

Integrating urban farming into buildings

Qualities and potentials of urban farming case studies

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Abstract – This paper investigates how urban farming techniques can be integrated into buildings, to provide a substantial response to the predicted immense population growth, city expansion and food scarcity. The objective of this research is to generate a clear overview of the qualities and improvement points (potentials) of case studies in which urban farming is integrated into buildings. These case studies are selected and organized within a certain framework. The resulting knowledge is intended to be used as a generic guide during design processes which seek for ways to implement urban farming into buildings.

Key words – urban farming, building integrated agriculture, rooftop farming, vertical farming, greenhouse architecture, food chain regionalization, case study research

1. Background

1.1 Problem statement

The urban farming research topic has emerged out of a combination of five main problems, either on a global scale or on the 'local' scale of The Netherlands. The first global problem concerns population growth: in 2050, the world will inhabit around 9,6 billion people, 2 billion more than today (U.S. Census Bureau, 2011). From this amount almost 18 million people will be living in The Netherlands (1 million more than in 2014) (Nationaal Kompas Volksgezondheid, 2011). These developments will stimulate the tendency of city growth even more than already is happening. To illustrate: in 1800, 3 percent of the world population was living in cities, in 2010 already about 50 percent (Steel, 2010). City expansion results in an increasing reduction of the amount of agricultural space, which means that food production will keep decreasing. This is

exactly the opposite of what is needed, because an increasing world population will result into a (rapidly) growing food demand.

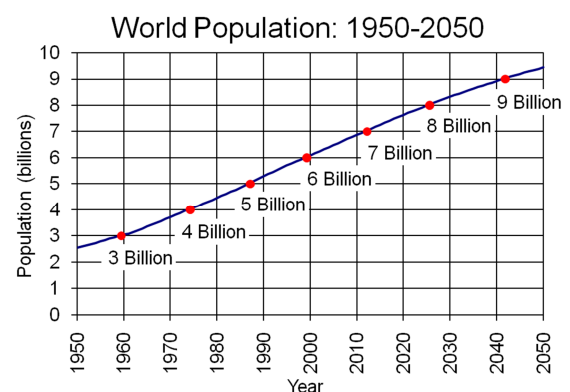


Figure 1. World population growth: 1950-2050 (U.S. Census Bureau, 2011).

The second problem that the world is facing is large-scale food scarcity versus waste of food, on a similar scale. About 1 billion people suffer from hunger and at the same time 1 billion people are

overweight or obese. In the UK 33 percent of the produced food is wasted and in the USA this amount is even 50 percent. Cities have become independent of their geographical location and therefore it seems that humanity has lost its connection with food and its resources. For example, the supper of an average Dutch family has been transported for 33.000 kilometers, till it's on their plate (Mulder & Oude Aarninkhof, 2010). In contrast to the period before industrialization, people seem not to have enough knowledge about their food, its origin and its social value within a community, which results in a weak bond with it and eventually in food neglecting/wasting behavior.

A third global problem is the lack of green in cities. Air pollution doesn't get filtered enough, resulting in bad air qualities in cities, which causes serious health issues and even shortened life expectancy for inhabitants. Besides that, the social potential of green as a space for citizens to interact, relax and learn from nature stays unused. The fourth problem is a more local one: the abundance of vacant office buildings in The Netherlands. Almost 15 percent of the office space in The Netherlands is unused, in Amsterdam even 18 percent. Together with Greece these are the worst percentages in Europe (Vastgoedmarkt, 2013). The last main problem, the second local one, is the (strong) demand for housing in cities. Amsterdam for example still needs 70.000 living spaces (mostly students and families) until 2040 (Gemeente Amsterdam, 2010), but this can't be fulfilled because of a 'lack of space' and money. The city contains plenty of vacant monofunctional areas, and municipalities and urban planners start to realize that creating mixed use areas is the main strategy for the future.

