Urban Greenhouses – smart architecture?

What is smart architecture? Although the discussion these days in architecture is also about whether a green roof is sustainable or not, new investigations in new fields of the built environment need to support and imply the future road for architecture. This article is about such a new field: Urban Greenhouses. The purpose of this article is to show that with both a new perspective on the city environment and a common known way of building, lost and poor spaces in the cities have potential to regain in quality. These spaces can be triggers for changing the entire environment of the city. Why is smart to develop and design Urban Greenhouses?

Designed for a purpose
Urban Greenhouses do not (yet) exist. Numerous researches have been done on greenhouses in cities by the “Innovatienetwerk” [1][2][3][4], a Dutch research platform in agro-business, and other architect companies [5]. Their intentions are focussed on energy reduction, making use of nature’s cycles and balancing agrarian and urban functions. The difference however between these greenhouses and the Urban Greenhouse is that they are designed with, instead of designed for a purpose. What does that mean?

The purpose of the Urban Greenhouse is to act as an answer, a sustainable solution to the current issues in cities. Moreover, the Urban Greenhouse tries to overcome negative features related to large-scale cultivation, and to make use of the positive features. Thus, the Urban Greenhouse is designed for spaces in the city, to add something to improve the city environment, instead to add something superfluous and over-designed on a space which fulfils already important functions. What are then current issues in cities, and how can the Urban Greenhouse make use of the greenhouse features?

1. City issues
While placing the Urban Greenhouse in its context, the thought behind its design and development will become clear in this chapter. First of all, the current developments around sustainability are vague. Therefore, specifying the term sustainability now, resolves vague arguments against: sustainability for a city is the optimal situation of a city in which the cities’ social, environmental and economical aspects flourish and balance each other. What is then not sustainable nowadays in cities? What are issues?

Waste management is one of them. Cities are dealing with their wastes in numerous ways: from land filling to waste incinerators. Waste water is one of the wastes: it contains valuable nutrients which are only sometimes recovered. The overall waste water treatment is an energy intensive process, while the contents of the water are still far from optimally extracted. Besides, the released purified water contains still dangerous matter which accumulates in the environment.

Another kind of waste is organic waste, still mixed with other solid wastes and therefore not suitable for applications as composting, and biogas extraction. On the other hand, if organic waste is separated and composted, it is often done on large scale and re-used as resource humus.

In 2008, more than half of the world’s population lived in towns and cities, and by 2030, this will swell to 5 billion [6]. Besides the increasing waste production, there is another issue linked to this global urbanization: the increasing demand of resources. Three important demands for the city, related to the Urban Greenhouse, are: 1. water, 2. food, 3. energy. The growing global urban population, needs more and more water, food and energy, while the local space in the city is limited and not (yet) able to supply the needs and fulfil the demands. How can Urban Greenhouses play a role in fulfilling these demands and how do they deal with the limited space in the city?

Pollution doesn’t have to be physical, as wastes described above. In cities noise pollution is also an acknowledged issue, mainly caused by traffic: cars and public transport. Noise can have a detrimental effect on humans, causing aggression and high stress levels, hearing loss and sleeping disturbances. Besides, animals are severely affected by noise, disturbing communication in relation to navigation and reproduction. Light pollution is another kind of ‘non-physical pollution’. It is defined as any adverse effect of artificial light. Like noise pollution, light pollution can cause severe damage to human health and ecosystems. Sources of artificial light vary widely: building exterior and interior lighting, advertising, commercial properties, offices, factories, streetlights, traffic and illuminated sporting
venues. Greenhouses are also a source of light pollution, however strong measures against have been taken recently in The Netherlands. **Air pollution** in cities comes mainly forth out of burning of fuel. Traffic in cities is a main trigger behind the release of the air pollutants. Smog is a well known phenomenon in large metropoleis and a consequence of vehicular and industrial emissions. Also other sources of air pollution, like nearby factories and power plants are contributing to the decrease of the air quality in cities. Nowadays, cities make already large efforts in the battle against air pollution. Control devices for traffic have been introduced and new regulations make it impossible for car producers to continue their production as before.

**Lack of green spaces** in cities is another rising problem of the highly dense cities. Nowadays, both the high density of buildings and traffic are the dominant factors which occupy the city’s space. Existing nature in the city's environment, as parks, are very valuable and intensively used for leisure activities. The creation of greenbelts, green infrastructure and greenways are sorts of green spaces in cities, which are created for a range of functions: improving air quality, protecting natural environments, supply a recreational area, as repository for flood waters etc. Moreover, nature can work as a stress reducing factor in the citizen's lives by creating those functions. Increasing those spaces, and maybe extend it to the whole city may look like a impossible task now, but is necessary for the development of a sustainable city. Can Urban Greenhouses contribute?

Besides environmental issues, also **social city issues** are present. **Crime** is one of the issues with which cities have to deal with. It is linked with the **unemployment** rate of a city and less present with the lack of green space. It is linked also with the city in general: what does a city offer to all of its inhabitants? What are the possibilities and chances to develop oneself? Crime is caused by various factors. First of all the direct social circumstances, the social background, influences a person to commit a crime or not: education by the parents and the relation with one's peers. This education is important for one being able or not to deal with drugs, alcohol and (violent) influences from television. Also the income plays a role: one has to make a choice between a long-term low income, or the prospect of a profitable crime. Besides the background and social circumstances, also the city environment is important: for instance the weather itself and the employment possibilities [7].

