent [7].

In addition to the biogas, the digestion output of the fermentation process (approximately 5 m^3/day) consists of slurry, that is divided into a solid fraction (approximately 40% solids) and a fluid fraction by a screw press. The fluid fraction is free from pathogens. However, it is still polluted, so that extra purification is necessary before it can be discharged to surface waters. This can be done by using helophytes filters.

Since there will be a Living Machine as part of the EVA Centre, the effluent will be added to the input flow of the Living Machine (that will also process the blackwater from the EVA Centre and the hotel). There are two solutions for the solid fraction from the screw press: compost it in heaps in a well-closed compost room, or entering the slurry from the fermenter into the Living Machine. Because of uncertainties with respect to the process quality of this subflow in the Living Machine, we are first focusing our attention on the first option. An advantage of using a compost room is that also the final maturation can take place there. After the maturation, the compost can be removed. The air in the compost room is extracted and purified by a biofilter [6].

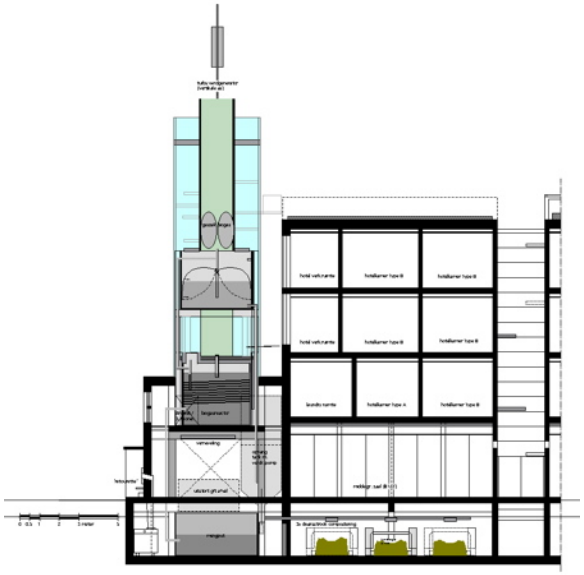

Figure 4: Section SI with compost room [6].

2.2 Interconnection of solutions and introducing direct reuse of energy, water and waste.

There are two options for the biogas from the fermentation tank, the first being its transportation back (as natural fossil gas equivalent) to the homes, the second being burning it in a small Combined Heat Power installation. The latter option has been selected. The following starting points: heating the slurry in the fermentation tank with 20 degrees Celsius, an electrical yield of 25%, a thermal yield of 65% and a specific heat of the slurry of 4.19 MJ/kg K (cf water), imply a possible exploitation of heat and electricity. In this project approximately 100 m^3 natural fossil gas equivalents can be obtained from each home. A small part of this total (appr. 30%) is needed for heating the process (2,85 kWth), so a net amount of approximately 70 natural fossil gas equivalents remains [7]. The electrical capacity of the CHP installation produces 118 kWh/d. About 37 kWh/d energy is needed for the entire installation, which gives an energy surplus of 81 kWh/d to be sold. From an economic standpoint this net amount of gas to be obtained is too small for the investment and exploitation of the installation, within this context [7].

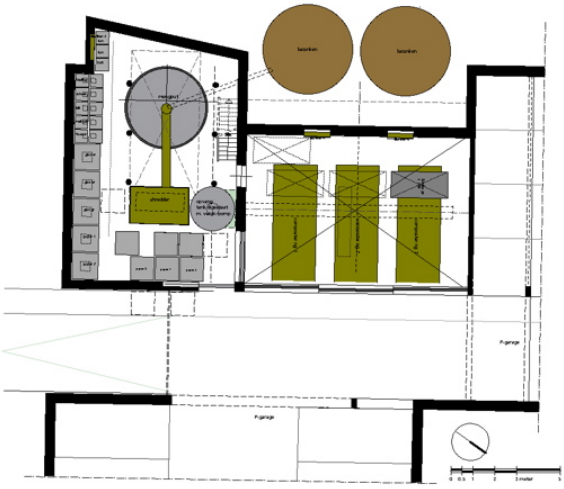

Figure 5: Plan (level -1) SI with storage tanks and containers, fermentation tank and compost room.