Leegstand oppervlakte kantoren

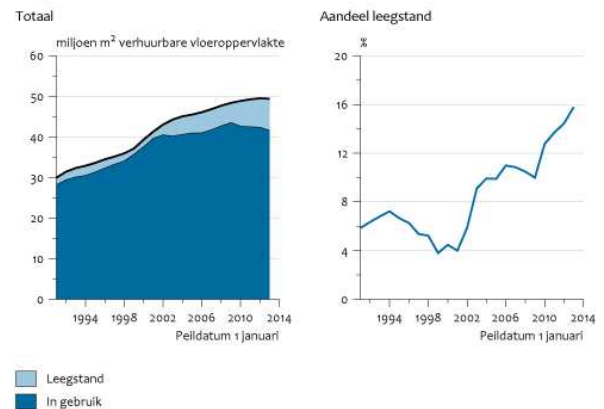


Figure 2. Office surface vacancy in The Netherlands: 1991-2013 (Compendium voor de Leefomgeving, 2013).

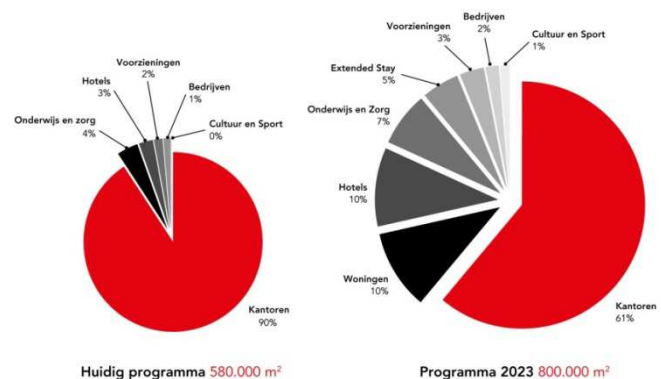


Figure 3. Mixed use strategy for 2023, made by the municipality of Amsterdam (Gemeente Amsterdam, 2012, p. 31).

1.2 Research topic: definition & relevance

An interesting principle that to some extent could solve abovementioned problems is *urban farming*, also often indicated as urban agriculture or city farming: food production within urban environments. Urban spaces get used more efficiently; not only for social and infrastructural purposes, but also to produce food. Besides that, this form of regionalization of the food system (which can be broken down into eight basic components, as can be seen in Figure 4) meets the increasing demand for local, organic (healthier) products and it can create more social cohesion and safety in neighborhoods, it can promote a more

active gardening lifestyle (which results in better mental and physical health conditions for users), it can provide education in the fields of biology and food management, it can create new job opportunities, it can contribute to climate change mitigation and adaptation strategies and it can restore the relationship between people and food, by creating more accessibility and awareness, eventually resulting in less waste (Holland & De La Salle, 2010).

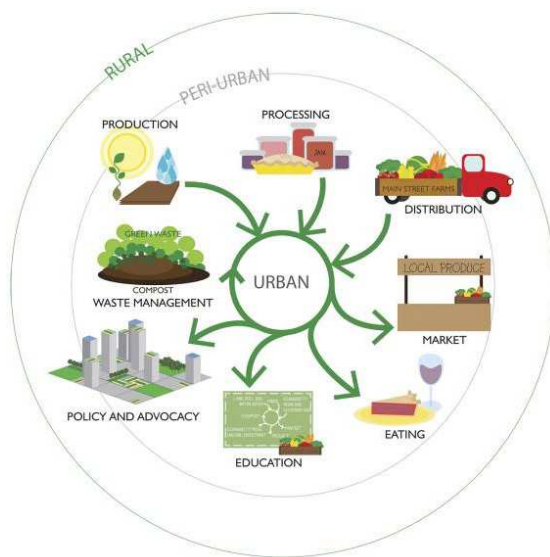


Figure 4. An urban food system: a cyclical process consisting of eight basic components (Philips, 2013, p. 46).