Cities are complex systems with flows going in and out. One of those flows is the traffic **flow of cars** and other motorized vehicles. They cause huge stagnation problems in cities, and consequently cause other problems: pollution of air, noise and light. Moreover, car traffic accidents is another emergent property of the intensive car flow in metropoleis. Another rising problem is the **parking space**: valuable space in cities is sacrificed for the sake of the car driver, being able to get rid of his vehicle. Parking lots arise, and have meanwhile evolved to parking buildings.

All the issues described above, are of course not the only ones in cities. This chapter intends to give a short and concise overview and introduction of main issues in cities, to keep in mind for the next chapters. The Urban Greenhouse tries then to formulate an answer to these issues.

### 2. Greenhouses – background

This chapter elaborates on the background of greenhouses, to give a better understanding of what exactly a greenhouse is, how they can serve as an answer to city issues through participation instead of being excluded from metropolitan areas. Before we look into the concept of Urban Greenhouses in chapter 3, the greenhouse principle, common greenhouse applications nowadays and their positive and negative features are described in this chapter. Both the city issues of chapter 1 and the features of the greenhouse described here, will acknowledge the issues to which the Urban Greenhouse can serve as a solution.

#### 2.1 The Greenhouse principle

The greenhouse as we know it, is a transparent building where plants are grown. Its walls are made out of glass or plastic and it heats up because incoming solar radiation from the sun warms the content of the greenhouse faster than heat can escape the structure. The **principle of the greenhouse** is the ‘semi-imitation’ of the earth's greenhouse effect: they both limit the rate of energy flowing out of the system. Different from earth’s greenhouse effect is the mechanism by which the heat is retained: heat of greenhouses is retained through convection (by isolating warm air inside the structure) (see figure A0, appendix 1), while the heat of the **earth** is retained and re-emitted by greenhouse gases.
2.2 Common greenhouse applications

A well-known application of the greenhouse is its use in the cultivation on large scale. The distinctive feature of greenhouse cultivation as compared to outdoor cultivation, is the presence of a barrier between the crop and the external environment, which creates a distinct and more stable microclimate within the greenhouse. It protects the crops against wind, precipitation, weeds, pests, diseases and animals and enables the grower to control the indoor climate [8]. This control has been evolved during the years from manual to digital, allowing the cultivator to create now the optimal circumstances for the crops. These circumstances vary from temperature to the amount of water and light plants receive. The cultivator is now able to grow its crops during the whole year. Current disadvantages of large scale cultivation are:

1) **Energy** is needed to warm the greenhouses day and night. About 10% of the Dutch use of natural gas goes to the greenhouses [9] to heat the greenhouses. The use of natural gas for heating the greenhouses is directly linked to the emission of greenhouse gases. A new concept of the greenhouse, the ‘closed greenhouse’, is currently implemented to reduce the energy demand in the near future.

2) **Manure and pesticides** are used to grow the crops. A part of manure used in greenhouse cultivation is released into the environment. There, manure causes some plants growing harder than other plants, by pushing them aside. Plants disappear and biodiversity is consequently reduced. Also the impact of manure on water, causes grow of algae, disturbing local ecosystems, reducing life in ponds and lakes. Pesticides released indirectly in the environment outside the greenhouses has also an impact on biodiversity. Moreover, accumulation of pesticides takes place causing a danger for species in other levels of the food chain. Thereby, pesticides can remain on the crops, which can negatively effect the health of the consumer.

3) Greenhouses are one of the main sources of light pollution. The surrounding ecosystems are consequently disturbed. New regulation has been implemented to use closed screens. In The Netherlands for example, the "Besluit Glastuinbouw" has recently been changed to reduce light pollution of greenhouses by 98% by 2014 [10].

Besides the greenhouse application on the large scale as cultivation means, the greenhouse is widely used for individual or public purposes and then called a conservatory. A conservatory can be found traditionally in the garden of a large house or a public park. It was used for growing rare plants, or less often for birds and rare species. In cities with cold climates among Europe, municipal conservatories have been built in the early 19th century to display tropical plants. Later on, a social function was added: the conservatory became a place for tea parties and meetings. Although the implementation is often dependent on the space (big gardens), modern conservatories are small and made for a very restricted space. They are suitable for small-scale crop growing in the gardener’s backyard. Also, they are often added to houses for home improvement purposes: conserving plants (greenhouse) and as a warm space in the winter, creating a feeling of being outside, but still in a pleasant environment (solarium or sunroom).

3. Why Urban Greenhouses? – the concept

Having the city issues from chapter 1 and features of the greenhouse from chapter 2 in mind, this chapter is an introduction to the Urban Greenhouse. The definition of the Urban Greenhouse is described and after its goals and means. With these goals and means a table can be made as a "check" for the Urban Greenhouse.

3.1 Definition of the Urban Greenhouse

A Urban Greenhouse is a greenhouse in a urban area. However nowadays, greenhouses are much related to either mass food production outside cities or to recreational use in one's backyard or public parks.

The Urban Greenhouse goes beyond the common known characteristics of the greenhouse by creating situation-dependent solutions as answers to the raising city issues of today. These solutions are connecting city functions and closing loops in the city.

