CIB2007-261

Decentralized Energy Generation and Waste (water) Treatment in Residential Districts: the 'Sustainable Implant'

Dr. ir. Arjan van Timmeren

ABSTRACT

This paper focuses on a project under development (partially under construction) in Lanxmeer, Culemborg, The Netherlands. It concerns the spatial integration and technical solution of a system to connect waste, and wastewater treatment with and energy generation inside a residential district. It concerns an integrated approach. The different decentralized subsystems are combined in a device, that is called Sustainable Implant (S.I.). The S.I. on its turn will be realized as a part of a building (a conference centre with hotel). Although it is integrated spatially in an attractive way, it works at the intermediate scale of both this building and the surrounding city-district (approx. 250 houses). The district is situated in an ecologically sensitive area, because it concerns a former drinking water extraction and retention area.

Principally, the concept is based on a biogas installation (anaerobic digestion) with treatment of black water and green waste, garden & park waste, Combined Heat Power and accompanying closed glasshouse, designed as a double skin façade of the hotel, based on the Living Machine concept with heat and water recovery, heat/cold storage in an underlying aquifer and with injection of the surplus CO_2 of the biogas plant. Some additional decentralized concepts, such as a far-going waste separation unit for the inhabitants of the district and an e-fulfillment (e-commerce delivery station).

The system layout, it's dimensioning 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: Energy, Sanitation, Sustainability, Decentralization, Self-sufficiency.

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 (Timmeren, 2006).

1.1 DECENTRALIZATION AND SELF-SUFFICIENCY

This research takes a limited and so-called ecological interpretation of autarkic systems as a starting point: 'systems that are closed for matter and energy, except for the continuous flow of solar energy'. Within this scope, the concept of autonomy is largely used as a synonym of autarky. However, autonomy cannot be considered a substitute, for autonomous concepts in the industries of environmental technology and building particularly deal with an autarkic ambition to sub aspects. In these cases, autonomous or possibly even autarkic systems emerge, that may be referred to as "local". The basis of solutions 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, carbon, nutrients and water) inside urban developments, or as close to them as possible. The decentralization and, in some cases, even complete disconnection of central (infra)structures are at the centre of the developing emancipation of systems of which they are a part.

Two development processes concerning decentralized technology for the purpose of autonomy have come forward as topical: viz. first, the efficiency and improvements in the integration of sub techniques and 'real-time' co-ordinated, connected concepts, and, second, a better harmony between supply (input) and demand of the (different) sub flows. Additionally, there are two more general underlying development processes. The first is the environment-technical, environmental and, to some degree, also social optimization of decentralized systems within semi-autonomous projects. The second underlying development process concerns the link to economic applications related to the surroundings, often determined by soil or users, including taking carbon and nutrients back to agriculture and other lateral applications or possibilities.

1.2 ECOLOGICAL DISTRICT EVA LANXMEER, CULEMBORG (THE NETHERLANDS)

Final case study within the presented research in which interconnection of public utilities and local autonomy has been elaborated is the project EVA Lanxmeer (EVA: Education, Information and Advice; in Dutch: 'Educatie, Voorlichting en Advies'). It concerns an ecological settlement in the small-scale city of Culemborg. The location of the EVA project is unique: near the central railway station of Culemborg, on 24 hectares of agricultural land and some orchards (www.eva-lanxmeer.nl) (Figure 1).

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.

Figure 1 Lanxmeer district with orchard, drinking water extraction area, retention ponds & helophytes (left) and semi-open court yards (right)

The structure of the urban plan is mainly based on the record of the existing landscape. 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).

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'. 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 coherence between *elements, places* and *processes*. The natural cycles are paramount within the overall structure. 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, Spa&Vitality and Sustainable Implant facilities.

1.3 THE EVA CENTRE WITH SUSTAINABLE IMPLANT

At first the district's energy concept 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 black water 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 black water 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 black water' 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 is taken as a starting point for purifying the effluent (Todd and Josephson, 1996). 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 in short: S.I. (Timmeren *et al.*, 2004).

Figure 2 Longitudinal section over the EVA Centre with integrated Sustainable Implant (left).