Currently, (mostly small scale) initiatives like allotment gardens for school children and recreationists, neighborhood gardens and community-supported agriculture (CSA: civilians financially support farmers and receive a part of the yield) gain popularity in the Western world. New, local types of public spaces, economies, distributions, markets and eating facilities have arisen (Vermeulen & Timmermans, 2010), which is a positive development. However, the potential of *buildings* (both new and existing) as carriers of urban farming activities is far from fully utilized, but will be in a few decades a big task due to the previously mentioned problems of

increasing world population, growing food demand and the resulting lack of space in cities. And to make sure that all previously mentioned urban farming benefits really get incorporated into the society, the building stock (both current and future) should get involved.

1.3 Research questions & research objective

These problems, considerations and fascinations have resulted in the following main research question for this paper:

How can urban farming techniques be integrated into buildings?

This question is supported by the following three sub research questions:

1: *What is the additional value of urban farming to the society?* (This is explicitly answered in this chapter, but will occasionally return in the next chapters.)

2: *What are the techniques, demands and principles of urban farming?* (This will be elaborated in the third chapter Results.)

3: *How can I implement the obtained knowledge into my own design and contribute new, innovative solutions to the working field?* (This will be elaborated in the concluding chapter.)

The objective of this research is to generate a clear overview of the qualities and improvement points (potentials) of existing case studies in which urban farming is integrated into buildings. These case studies are selected and organized within a certain framework. The resulting knowledge is intended to be used as a generic guide during design processes focusing on the integration of urban farming into buildings.

2. Method

In this chapter the research structure, used for this paper, is explained. It's a case study based research, which can be divided into four main steps.

Step 1: Selecting urban farming case studies

In a rather informal way, through literature study and internet research, as much as possible case studies and information resources are collected. In this step only two boundaries play an important role: the case study has to be a building in/on/next to which urban farming facilities are clearly integrated and the urban farming facility itself has to have the purpose of vegetable and/or fruit production. Meat production integrated in buildings is deliberately omitted from the research scope, because first the offer of these kinds of case studies is negligible and second because meat production accommodations don't provide much room for architectural innovation. Parameters like building function, location, addition or integration of the urban farm, private or commercial use and monoculture or polyculture are not constrained.

Step 2: Categorizing the case studies

In the second step a matrix is composed, containing four vertical columns and two horizontal rows which intersect one another (Figure 5). This typological division is a further elaboration of the list of physical types proposed by Philips (2013, p. 124): Traditional, Roof-top, Vertical, Streetscape and Greenhouse. The vertical columns signify the four ways in which a building can get connected to an urban farming facility: next to the building ('Plot'), on top of the building ('Roof'),

against/along the building ('Facade') and in the building ('Interior'). The two horizontal rows are based on the two most general physical features urban farming facilities for vegetable and/or fruit production can have: an earth field in the open air on which green grows ('Open field') and a glass/metal construction in which green is cultivated in different ways ('Greenhouse'). The eight intersections of these columns and rows provide the places over which the selected case studies can be divided. Every place can contain one or more case studies, depending on the type of intersection.

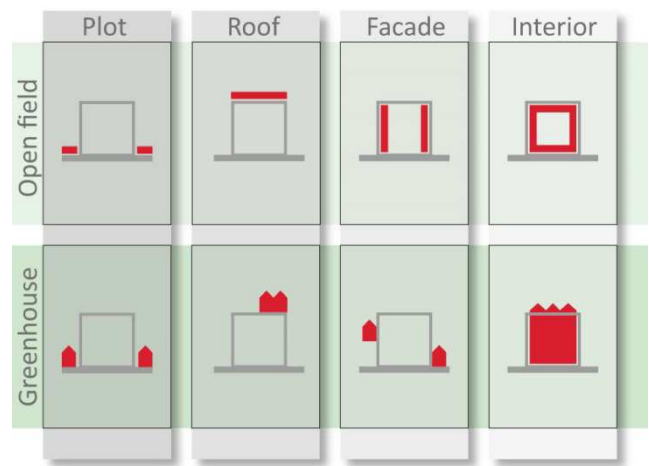


Figure 5. The matrix which has developed during Step 2 of the research (Own illustration, 2014).