And since we are talking about a concept which is dependent on situation and thus location, the Urban Greenhouse does not exist but its design is different in each case.
The Urban Greenhouse connects city functions. Designing a Urban Greenhouse, is more than just creating an answer to problems as creating a greenhouse for growing food or a pleasant environment. As trigger of the city, a Urban Greenhouse is a place to have the opportunity to cross people from a different background, with a different daily rhythm. This creates a diverse environment. Different functions of the city are connected: living, working and recreation (figure A1, appendix 1).

As we have seen before, in chapter 1, both waste (organic and water) and demand are two issue in cities. The Urban Greenhouse can play a role in connecting and solving these two issues, by trying to locally close material (food), water and energy loops (figure A2a, A2b, A2c, appendix 1). Waste is used as a resource, being a primary solution for both issues. But why closing loops on a local, urban scale rather than on a large scale?

First of all, closing loops on a local scale reduces the transportation of resources (water, food, energy). Consequently, financial costs and energy costs (losses) of transportation are reduced. Reduction of transportation reduces also the pressure on the road and pollution caused by traffic flows.

Secondly, by closing loops on the local scale valuable waste (organic, water, energy) can efficiently be reused, rather than ending up outside the city being burned or dumped. Local investment is local enrichment. Moreover, energy intensive large-scale (water)waste purification processes are consequently avoided.

Thirdly, people’s awareness of nature’s material (food), water and energy cycles is raised. When domestic waste is literally taken up by nature in one’s backyard, it may positively affect one’s consumption behavior: buying environmental friendly, less waste-producing, organic products; environmental responsible domestic use of water and energy. People have a better connection with nature and therefore take care of it in another way.

3.2 Goals of the Urban Greenhouse
The Urban Greenhouse is a greenhouse in a urban area. It has two important goals:
1) Being an answer, a sustainable solution to the current issues in cities (chapter 1)
2) Overcoming negative features of the (large scale cultivation) greenhouse as we know it today (chapter 2)

These goals can be reached by three important means:
1) Making use of the positive features of the greenhouse (chapter 2)
2) The connection of city functions
3) Closing loops in the city

We can thus check a Urban Greenhouse design, by concluding from the previous chapters and paragraphs a table (appendix 2): is the Urban Greenhouse an answer to the city issues? Does it overcome negative features of the greenhouses? Does it make use of the positive features of the greenhouse? Does it connect city functions and close loops?

After having defined the Urban Greenhouse in chapter 3, the next step is to explore where the Urban Greenhouse can be implemented, on which scales and for what public. Where is the Urban Greenhouse needed and is there place for it?

4.1 Investigation of potential space
For a potential place in the city to implement a Urban Greenhouse, we distinguish four different scales/locations of Urban Greenhouses connected with: (1) single houses, (2) housing blocks, (3) office buildings and (4) infrastructure. These are in the order from a small (1) to a large scale (4). Since these scales are important for a fair comparison of Urban Greenhouses, we add them as ‘check’ to the table in appendix 2.

Where do we actually foresee a Urban Greenhouse and under which circumstances? The potential of the location in the city, depends on three intentions: (1) on what scale is the Urban Greenhouse implemented? (2) what is the time in the day when the Greenhouse is used? (3) what kind of public is addressed with the Urban Greenhouse? On the base of these three facts we have a better idea of: (1) the public importance of the place and, to a lesser extent, how much space the Greenhouse will need, (2) in which intensity the Greenhouse will be used and (3) what the extent of accessibility (threshold) is for the Greenhouse’s public.
First of all: what is the **scale** on which the Urban Greenhouse can be implemented? The graph C1 (appendix 3) shows the link between private/public scale and the Urban Greenhouse scale. We see that the bigger the scale of Greenhouse implementation, the more public it becomes. Private Greenhouses concentrate themselves especially among single housing and single housing blocks. The more public the Urban Greenhouse becomes, the more it should take into account the **importance** of the location because the value of the location is directly linked to public opinion, value of the ground, space characteristics etc. Another point is the **size** of the Urban Greenhouse: an increasing scale of Urban Greenhouses will mostly lead to an increasing **size** since it is accessible to a different amount of people.

Secondly, what are the **times** in the day, when the Greenhouse will be used? The graph C2 (appendix 3) shows an estimate level of occupation of each scale of the Greenhouses. The graph gives information of the occupation by people and thus the **intensity** in which the Greenhouse will be consequently used. If the aim is, for example, to improve the daily experience of green in the city for all its inhabitants, the municipality can look with which Greenhouse scale they can have the biggest effect.

Thirdly, what is the kind of **public** that will use the Urban Greenhouses? For a potential place in the city, knowing the public is important and a distinction of public is made. With a specific public is meant 'public which has a strong relation with the place' and with a diverse public is meant 'public with a weak relation with the place' (graph C3, appendix 3). To reach the right public with the right intensity, a Urban Greenhouse should be implemented on the right scale. The more diverse the public, the less the relation with the place and thus the more **accessible** the Urban Greenhouse should be. For example: a Urban Greenhouse needs to be implemented for people staying in a hospital, for improving their well-being. This specific public will be addressed, having a strong relation with the place. The threshold is low and the Greenhouse does not have to be very accessible for a large public.

### 4.2 A flexible place for the Urban Greenhouse (figures in appendix 4)

As we have seen before, the Urban Greenhouse can be applied on different scales, for different timings and different publics. Depending on the situation and thus location, the place for the Urban Greenhouse will be different in every case. Since in cities, space is rare, smart solutions for the implementation of Urban Greenhouses need to be proposed and explored. Hereunder, several case studies are elaborated upon and visualized.