2. COMBINED DECENTRALIZED FACILITIES: THE SUSTAINABLE IMPLANT (S.I.)

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 (Figure 2, Figure 4). The technical installations will be integrated in an architectural solution, in such a manner that they will take up as little space as possible. The main component concerns the anaerobic treatment of waste and wastewater.

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 black water on the one hand and green household waste (and to some extent garden 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.

In addition a re-use step of the methane (biogas) is added:

6. Using the biogas in a combined heat power plant (CHP).

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.

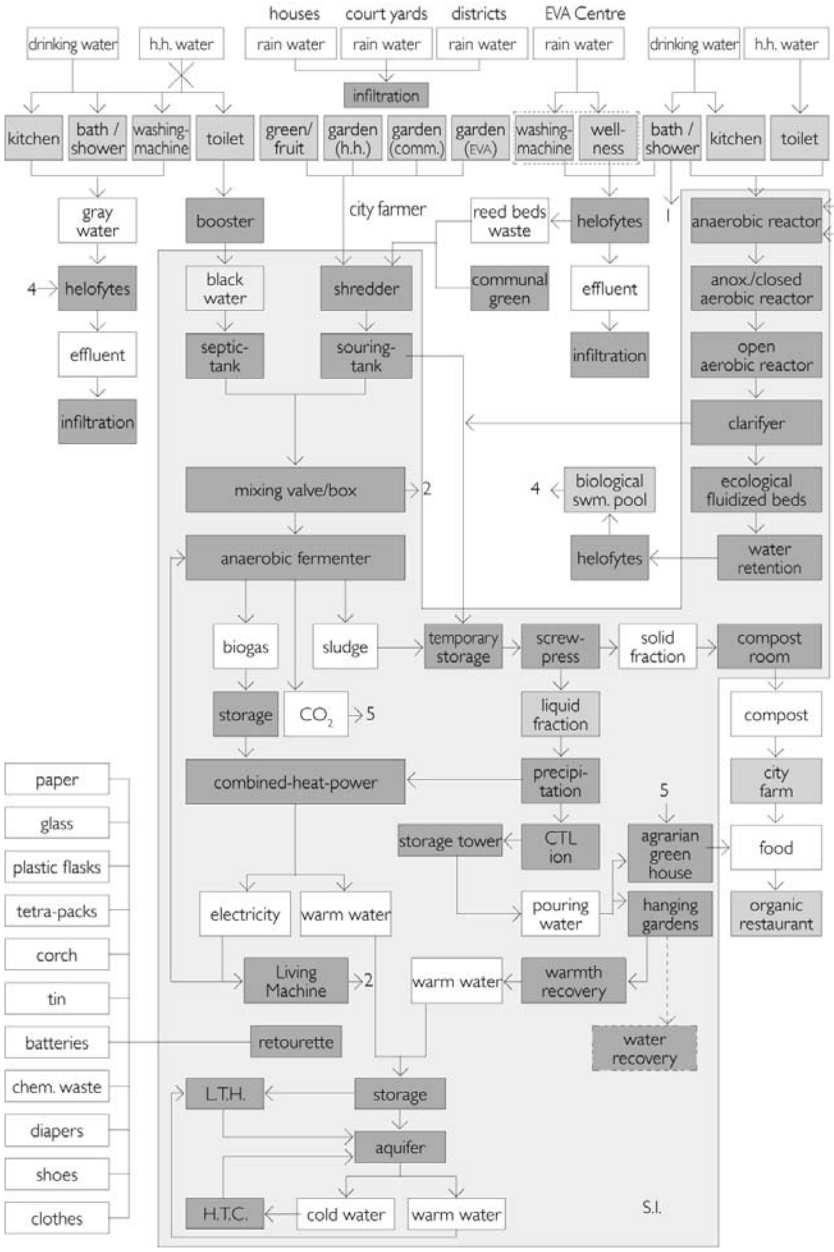

Figure 3 The treatment and cascading of the different waste and water-related flows in the Sustainable Implant within the EVA Centre, Lanxmeer district, Culemborg (The Netherlands).

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. 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.