By means of this matrix the research gets structured, offering a clear overview of all case studies and their physical and typological features. However, there are some overlapping situations. A greenhouse which is connected to the facade of the building can also stand on the plot next to the building. Or planters which are hanging from the facade can also be located in the interior. The case study then gets categorized in the column of the building part which gets technically and architectonically the most affected by the urban farming facility. Also between the horizontal rows 'Open field' and

'Greenhouse' there is a kind of overlap: the green inside a greenhouse also often is cultivated on smaller or larger fields. The physical appearance (is there a glass structure for the purpose of plant cultivation around the farm or not?) is the deciding factor.

Step 3: Analyzing the case studies

After the categorization with a matrix, the knowledge of the case studies is further deepened by means of relevant literature study and information from companies who were involved in the realization of these case studies. In some situations information about a case study is obtained by analysis of similar projects or designs. Another way of getting a deeper understanding of a case study is by sketching and redesigning, or applying ideas to your own design project: research by design. Case studies are analyzed and described according to characteristics proposed by Philips (2013, p. 124): participants, organizations, objectives, location, scale, activities, resources, technique and period of use. The extent to which an urban farm provides for the annual food need of one person, is estimated (if applicable) with the help of the statistics from a tool developed by Wageningen UR: Stedelijke foodprint (Figure 6). This model, based on model crops and average production figures, calculates how much hectares of plants (fruit, vegetables, wheat, potatoes and sugar), animals and hectares of animal nutrition is needed for the annual diet of a certain amount of people. And also the other way around: how many people can be fed with a certain amount of farmland. For this research paper the plant column, and especially the fruit and vegetables section, is the most relevant.



Figure 6. The Stedelijke foodprint calculation model which connects the food demand of a certain amount of people with a certain area and vice versa. Twenty people annually need 0,02 hectare for fruit and 0,03 hectare for vegetables (Stedelijke foodprint, n.d.).

Step 4: Comparing and evaluating the case studies

The final step in the research process is the comparison and evaluation of all case studies. This is done by means of a criteria list, which is divided in four main topics: Technical Value, Functional Value, Social Value and Architectural Value. Every topic carries five propositions, which can be answered with either yes (it becomes a quality) or no (it becomes a downside, and maybe a potential). These propositions are partially based on the 'key dynamics' which Miazzo and Minkjan (2013) address to their case studies: social, economic, education, environmental, health, infrastructure and liveability. The amount of yes's or no's determines the final rating of a case study for one topic. The overall average rating gives an idea about the score distribution, but the ratings per value are the most relevant and useful.

3. Results

In this chapter the results of the case study analysis are presented. The case studies are listed according to the easiest way to read the matrix (see Figure 7): from left to right, from top to bottom.

	Plot	Roof	Facade	Interior
Open field	1. Allotment gardens Amsterdam	3. Harvesting field Rotterdam	6. Second skin facade planters Amsterdam	8. Field and wall farms Shanghai
	2. Raised beds Alameda	4. School farm Chicago	7. Vertical hydroponics curtain London	9. Field, wall, ceiling, facade farms Tokyo
	10. Rotating rack towers Singapore	11. Circulating hydroponic trays Vancouver	13. Horticulture planters Boston	15. Atriums Wageningen
Greenhouse		12. Urban farming laboratory New York	14. Balconies Saint-Herblain	

Figure 7. The matrix filled in with the case study names (Own illustration, 2014).

1. Open Field - Plot: Allotment gardens (Amsterdam, The Netherlands, 1920)



Figure 8. Allotment gardens (Want to Know, 2010).