**The Urban Greenhouse fulfils additional functions on places in the city which are not used (lost places), or places which are poor in itself.**

First of all, the Urban Greenhouse can be applied as a connection **between building blocks**, see figure D1. In a project of 2012 Architecten [11], one side of the housing blocks is reachable by car and on the other side the Greenhouse is proposed (see figures D2, D3). Removal of road and pavement on this side of the house, gives back a green environment, closing loops and connecting functions. In this case, a big part of the streets was in use by cars and the quality of the public green was very low. The greenhouses change this low quality into a high quality environment. This solution does apply in urban areas where there are low building blocks close to each other. The greenhouse is implemented then on a private scale for people living in the building blocks. This specific public will moreover maintain the greenhouses themselves for own profit. This idea might also be applied to higher buildings and building blocks.

Going to Rotterdam, one can notice numerous streets, almost unused, where the only function seems to be parking for cars (figure D4). Implementing an Urban Greenhouse on such spaces, needs relocation of such a function. But the living quality will consequently increase, connecting functions and people, supplying spaces for closing energy and water loops (figure D5).
Approaching closer the city center, where the size of the Greenhouse will increase towards a public scale with diverse people, with mixed timings, and where the spaces become smaller, what are then suitable potential locations?

A first option is looking at empty, unused lost spaces in the city. If a greenhouse can fulfil useful additional solutions and functions to the space, locally a Urban Greenhouse can be implemented. A lost square without fulfilling functions for example might be an appropriate space. Around a square, often numerous shops are located, having different functions. A square is often an central place, for a diverse public. Chaotic movements are taking place; people walking in the streets with different goals, with different intensities. A unused or a lost square is then a good place for the Urban Greenhouse to be implemented and to fulfil different functions: improving the local experience by the supply of green, being a distraction for people's daily's rhythms, slowing movements of traffic and people, increasing interaction etc. But also technical functions as supplying food to local restaurants, gathering and processing organic wastes from surrounding houses and cleaning the air from surrounding traffic (see chapter 5). The pictures D6 and D7 show the impact of an Urban Greenhouse on a square on the rhythms and movements of people.

An example of a ‘lost space’ is the ‘Schouwburgplein’ in Rotterdam. The square is an empty, cold and grey place, existing of stone and concrete. The square (green area) is surrounded by public facilities (conference center, cinema, restaurants, shops) combined with apartments (see figure D8). The Schouwburgplein is a public place where ‘diverse people’ cross in different times of the day. An Urban Greenhouse on this place might fulfil several social and technical functions, thereby increasing the environmental quality of the location.

Another lost space in picture D9 for example does not have any function. It exists of stones and radiates a cold atmosphere. A Urban Greenhouse could perfectly fulfil functions in this space, by adding several layers connected to the surrounding housing (figure D10).

The larger scale of the The Urban Greenhouse, the office building scale, requires smart solutions. The environment around office buildings can feel quit cold, grey and concrete-like. Often a nasty wind is blowing between the high buildings, which does not give pleasure to walk in this environment. Office buildings are often high buildings, with no surrounding empty space. It is thus important to be creative with the scarce space. The Urban Greenhouse can increase the quality of the environment and come up with additional functions.

We notice first of all, the streets around the office buildings. A new way of implementation arises: roofing entire buildings with glass (figure D11), instead of locating an Urban Greenhouse in between them. Besides fulfilling the function of increasing the local environment, it fulfils then also additional important functions, like ventilating the building through implementation of glass facades (figure D12), which make part of the Urban Greenhouse.

Roofing buildings creates a more open atmosphere than building a Urban Greenhouse in between the office buildings, like in figure D1. The open atmosphere answers the requirements of this scale of Greenhouses: the Urban Greenhouse is more or less accessible for a diverse public. An example of roofing entire buildings is the example of Alterra in Wageningen, The Netherlands, by Behnisch Architekten (1998) [12]. The workplaces are in direct contact with indoor and outdoor gardens (figure D13, D14). The indoor gardens provide the focus for daily activities and function as informal meeting areas. Beyond this, they are part of the energy concept, improving the performance of the external envelope. The function of street may change to a less public place, but this can be overcome by opening both sides of the Urban Greenhouse.

Another space which is present already around office buildings, besides the street space, is the roof space. The roofs of buildings are often empty spaces, with which nothing is done. How can Urban Greenhouses fulfil functions in these spaces? Again here, the Urban Greenhouse can fulfil all sorts of technical functions. In offices however, a stressful and pressurized environment is present. Green spaces will have a fruitful effect on this environment, because the roof can also be connected in all sorts of ways with inner spaces in the buildings. A more social function is then fulfilled.

A good example of office design in combination with greenhouses is the project 'De Zuidkas' carried out by Paul de Ruiter Architects [13]. It centers on an imaginary office building of over
11,000m² on the Zuidas tangent in Amsterdam (figures D15, D16). As a sustainability strategy, the project mixes functions. Concepts that have been used as foundation for the Zuidkas concept are "Unité d'Habitation" (Le Corbusier) and "Zonneterp". The design includes a glass shell, creating a variety of climate buffers which will work as an intermediate zone that tempers the effects of the outside climate. The greenhouses on the roof and the inner spaces of the building are connected via a shaft leading from the parking garage under the building to the greenhouse on the roof. Besides creating a strong ventilation flow, plants in the shaft will purify the air from the parking garage.