The biogas is a mixture of 65% methane, 34% CO_2 and some remaining gases (with a maximum of 1%), e.g. sulphur hydrogen. 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 (Sidler *et al.*, 2004). 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 black water 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 sub flow in the Living Machine, the first option was chosen (Figure 3). 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 and brought back to the city-farm. The air in the compost room is extracted and purified by a bio-filter.

2.2 INTERCONNECTION OF SOLUTIONS & DIRECT REUSE OF DIFFERENT SUB FLOWS

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 (Figure 3).

A net amount of approximately 70 natural fossil gas equivalents remains and electrical energy surplus of 81 kWh/d remains to be sold (Sidler *et al.*, 2004). 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. Therefore energy revenue is introduced and used within the EVA Centre. Besides the Sustainable Implant is integrated (implemented) in the EVA Centre (Figure 4).

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. In addition to this, there is a (small) reduction of CO_2 discharge and some energy saving. In the current configuration with CHP and composting of the sludge in the basement approximately 194 kg/home*year of CO_2 reduction for this district of 250 homes will be prevented (Sidler *et al.*, 2004). 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 (Vries and Timmeren, 2006).

Essential for this type of local solution is the way that possible types of trouble are dealt with. The main environmental aspects here include noise nuisance, odour trouble and dust trouble. Noise nuisance can be the result of waste collection and nuisance caused by the installation. 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, while the larger part of the fermentation is carried out under surface level.

2.3 SPATIAL INTEGRATION OF THE SUSTAINABLE IMPLANT

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.

Figure 4 Conceptual plan of the EVA Centre with Sustainable Implant and model of the building (preliminary design); more detailed information available at: www.evacentrum.com.

Similar to that of the houses in the district, from the EVA Centre gardens towards the rest of the district 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. Together these green zones form an environment that displays the diversity and resilience of natural ecosystems and is called the 'Park of the 21st century' (Timmeren and

Röling, 2005). Moreover because of the added links to the (waste)water-, energy- and waste concept of Lanxmeer. 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 district, with in the middle the former 'conventional' water tower. 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. Nevertheless, the City Farm is supposed to work independently.

An 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 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 Sustainable Implant by the city farmer.

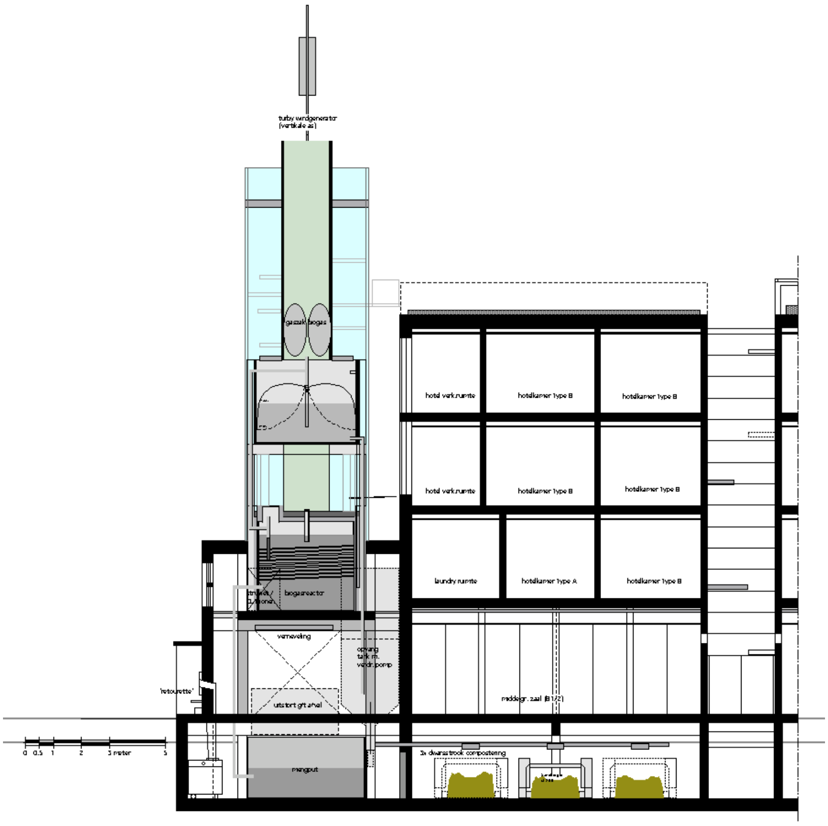

Figure 5 Schematic overview on the Sustainable Implant within the EVA centre (top left: first floor, top right: ground floor, bottom right: basement and left: section).