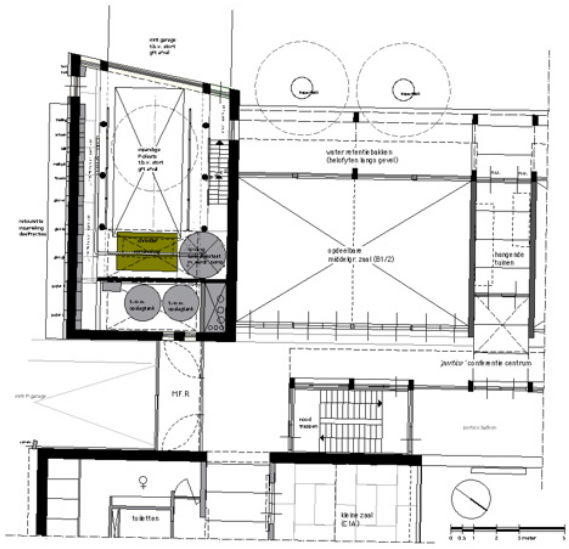

Figure 6: Plan ground floor SI with CHP & retourette.

However, there are more added values. For example, the local, small-scale sanitation can cause less expansion of the present conventional sewage purification installation to be necessary, and lower costs for building and maintaining sewage systems and pumping stations. In addition to these two added values, there is a (small) reduction of CO_2 discharge and some energy saving. In the current configuration with CHP and composting of the sludge approximately 194 kg/home*year of CO_2 reduction for this district of 250 homes will be prevented (if the sludge is re-entered in the Living Machine this amount rises even to 210 kg/home*year [7].

To a certain extent there is also some reduction of waste collection and energy saving as a result of transport and pumping energy saved. When this saving is also taken into account, there is a total energy saving of approximately 8 GJ per home produced by the biogas installation.

For this type of local solution, the way that possible types of trouble are dealt with is even more essential than it usually is. The main environmental aspects here include noise nuisance, odour trouble and dust trouble. Some people also experience some aesthetic pollution in this type of local (energy) facility. Noise nuisance can be the result of waste collection and nuisance caused by the installation. The noise sources of the installation are all focal point sources (pumps, electric motors etc.). If necessary (e.g. when legal noise nuisance demands are not met) sound-insulating measures can be taken. In the Netherlands there are also restrictions as for odour nuisance. Effective biofilters should guarantee that this type of nuisance will not occur. As to dust trouble it can be observed that there will not be any dust emitting process steps in the installation. As to possible aesthetic pollution perception it can be remarked that especially the Living Machine is perceived as a positive factor, looking like a 'green' hothouse and oasis [3], while the larger part of the fermentation can be carried out under surface level.

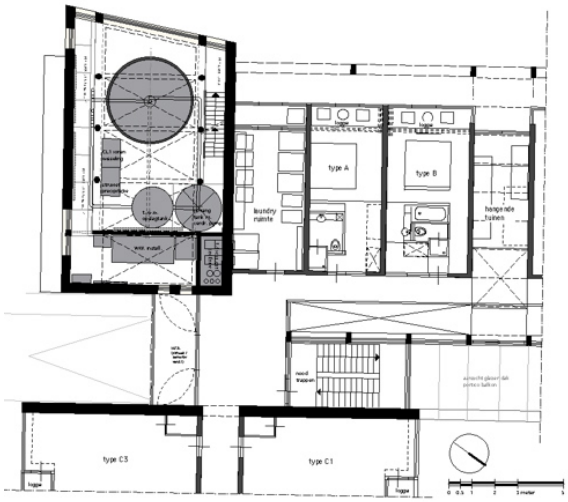

Figure 7: Plan first floor SI with CHP / digester tank, struvite precipitation and CTL ionisation; on top of this level is situated the 'water-effluent retention-tower', with biogas storage within the inner centre of this new 'watertower'. Next to the SI: hotel-laundry rooms [6].

3 INTEGRATION WITH THE EVA-CENTRE AND LANXMEER DISTRICT

Local interventions, e.g. with regard to sustainability, can be made without leaving the existing scaling-up The overall design of the district Lanxmeer and the architecture of the most of the buildings is based on permaculture and organic design principles.

The structure of the urban plan is mainly based on the record of the existing landscape (www.eva-lanxmeer.nl). Especially the subterranean structure has been used for the overall plan, the water zoning- and ecological plan. Besides of that general principles of Permaculture affected the spatial structure of the plan, especially the green zoning) [1].

Figure 8: Conceptual plan of the EVA Centre with SI; detailed data is available at: www.evacentrum.com [2]

There is a gradual transition from private-, semi-private-, and public space towards a more natural landscape in the protected zone of the Water Company. Basis was the creation of four different green zones (actually five if one counts the private gardens, within the half open courtyards), which are connected spatially and ecologically: (1) the collective gardens, as a part of the building clusters, with playgrounds, relax areas and 'edible gardens', (2) public green with retention ponds, extensive planting and reed beds, (3) agricultural grounds, city farm and orchards, and (4) ecological developing areas with infiltration ponds, woodland and hayfields. Together these green zones form an environment that displays the diversity and resilience of natural ecosystems. It can be called the 'Park of the 21st century' [8].