Picture D17 shows the potential of roof area in a part of Rotterdam. The greenhouses on the roof can be extended towards the facades of the buildings, connecting spaces with each other, improving the environment both inside the building as outside. Extending the facades with glass, creates a climate buffer and creates a ventilation stream through the building (figure D12).

On the other extreme of the spectrum, the infrastructural scale can be connected to the Urban Greenhouse. This last scale of Urban Greenhouses, may look a bit strange because it is not a building in itself. However, infrastructure is an important part of the city, of the urban environment. Therefore, the Urban Greenhouse connected to infrastructure has a high potential. A wide variety of people can make use of it and therefore the effects of new additional functions can be substantial.

Infrastructure has to deal with different intensities of people and traffic. The emission of exhaust gases cities is connected to these intensities, causing problems as described in chapter 1. A Urban Greenhouse can overcome these problems by making use of the space above the infrastructure, purifying exhaust gases and adding new other functions (figure D18, D19).

An example of connection greenhouses to infrastructure is the study "Kas Kantoor" of the project "Infra Ecology" of Doepel Strijkers Architects [15]. It is a combination of greenhouses and offices. All the emissions of the road traffic are purified and used for growing crops or for example cooling the offices above the roads. The greenhouse functions as mediator between road and office, providing a clean, green and productive work environment (picture D20).

The infrastructural scale is connected with the other scales of Greenhouse-connections. When a Urban Greenhouse connection is made on the office building scale, by roofing the buildings, the infrastructure is immediately involved. How does this affect the city environment? Roofing the buildings means that road traffic might be re-routed. The reachability of the streets can diminish, but other solutions should then be proposed. For example a combination of public (underground) transport with Urban Greenhouses might be one of the various solutions (see picture D21).

When all kinds of Urban Greenhouses are flourishing in the city, it is possible that they are connecting themselves through the movement of animals and seeds. This will also affect the city environment outside the greenhouses: the city is receiving now new kinds of flows which will let their traces also in the streets. Diversity will be triggered, giving the city a green look. New 'green corridors' will arise in the city, creating networks of green space throughout the city (see picture D22). A similar concept is further elaborated upon in Andre Viljoen's book [16].

5. How are Urban Greenhouses solutions? (figures in appendix 4)

In this chapter the Urban Greenhouse is further explained. After having explored possible locations in the city for the Urban Greenhouse in chapter 4, this chapter elaborates on how the Urban Greenhouse is a smart solution. Hereunder, the Urban Greenhouse features will therefore explain how they can reach the goals of the Urban Greenhouse: to serve as solution for the city issues.

5.1 Resolving waste water issues

Looking at the first city issue from chapter 1, the Urban Greenhouse is able to deal with certain features of the (waste) water problems.

The first problem is (heavy) rainfall. We see that in a normal case, pavements channel the water to the sewage, where it goes to the sewage treatment systems which is consequently under heavy pressure. Even separate systems for sewage and rainwater are not always able to perform a good runoff. The best solution is just to let the water flow directly into the ground. The Urban Greenhouse can open its roofs to let the rainwater coming if needed, to water the plants and crops inside and furthermore to filtrate the water into the ground. Excess water run off can be caught, if necessary, in underground storage tanks, from which later on the water can be extracted for watering the plants.
A great feature of a greenhouse is that it can create a perfect environment for a living machine. A living machine is a way to biologically treat waste water on a local scale. When the temperature in the greenhouse raises, the biological activity raises too, which stimulates the treatment process. A **Urban Greenhouse would therefore be a perfect host for treatment of waste water**. Living machine technology is quite elaborate, but applicable from backyards to public areas. The machine exist of huge buckets with plants floating on waste water, both black and grey. A well designed machine requires little management. Moreover, the micro-ecosystem of the living machine can be integrated with the macro-ecosystem. An open greenhouse promotes interaction with the surrounding environment [17]. If the living machine is well able to treat the influent flow of waste water, the effluent flow can be consequently released into the environment.

Another waste water flow is **urine**. If separated at the source, with help of urine separation toilets, the urine can be used for growing crops and plants in the Urban Greenhouse since the content is very valuable: it contains 70% nitrogen and more than half the phosphorus and potassium found in urban waste water flows, while making up less than 1% of the overall waste water volume. Separation of urine at the source avoids costs and energy intensive sewage treatment, and moreover eutrophication of aquatic ecosystems.

The natural treatments and systems described, demand another way of consumption of people living in connection with the Urban Greenhouse. Chemical products should be avoided and waste carefully separated. However, several wastes can hardly be avoided, as the waste products of medicines. Measures should be taken to avoid this coming into the micro- and, later on, macro-ecosystems, if no natural purification is forehand.

Figure D23 summarizes the possibilities for the house-Urban Greenhouse combination. The urine and the black water from the toilet are separated. Urine is used for growing plants and crops, which can uptake the valuable compounds. Grey and black water flows from the sinks, showers and toilets are going to the living machine. Rainwater is directly absorbed by the ground in the Greenhouse or otherwise stored underground and used in a later stage.

**5.2 Resolving food issues**

In what ways can the Urban Greenhouse deal with the organic waste of cities, and in the same time the demand for food? How can food be cultivated in a sustainable way to overcome issues as the use of manure and pesticides while cultivating monocultures?