Allotment gardening is probably the best known type of urban farming. The allotment garden park Nut & Genoegen is a large green area in the western part of the city of Amsterdam (Tuinpark Nut & Genoegen, n.d.). The park is subdivided in 375 parcels, which can vary in area between 200 and 600 m² and each parcel is connected to a pavilion of about 30 m². Interested recreationists buy a pavilion

from the previous owner and rent the adjacent parcel from the allotment association, which leases or is granted all the land from an owner, and use it for private, non-commercial purposes. The gardeners become member of the association and also of the nationwide union (Bond van Volkstuinders), and are obliged to keep their parcel and the full park (association buildings included) in good shape. From April to October gardeners may sleep in their pavilion, during the winter this is forbidden. Their gardens are equipped with a water system (consumption is measured) and a sewage system, and the soil of their parcels is built up of four layers: under the top soil with the organic matter lie the surface soil, the sub soil and the parent rock (Philips, 2013, p. 163). Although the gardens nowadays mainly are used for the cultivation of flowers and plants, the fruit/vegetable production potential of an average parcel (300 m²) is quite high: according to the statistics of the Stedelijke foodprint (SF) tool, about 12 people can be provided fruits and vegetables for a whole year.

2. Open Field - Plot: Raised beds (Alameda, USA, 2012)



Figure 9. The urban farm in Alameda (Philips, 2013, p. 211).

For a sustainable designed campus in Alameda (California) - including office buildings, a café, an employee fitness center, an outdoor courtyard, conference

facilities and an outdoor yoga court - an organic food garden of raised beds is constructed (Philips, 2013, pp. 209-212). The urban farm (about 100 m²) has two purposes: to provide year-round food production to use in the wellness cafeteria and to create a place for employees to socialize and relax. The modern corten steel planters help define the circulation and the gathering areas containing dining tables and chairs. An olive tree, from which olives can be harvested semi-annually, provides shade above the gathering places. A sustainable harvested wooden fence around the garden forms a structure for espaliered fruit trees and a living herb wall. A butterfly garden and a native grasses meadow surround the farm to stimulate biodiversity, and there is a special composting location. The garden is harvested and maintained by a special gardening team and volunteers. Excess produced food is donated to local food banks.

3. Open Field - Roof: Harvesting field (Rotterdam, The Netherlands, 2011)



Figure 10. The Schieblock from a bird's eye view (Dutch Creative Residency Network, n.d.).

For the old office block Het Schieblock, which was vacant for twenty years, a new program has been designed: working studios for creative companies and (semi)public spaces for interaction and performance (Schieblock B.V. & RMC,

2012). One of these spaces is the urban farm of 700 m² on top of the roof (the 7th storey, 23 meters high), which is reachable through two staircases. The farm, including a pavilion with a kitchen (the old caretaker's house), has the main ambition of food harvesting but also can be used for scientific testing, gatherings, workshops, educational programs and dinners. The roof is managed and maintained by a professional agrarian, with knowledge of biological plantation. The harvest is eaten directly or is sold at the pavilion (only in harvesting season), and is distributed to restaurants in the neighborhood. According to the SF tool this roof can provide about 28 people fruits and vegetables for a whole year.

The extra weight of the urban farm shouldn't exceed the average of 180 kg/m², so the weight had to be divided in heavier and lighter zones: paths and beds with less deep substrate, respectively 50 mm and 200-500 mm, have been organized in a special rectangular grid (Van den Hout, 2012). The maximum roof occupancy has been set on about 34 people. The construction has been kept sober because of financial reasons and life expectancy of five to ten years. The original roof covering has been reserved and is topped with an insulation layer, a drainage layer (25 mm), a protection layer and special substrate with more organic particles for vegetable growing. On the old roof edge, milled planters of UV stable polyurea coated EPS 200 have been clicked to block roots and to protect people from falling. The bins are 1,2 meter (at the facade side) and 0,9 meter (at the farm side) high, two meter long and 0,9 meter wide. On the roof corners the bins are made of one piece. In the bins 380 mm deep substrate is put, making it possible to grow food too. The bins are drained via the roof with a buffer and overflow

system (small pipes in the bottom of the bins). This intervention has resulted in an image of a solid edge from the street.