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 southwest 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 centre 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’ is placed for additional electricity generation (Figure 5, Figure 6).

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 (Figure 6), 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 optimize 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.

Figure 6 Impression of the Sustainable Implant (Subcomponent I and II) integrated in the EVA Centre, in the Lanxmeer district, Culemborg (The Netherlands).

3. DISCUSSION

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.

In the in this research presented preliminary design the total surface of the Sustainable Implant is reduced to 680.1 m^2, with 154.2 m^2 ground surface. 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 in the building, 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 visual prototype has been introduced in the central atrium/entrance of the building.

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 water, nutrients, energy, materials and waste. Still a central grid connection will be needed: for starting up and back-up purposes. A connection to the centralized sewerage also still stand.

This is mainly due to the fact that (parts of) the Lanxmeer district already have been realized. The sewer system of these parts however is anticipating the disconnection (planned in 2007/2008). For emergency backup (hygiene related) the connection still will be held available.

4. CONCLUSION

Specific local circumstances are a strong stimulus for the implementation of decentralized systems for closing cycles on a local basis. Decentralized sanitation systems often offer a solution in places where traditional sewers are not possible, because of soil conditions, water conditions or related rules and regulations. Decentralized systems turn out to be able to gain efficiency advantages as compared to fully centralized systems, particularly through the design of an integrated system of energy generation and supply, and through the connection of this system to a waste water treatment system coupled to nutrients recycling. In this case, in which an anaerobic fermenter is used, the necessity of a protected environment for development was evident. The choices made arise mainly from technical and social optimisation. There are several reasons for the decreasing level of ambition for closing the local (waste) water flows in case of larger scales of application. Occupants turn out to have more commitment when systems perform on the scale of a house or apartment, as compared to the scales larger than a district. As scale size increases, the supply and removal of waste(water) and similar flows get more and more anonymous and gives less possibilities for integration with its source/users (the buildings / houses), with decreasing commitment as a consequence.

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, preferably at lower scale levels. The introduction of solutions on an intermediate scale-level, like in Lanxmeer, Culemborg, offers opportunities for autonomous design of the whole or elaborations in which buildings can be semi-autonomous.

Introducing the analogy of the functioning of buildings with respect to energy and sanitation flows with that of a parasite. 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.

5. REFERENCES

McDonough, W. 2002 *Cradle to cradle. Remaking the way we make things*, North Point Press, New York, USA

Sidler, H.F.A., Velsen, A.F.M. van, Gaalen, F. van, Bijman, Th. 2004 *Lokale afvalverwerking met biogasproductie in Lanxmeer.* CORE Int. Lochem

Timmeren, A. van, Kristinsson, J., Röling, L.C. 2004 *Sustainable Implant and EVA Centre, Culemborg; a hub for Sustainable Development*, Int. Conference PLEA 2004, Eindhoven

Timmeren, A. van and Röling, L.C. 2005 *Introducing Urban Agriculture concept in Urban Planning: The 'Park of the 21st Century'*. Int. Conf. Sustainable Building (SB05), Tokyo, Japan ('Best Paper Award')

Timmeren, A. van. 2006 *Autonomie & Heteronomie. Integratie en verduurzaming van essentiële stromen in de gebouwde omgeving.* PhD thesis ('Cum Laude'). Delft University of Technology. Eburon Delft

Todd, J. and Josephson, B. 1996 *The design of living technologies for waste treatment,* Ecological Engineering, volume 6

Vries, G. de, Timmeren, A. van 2006 *Lokale afvalverwerking, lokale biogasproductie en lokale afvalwaterzuivering in de wijk EVA-Lanxmeer te Culemborg*, BSE-2004, 2020-04-13-24-017, V&L Consultants / Atelier 2T -Architects, Haarlem