First of all, **composting organic waste** should play a bigger role in the city. Nowadays organic waste is often mixed with other solid wastes in households and thus will probably end-up in waste incinerators or landfills. Large scale recycling of organic wastes is very little done in metropoleis. Closing the loop of food on the urban scale of a city, means making use of food wastes through composting processes. In the compost process the end-product is enriched with all nutrients needed for organic matter to grow. Therefore it is perfect fertilizer for the soil of the city.

The treatment process for organic waste in a city greenhouse, is extendedly studied by the "Innovatienetwerk" [2]. Figure D24 summarizes their study. Especially organic wastes and waste water are gathered. After that, composting and fermentation processes deliver the basic resources, as compost, biogas and water. These are successively turned into end-products for the consumer. The whole process takes place in the greenhouse, but takes a lot of space for all the process stages.

That is why **composting** can also be done on **single house scale**. So, it depends on the amount of people connected with the Urban Greenhouse. Citizens living in a building block connected to a Greenhouse can compost there for example. Urban Greenhouses in more central and public spaces of the city will be more dependent on waste of a wider range of people surrounding the Greenhouse, and therefore **composting processes on a larger scale** as described in the table are not superfluous.

The compost can serve as **manure** (organic fertilizer) for **crops** which can be cultivated in the Urban Greenhouses. Like in cultivation on large scale, the danger exist of adding an excess of manure to the ground, causing thereby negative impacts on the environment. Therefore, strict regulation and bookkeeping is necessary to avoid this problem while cultivating crops in the Urban Greenhouse on a large scale. However, since food production in the Urban Greenhouse will mostly not be comparable with large scale greenhouse cultivation as we know it, the problem may be not significantly present.
The intention of the Urban Greenhouse is to produce **season dependent food**, growing sustainably in a field among a diversity of crops which can be locally sold and/or consumed: the food loop is closed on the local scale. Facilities around an Urban Greenhouse, like restaurants or hotels, can promote their food as being ‘from the backyard’. Although the available space is far from satisfying the demand of food in the city, the space which is available can in this way be productively used.

Growing food sustainable and seasonal, does also mean that **no fossil energy** is needed for growing the crops, than sustainable energy. This is of course the direct warmth of the sun, but also stored heat of the sun can be used through geothermal systems. Moreover, light pollution through artificial lighting by night is in terms of the sustainable Urban Greenhouse not allowed. Figure D25 summarizes how the Urban Greenhouse tackles the food issues.

Since the aim of this project is not to examine the possibilities of growing sustainably food in the city, I will not go further into detail. Extensive research has been done already in numerous studies, with different convictions, as urban agriculture, permaculture, vertical farming and the recent development of Continuous Productive Urban Landscapes [16].

### 5.3 Reducing fossil energy demand

In the previous two paragraphs we saw that waste water and organic waste, both can serve as a resource: by urban cleaning processes and composting it is possible to recycle on the local scale. For energy, it is a different story, since waste energy is often an uncontrolled by-product of processes and therefore it is hard to get grip on. How can the Urban Greenhouse contribute to the rising energy demand in cities?

First of all, the Urban Greenhouse makes use of free solar energy, because of the working of the greenhouse principle: the heat is trapped in the greenhouse. This energy can be used to serve as a climate buffer in the winter for single houses for example, causing a reduction in heat loss (see figure D26).

Also offices profit of a glass shell covering the building and working as a climate buffer (figure D12). With this buffer, an intermediate zone is created, reducing the heat loss in the winter. In summer, natural ventilation is possible by opening the shell. Fresh air is sucked in and circulated.

The buffer area is a green space, which serves moreover as a pleasant work environment. The green environment serves as a cool source in the winter, from which the surrounding offices can be naturally ventilated. In winter, the green environment serves as a double skin, reducing the loss of heat from the offices.

The Urban Greenhouse can store excess heat in the summer under the ground with geothermal heat pumps. The energy can be recovered in the winter. In the same time, it is possible to cool in the summer (picture D27). The heat and cold can as well be used for the housing. This system might however be complicated in cities, since the ground is scarce and intensively used: the amount of people per square kilometer is relatively high compared to the countryside.

Another nice feature of the Urban Greenhouse is that it can produce biogas from the organic waste it receives. This is produced during the fermentation process. Both black water and organic wastes are resources for the process. The biogas can serve next as a fuel for the production of both electricity and heat. As for composting, the production of biogas will be only feasible if produced on a large scale.

### 5.4 Acting as air purifier

Air pollution was one of the issues described in chapter 1, mainly caused by car traffic. The two issues are strongly linked to each other. If car traffic is diminished, consequently air pollution will also diminish: tackling the problem at the source. Since that is still not feasible, other solutions have to be come up with. Can the Urban Greenhouse play role in this problem?

Unfortunately, the Urban Greenhouse in this case only can play a role as “end-of-pipe solution”: tackling the problem when the damage, the exhaust emissions, has already been done. There, the Urban Greenhouse can be a solution by purifying these emissions (figure D28).

First of all, particulate matter (PM), originating from traffic, can be partly caught by a green environment. This is however not the case for all particulate matter: only the relatively large particles
can be caught by green [18]. Especially the smaller particles, are expected to have the highest impact on people's health.

Secondly, plants can uptake CO2, one of the most important greenhouse gas emissions these days.