4. Open Field - Roof: School farm (Chicago, USA, 2006)



Figure 11. The courtyard rooftop of the Gary Comer Youth Center (Gorgolewski, Komisar, & Nasr, 2011, p. 180).

The Gary Comer Youth Center (after-school learning) has an outdoor classroom space on the third floor to study plants and food: a 760 m² roof courtyard, surrounded on all sides by circulation corridors and classrooms (Gorgolewski et al., 2011, pp. 180-183). These corridors and classrooms are separated from the garden with floor-to-ceiling windows, on which informative graphics about the various plants are depicted. Large round skylights provide daylight to the gymnasium and the café below the roof, and act as sculptural elements in the farm which is set up in a grid of straight strips of plant beds. These beds contain soil of 45-60 cm deep and allow many types of vegetables to be grown, stimulating biodiversity. This soil depth and the wide span resulted in the demand for extra structural roof support (Philips, 2013, p. 118).

Between the lightweight soil beds, circulation pavers of recycled milk carton material are placed, which align with the surrounding window frames, uniting exterior and interior (Gorgolewski et al.,

2011, pp. 180-183). These pavers are supported by expanded polystyrene fill, which lies on a double protection layer for garden tools. The layers below are: a layer of drain board, a layer of insulation and waterproofing and the concrete roof slab. The annual harvest is about 450 kg, which is consumed at the café and sold (by students) to local restaurants. According to the SF tool this roof can provide about 30 people fruits and vegetables for a whole year. Solar gains and heat loss from the spaces below make it possible to keep some plants above freezing in winter, extending the growing season. Besides that the vegetation also has an insulating effect, reducing the building's climate control costs and the urban heat island effect. A fulltime garden manager maintains the farm and manages the educational tours for youth as well as seniors. The gardening activities are incorporated into the schools science and sustainability curriculums.

5. Open Field - Roof: Office farm (Amsterdam, The Netherlands, 2012)



Figure 12. Raised beds and fields on top of the Zuidpark office (Bouwwereld, 2012).

On the roof of an old office block (Zuidpark) an urban farm of 3000 m² has been constructed (Van der Tol B.V., 2012). The farm consists of two types of food growing: frames with substrate - which have been placed directly on the existing roof (with a protective layer in between) -

and portable planters from sustainable hardwood, which both define the circulation and the gathering spaces. An integrated detection system checks if offices below the roof aren't damaged by a water overflow. For the same reasons as with the Schieblock a special rectangular grid had to be designed to divide the soil load. This means that the potential to provide 120 people vegetables and fruit for a whole year (SF) never can be reached. For reinforcement an extra steel roof (SAB 106R/750) has been put on the existing roof, covered with a 120 mm insulation layer of pressure resistant EPS 200 SE (Bouwwereld, 2012).

The building is controlled by a director, office manager and a facility manager, who direct and help the gardening club consisting of office employees (Zuidpark, n.d.). This club encourages all employees (about 1000, from various companies which are renting a part in the building) to maintain and harvest the grown vegetables/herbs/fruits (about 50 varieties) for personal use or for the café downstairs. The roof is used for lunches, gatherings, dinners, receptions or other small events.

6. Open Field - Facade: Second skin facade planters (Amsterdam, The Netherlands, 2013)



Figure 13. The double skin facade containing planters (AT5, 2013).

Two residential towers of about 40 and 50 meters high with the same physical appearance (therefore the project is called De Tweeling, 'The Twins') were made close to a railroad (Duco Ventilation & Sun Control, n.d.). As a solution to the noise, the windows of apartments at higher storeys have been constructed as a double skin glass facade, with an insulating air cavity of around 40 cm deep. Some residents find this cavity useful to grow smaller vegetables, fruits and herbs in planters filled with earth, imitating a small greenhouse.