Figure 9: Model of the EVA Centre with (below) the integrated SI of the Lanxmeer district [2].

Moreover because of the added links to the (waste)water-, energy- and waste concept of Lanxmeer. The arrangement and the management of the four zones is oriented on biodiversity, natural dynamism and a coherence between *elements, places* and *processes*. The natural cycles are paramount within the overall structure. The 'triad' City Farm 'Caetshage', Sustainable Implant (SI) and the EVA Centre form both the important ends (or beginnings) of the main east/west greenbelt that forms the backbone of the Lanxmeer district, with in the middle the former 'conventional' water tower, which is out of use but will be re-developed.

The City Farm is situated in the originally agricultural area in front of the water extraction area. In buying houses the residents of Lanxmeer partly have contributed in the realisation costs. In return the residents can visit the farm freely, and if desired even can help with the maintenance of fields. The idea is that many people like to garden, but don't have sufficient time to maintain their own kitchen garden. Nevertheless, the City Farm is supposed to work independently. Plan is to include a small-scale 'care-function' [8]. Apart from that, the City Farm offers recreational facilities for the residents of Lanxmeer and Culemborg, Another important role is set aside to the maintenance aspects and collection of green waste by the city farmer. Together with the remaining green waste of the other green areas of Lanxmeer, the kitchen- and green waste of the houses ('garden waste') and Lanxmeer's sewage effluent, this is being transported to the Biogas-plant within the concept of the Sustainable Implant. The role of the SI is not only ecologically, but also introduced from a social-, participative and educational point of view. Separate water systems for drinking water and water for domestic use are installed in all houses (the latter though still isn't apt for use due to legislation changes), and also decentralised separate sewage systems for 'grey' and 'black water'.

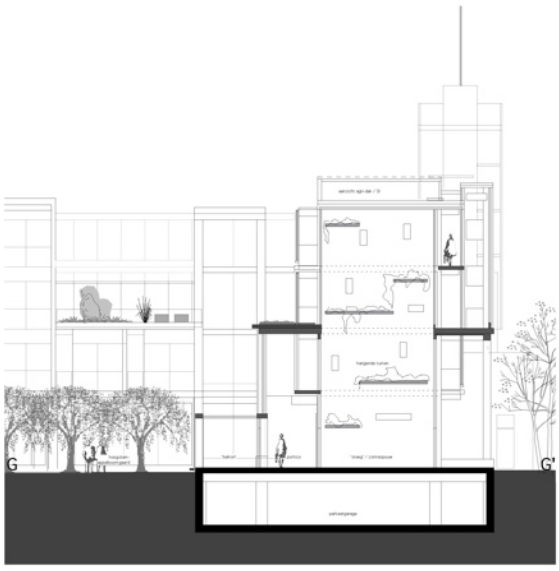

Figure 10: Cross-section EVA-Centre with SI (in the back); solar cavity space with hanging gardens.

The Sustainable Implant cannot be regarded as a fixed design that can be repeated. The instrument comprises a guiding principle for a sustainable solution to the mainly non-sustainable streams in new or existing neighbourhoods. On a neighbourhood level the S.I. entails the design of a more sustainable main structure for the transportation of (waste)water, nutrients, energy, materials and waste [6].

As indicated in the previous paragraph the SI can be divided into two main components. The first main component consists of the anaerobic fermenter, CHP, Retourette and e-fulfilment miniload. This part of the installation is situated in a closed, garage-like volume in the south-west corner of the building complex. On top of this mainly closed volume the new 'water tower' is situated with storage of biogas (in inflatable bags) in the center of the tower and retention of the water effluent round about this core in the transparent volume, cascading down in five (repeating) levels. On top of this (new) 'water tower' a vertical hub based windmill, named 'Turby' (CORE Int.) is placed for additional electricity generation [2].

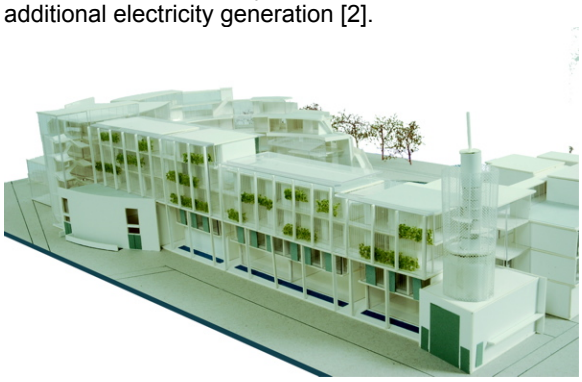

Figure 11: Model of the EVA Centre; with in front the Sustainable Implant, connected to the double skin façade with Living Machine and hanging gardens [2].