Urban Greenhouses can also purify additional emissions of cars, but this is only feasible when the Greenhouse is situated above the source of emission (roads or highways, but also waterways). This concept is developed by Doepel Strijkers Architects [15]. Additional emissions purified are: CO, **carbon monoxide** can be taken up by the soil and enrich it, **small particles** clean the water, while the above situated office building itself is cooled by the absorption of **sulphur dioxide** in water vapour. **Nitrogen oxides** can be transformed into nitrogen and water, through the use of manure. The feasibility of this system is not known, however further research can prove economic and technical feasible implementation.

5.5 Providing a pleasant environment

Talking about a green spaces, a green environment, the last features of the Urban Greenhouse are (1) a trigger for the quality of the city environment and (2) a strong social function (figure D29).

First of all, the Urban Greenhouse increases the amount of **natural green spaces** in the city environment. As described in chapter 4, a range of Urban Greenhouses can trigger **green corridors**, or greenbelts throughout the city, increasing the amount of green and improving the quality in the city.

The green in city enhances also the **biodiversity**. Research nowadays already showed that cities count more wild plant species than natural reserves do and many more than the surrounding countryside does [19]. More green with the implementation of the Urban Greenhouse will only increase the biodiversity.

The Urban Greenhouse can moreover function as a **noise buffer**, both the glass house and the green itself.

As numerous research showed, green spaces in city fulfils several important **social functions** [20][21]: 1) it lowers crime and enhances self-esteem, 2) it is beneficial to children, 3) it creates communities and 4) it enhances mood.

5.6 Connecting city functions

Besides trying to close loops of food, water and energy on a local scale, and solving issues of the city, the Urban Greenhouse connects the main functions of the city: the city for living, for working and for recreation.

On the individual scale, the Urban Greenhouse connects directly living and working. The Urban Greenhouse needs maintenance for growing crops, recycling organic matter etc. Crop growing on larger scales can be managed by companies who take care of that. In that way, the Urban Greenhouse provides **jobs**. Also other jobs will be provided: maintenance of the green, of recycling processes, technical systems, etc. On the building block scale, the local community may take care of the crop growing. Implementing the Urban Greenhouse in the city center, means also that **trade** is present: the local grown food, can be directly sold in local restaurants, or supermarkets. Also other products produced through the organic waste processing can be sold.

The Urban Greenhouse moreove provides a pleasant environment both for work places (offices) and living places (housing). As said before, a green environment enhances the efficiency in an working environment by providing a pleasant environment. The connections of the three city functions (living, working, recreation) and their relations are made visible in figure D30.

6. Starting today – implementation

Starting today with the implementation. Who takes the responsibility and how long does it take to implement a Urban Greenhouse in my backyard, in my street? Who is going to pay for this greenhouse and why?

The municipality of the city will play an important role. It is likely that they will have an important input in the process, since the ground on which the Urban Greenhouses are going to be build is their property. Since nowadays, municipalities take a supportive role rather than an initiating role, it is likely a company invests and profits of the Urban Greenhouse. The municipality can support the company
with regulations, since the profit is also for them: the municipality will benefit of the improved environment in the city, besides the company from their financial profit.

The company (for example UG4city) can be a private company, or a company with stakeholders who have interest by an improved environment in the city, or who want to profile them as sustainable (figure E1, appendix 5).

The scheme (figure E2) explains the system of implementation of Urban Greenhouses with financial flows: after the check for a potential space for the Urban Greenhouse has been done by both the investor (UG4city) and the municipality, the investment process can start. Single houses, housing blocks and offices will receive financial incentives from the municipality, in order to get their cooperation and facilitation. The infrastructure connections to Urban Greenhouses will not receive financial incentives, since it is likely that the municipality itself will facilitate this process.

Then, the investment can be done: UG4city can invests in the different scales of Urban Greenhouse-connections and in the time the profit will slowly grow from negative to positive: through for example the sale of crops, the revenues from the owners of the buildings for which UG4city now deliver replaceable local services (water purification, organic recycling etc), the sale of excess heat etc. The Urban Greenhouse becomes a viable solution in the time. And in the end, everybody who is involved is satisfied: 1) UG4city, because they will receive financial profit, 2) the municipality, their investment will be paid back by an improved city environment on all levels, and 3) the citizens, who are provided with a better environment without taking any initiative or doing any investment.

7. Conclusion

As answer to the question: why is the design of Urban Greenhouses in cities smart for Planet, Prosperity, People and Architecture? we can conclude the following:

**Urban Greenhouses are smart for Planet, because they..**

...try to close loops of water, food and energy locally
...use wastes as a resource: waste water and organic waste
...reduce the use of fossil energy for heating buildings and Greenhouses' crop production
...are purifiers for the air: the quality improves
...trigger biodiversity by diverse growing of crops, implementation of a natural environment acting as green corridors throughout the city

**Urban Greenhouses are smart for Prosperity, because they..**

...produce food locally, no transport costs involved
...are an energy reducing measure
...provide jobs for maintenance, management and production
...increase the local trade of food and recycled materials
...create a pleasant working environment during the whole year, which increases the efficiency
...they close loops locally, no invisible treatment costs outside cities
...are profitable for all the stakeholders involved: win-win situation

**Urban Greenhouses are smart for People, because they..**

...are flexible and adaptable, suitable for every initiative on every scale of the city
...work as noise buffer, which has a positive impact on people's health
...improve the quality of life: happiness and daily pleasure
...are a trigger for strong communities, as meeting place
...create favourable conditions during the whole year
...favor clean air for healthy respiration
...lower crime

**Urban Greenhouses are smart for Architecture, because they..**

...connect city functions: working, living and recreation
...improve the city environment
...are a **challenge for design**: space in city, location, involvement of people, technical details
...give **extra features** to one’s building design
...are a way to sustainably **play** with urban spaces
...are **sustainable**: profitable for people, planet and profit

### 8. Discussion

Is it realistic to implement Urban Greenhouses in cities?