7. Open Field - Facade: Vertical hydroponics curtain (London, England, 2009)



Figure 14. The vertical farming installation behind a window frame of a café in London (Bohn and Viljoen Architects, n.d.).

In the café of The Building Center in London a vertical agriculture installation was implemented (Bohn and Viljoen Architects, n.d.). Eight planting trays without soil are hung on an off-the-shelf cable system behind the glass facade of the café and are connected with a pipe to a nutrient-rich water supply. This high-yield and low-maintenance hydroponics system produces vegetables for a whole year, which are used in the café. The curtain, with a growing field which is four times as space efficient compared to a horizontal arrangement, is harvested and

reseeded every two weeks. The measurements of this installation are estimated as 2 m long, 2 m high and 25 cm deep, giving a total of 2 m² vertical farm space.

8. Open Field - Interior: Field and wall farms (Shanghai, China, 2013)



Figure 15. Interior food beds, lighted by LED lights in the K11 shopping and art mall (Inhabitat, 2013).

In the K11 Art Mall a shopping center, art galleries, exhibition spaces and an urban farm are merged (Inhabitat, 2013). The urban farm (300 m², SF: 12 people) is located in the middle of the mall on the third and the fourth floor, surrounded by the malls food and beverage venues. It uses soil-free cultivation methods and produces tomatoes, eggplants, hot peppers and seasonal products. Automatic irrigation systems and LED lighting (the amount is depending from the amount of daylight through windows) are implemented to control the farm. With the education given by an expert, visitors can obtain their own small parcel to sow their own plants, which they can take home. There is only one condition: visitors may only participate if they have the proof of that they have purchased an article from the mall, for at least 150 dollars.

9. Open Field - Interior: Field, wall, ceiling and facade farms (Tokyo, Japan, 2011)



Figure 16. Exterior living wall of the Pasona building (Architizer, n.d.).

The nine storeys high office building of the Japanese recruitment company Pasona is a major renovation project consisting of a double-skin green facade, offices, an auditorium, cafeterias, a rooftop garden and integrated urban farming facilities (Architizer, n.d.). The building contains 4000 m² of green space with 200 species of fruits, vegetables and rice which are harvested, prepared and served at the cafeterias within the building. Maintenance and harvesting is done by the office employees, with the help of agricultural specialists, to stimulate the social interaction within the company, the mental and physical health and the work productivity (which is also stimulated by the CO₂ reduction by the plants). Besides that, Pasona offers special programs to educate next generation farmers, aiming to reverse the declining trend of farming in Japan.



Figure 17. Interior rice paddy of the Pasona building (Architizer, n.d.).

Vegetables and fruits are integrated as much as possible into the interior, with hydroponic as well as soil based farming techniques: tomato vines are suspended above conference tables, lemon and passion fruit trees are used as partition walls for meeting spaces, salad leaves are grown inside seminar rooms, bean sprouts are grown under benches and in the main lobby a rice paddy and a broccoli field are constructed. The paddy and the field are equipped with LED lamps and an automatic irrigation system. A climate control system monitors humidity, temperature and breeze to balance human comfort during office hours. The facade has been doubled with a one meter deep cavity in between: seasonal flowers and orange trees, which just partially rely on the exterior climate, grow from planters placed in the facade through the steel facade frame, becoming a living wall towards the street.

10. Greenhouse - Plot: Rotating rack towers (Singapore, Singapore, 2012)



Figure 18. The vertically rotating A-shaped steel frames carrying hydroponic racks filled with leafy vegetables (Singapore Ministry of National Development, 2013).