The second main component of the SI consists of the water retention cisterns, a sealed double skin façade with wastewater treatment of the EVA Centre, the agricultural glasshouses and 'hanging gardens' and the heat recovery installations with seasonal storage in aquifer. Three of the installations within this second main component (the façade, the solar-cavity spaces with hanging gardens and the agricultural glasshouses on top of the building) are fully integrated in the design of the EVA Centre. Most visible is the double skin façade: in fact it can better be defined as a 'Vertical glasshouse'. This vertical glasshouse is 1.4 meter deep and is entirely sealed to optimise the heat-recovery potentials. Inside this glasshouse wastewater of the EVA Centre (hotel, conference centre, restaurants and wellness centre) is being treated in a Living Machine like configuration. In making the water treatment stacked considerable space is won in comparison with concepts like the Living Machine. The façade is situated in a noise nuisance zone due to its location parallel to railways (approx. 200 metres from the building). Therefore the double skin concept is continued for the entire length of this side of the building, in this way noise protection is achieved for the functions at its rear side [6].

4 DISCUSSION

The entire energy turnover of the Sustainable Implant is being used in the EVA Centre and SI-installations related processes. If the energy wouldn't have been used for the EVA Centre it would have been possible to return about 6,4 GJ (8 GJ if reduction in transportation of waste is taken into account) of energy to each house in the Lanxmeer district (with approx. costs of €50/month*house). This cost reduction is relatively positive in comparison with other possible interventions to improve the sustainability: apr. €150/month*house for 3 GJ energy reduction in case of a solar panel with boiler, or €150/month*house for 2 GJ energy reduction in case of p.v.cells [7]. The energy turnover however isn't enough to make the EVA Centre self-sufficient for its electricity demand. To make the building autonomous for its energy (esp. electricity-) demand, additional electricity is generated in the previously mentioned decentralised 'turby' windmill and several surfaces with photovoltaic cells in the EVA Centre.

Still a central grid connection will be needed: for starting up and back-up purposes. A connection to the centralised sewerage also still stands. This is mainly due to the fact that (parts of) the Lanxmeer district already have been realised. The sewer system of these parts however is anticipating the disconnection (planned in 2007). For emergency backup (hygiene related) the connection still will be held available.

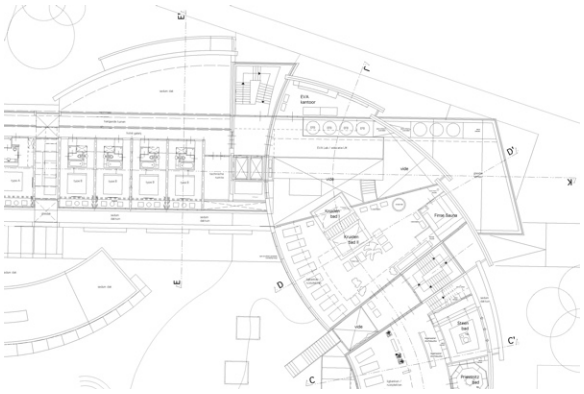

Figure 12: Plan (detail) second floor entrance hall of EVA Centre with the educational part of the Living Machine in the atrium.

During the design process, several alternative configurations and ways of integration of the SI in the EVA Centre building were studied. Five different alternatives were studied more in detail [8]. In the (in this paper presented) preliminary design (Variant V+), the total surface of the Sustainable Implant is reduced to 680,1 m^2 (Variant I was 907,6 m^2) with 154,2 m^2 ground surface (Variant I: 352,8 m^2). This can be subdivided in 137,8 m^2 for the biogas installation and CHP, 62,1 m^2 for the composting facility, 324 m^2 for the Living Machine, 54,3 m^2 for the Retourette and 119,4 m^2 for water retention. Although this surface can be reduced easily (by integrating the composting facility in the City farm, and water retention in the gardens), within the presented design these facilities are integrated, to prevent any form of possible nuisance to the surrounding environment and users. Therefore the surface needed for the biogas plant also includes a sealed drive-in with unloading stage for the supply of green waste from the district without any possibilities for nuisance (through the use of bio-filters and atomization. Another aspect is the educational approach of the EVA Centre. This led to a necessity of an improved accessibility for visitors and users of the building. With respect to some installations, like the Living Machine, therefore a more visual prototype has been introduced in the central atrium/entrance of the building.

It is important to change the general attitude towards the different components of design, development, use and management of urban areas. A way to do so is the 'interconnection' of different themes and cycles within cities. An example is the linking of sanitation to energy- and food production. The appealing-, and already partly realised, example of the linking of agriculture, waste(water)treatment and energy production in the urban district Lanxmeer in Culemborg might be exemplary for the potentials of the supposed need for a change in attitude.

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