The proposals made for design, solution and implementation in the previous chapters are not “out of the box” proposals. Greenhouses are extensively researched upon, and new innovative designs are introduced in the market. A new factor however, is the space in which the Urban Greenhouse will be implemented: building technology for difficult spaces might be a problem.

Some described technologies exist and are already applied (living machine, biogas fermentation), whereas other technologies have to be further researched and experimented with (car exhaust purification). Social science researches also proved the positive impact of a green environment on the individual and group behavior. So, technically the Urban Greenhouse is possible.

Another more important factor is the social aspect of the Urban Greenhouse: who is ready to invest in Urban Greenhouses; how can one be guaranteed of profit? Moreover, is the municipality willing to invest in a new Greenhouse-like environment and what is the perception among the citizens? Are people willing to accept their backyard maybe becoming more open and shared with neighbours, in exchange for a better environment? What are the amount of new regulations citizens can handle?

The municipality first of all needs to be willing to change its city environment. They can for example begin with a pilot project in an urban area which’ quality needs to be improved, and which has a high potential of spaces for Urban Greenhouses. Once these needs and potentials have been acknowledged, a company can be attracted to guide the project. But, the company needs a certain guarantee of the investments it makes. There the municipality can play a supportive role, since the project is a pilot project. Once the investments have been done, being profitable or not, further decisions on new implementations can be made by the government.

The municipality can play also an informative role towards the citizens, providing meetings and involving the citizens who are involved in the Urban Greenhouses. They have to be convinced by the municipality and/or the company of the advantages. Moreover, the implementation of an Urban Greenhouse should not lead to any financial incentives of people themselves.

We see that socially and economically the implementation of Urban Greenhouses is very challenging. To become a realistic project, the implementation of Urban Greenhouses needs support of municipality, companies and citizens. The willingness of these different actors has to be studied. A pilot project can give valuable insights for further investments.
References

http://www.verkeersnet.nl/851/bomen-langs-de-weg-leiden-niet-to-betere-luchtkwaliteit/
Appendix 1

Figure A0: the greenhouse effect

City functions

Living  Recreation

Working

Figure A1. Connecting city functions

City loops

Figure A2a. Water loop
Figure A2b. Food loop
Figure A2c. Energy loop
### Appendix 2

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*Table B: Urban Greenhouse check*

**City issues** are: waste water, organic waste, increasing demand of resources, noise pollution, light pollution, air pollution, lack of green space, city crime and unemployment, car density  
**Negative features greenhouses** are: additional need of energy, use of pesticides and excess manure, monocultures, light pollution  
**Positive features greenhouses** are: free use of solar energy, controlled micro-climate, protection against external influences, growing crops for food consumption, growing rare species and increasing biodiversity, social functions  
**City functions** are: living, working, recreation  
**City loops** are: water, food, energy  
**Scales** are: single houses, housing blocks, office building, infrastructure
Appendix 3

Graph C1: potential scales of the Urban Greenhouse

Graph C2: potential timings of the Urban Greenhouse

Graph C3: potential public of the Urban Greenhouse
Appendix 4

Figure D1: section between building blocks

Figure D2: section of 2012 Architecten [11]

Figure D3: impression 2012 Architecten [11]

Figure D4: unused space in Rotterdam

Figure D5: Urban Greenhouse in figure D4

Figure D6: a square with movements

Figure D7: change of movements of people on a square with a Urban Greenhouse
Figure D8: Rotterdam Schouwburgplein

Figure D9: lost space in Rotterdam

Figure D10: Urban Greenhouse in figure D9

Figure D11: section street

Figure D12: glass facades ventilating building
Figure D13 & D14: roofing greenhouse Behnisch Architekten [12]

Figure D15: De Zuidkas [14]  Figure D16: De Zuidkas [13]

Figure D17: potential roof space in Rotterdam
Figure D18: impression Rotterdam

Figure D19: Urban Greenhouse on infrastructure in figure D18

Figure D20: 'Kas Kantoor' van Doepel Strijkers Architects [15]

Figure D21: section street with tube

Figure D22: city plan with green corridors
Figure D23: waste water use and purification on a small scale

Figure D24: Organic waste recycling in a greenhouse [2]
Urban Greenhouse as solution for food issues

Figure D25: Urban Greenhouse as solution for food issues

Figure D26: Urban Greenhouse as heat buffer

Figure D27: heat storage with the Urban Greenhouse
Figure D28: purifying air on the infrastructural scale

Figure D29: the Urban Greenhouse as trigger for the local quality of the city environment and as strong social function
Figure D30: Connection of the city functions and their relations
Appendix 5

Figure E1: company UG4city with stakeholders

A. INITIATIVE

"I see potential for Urban Greenhouses in your city!"

B. POTENTIAL?

John
neighbourhood
company
municipality

major
"does the Urban Greenhouse bring sufficient benefits to my city?"

C. POSSIBLE?

"does the Urban Greenhouse bring sufficient benefits to my company?"
Figure E2: Implementation scheme of Urban Greenhouses