In the densely populated Singapore the low-carbon, vertical, commercial urban farm for tropical, leafy vegetables Sky Greens has been constructed (Sky Greens, n.d.). Within protecting greenhouses (no external factors like extreme climates, pests and insects), 120 vertical A-shaped steel frames of 9 meter high are placed. Those contain 26 racks filled with composted soil media (hydroponics), on which the leafy vegetables (about 10 different types in total) grow. With a semi-automated, water-driven pumping system the racks are rotating up and down three times a day, getting a total of two hours of sunlight each day. Rainwater and recycled water are collected in tanks and are pumped around with this 'Water Pulley System', which makes the racks rotate with the principles of flowing water and gravity. Micro-sprinklers water the plants three times each day as the racks rotate. The system is characterized by low energy and very low water usage, and all organic waste is composted and recycled. The

yield is five to ten times more than normally possible with the same amount of land. Sky Greens is able to supply about 500 kg per day, all year round, and delivers it to the consumers through retail outlets. Given the fact that a Dutch man of 19 to 30 years old eats on average 60 grams of leafy vegetables a day (Van Rossum, 2011, p. 38), Sky Greens can provide about 8300 Dutch men leafy vegetables a day. Sky Greens also offers educational schemes combining theory and practice on site for students, who are guided by professionals.

11. Greenhouse - Roof: Circulating hydroponic trays (Vancouver, Canada, 2013)



Figure 19. Greenhouse on top of a parking garage in Vancouver (BuzzBuzzHome, 2012).

On the rooftop of a parking garage in Vancouver (20 meters high) a greenhouse (550 m², 4 meters high) has been built, in which the hydroponic system VertiCrop is implemented (Alterrus, 2012). Leafy green vegetables and herbs are planted in series of suspended trays which rotate on motorized conveyors. During this process, controlled by a group of experts, the food gets optimal exposure to either natural or artificial light, with each plant receiving precisely measured nutrients. Pesticides or herbicides aren't used, because the greenhouse is protective. Only 8 percent

of the water typically required for field agriculture is used. The annual harvest of about 70.000 kg (190 kg a day, providing 3200 Dutch men (Van Rossum, 2011, p. 38)) is transported directly to local markets and restaurants in the city, which results in a smaller carbon-footprint than with normal agricultural distributions.



Figure 20. The VertiCrop system inside the greenhouse (BuzzBuzzHome, 2012).

12. Greenhouse - Roof: Urban farming laboratory (New York, USA, 2010)



Figure 21. Greenhouse on top of a school in New York (Gorgolewski et al., 2011, p. 179).

The Manhattan School for Children has built a 130 m² greenhouse laboratory on

top of its roof, about 10 meters from the ground floor (Gorgolewski et al., 2011, p. 179). About 40 students get a year-round education of theory and practice in the fields of sustainability and food production. There are also collaborations with other institutions and workshops for teachers, students and other community members. The initiative doesn't have a commercial goal. The laboratory utilizes different technologies like hydroponics (for example hanging facade planters), aquaponics (growing green surrounded by fish), renewable energy from solar panels, rainwater collection, water reuse, evaporative cooling, vine crop systems and integrative pest management. There are also raised beds for food production, a composting center and a kitchen corner. The greenhouse is heated in winter with a low-carbon blower unit and is cooled in summer with an evaporative cooling system.

13. Greenhouse - Facade: Horticulture planters (Boston, USA, 2013)



Figure 22. Greenhouse next to a museum in Boston (Growing with plants, 2012).

For the Isabella Stewart Gardner Museum in Boston a new addition was built, containing a 150 m² footprint of a sloped greenhouse connected to the facade (The Boston Globe, n.d.). The greenhouse doesn't have a commercial, food producing objective; it's only used for horticulture, managed by a specialist who

organizes educational tours. According to the SF tool this space could provide about 6 people fruits and vegetables for a whole year. Climate is controlled with fans, windows and sun shading.

14. Greenhouse - Facade: Balconies (Saint-Herblain, France, 2013)



Figure 23. Greenhouse balconies in a residential complex (ArchDaily, 2013).

The design of a newly built resident complex in Saint-Herblain (89 social housings) was inspired by the agricultural history of the site (ArchDaily, 2013). The balconies have been designed as greenhouses, which give an individualistic as well as a collective image. The balcony greenhouses have an area of about 10 m² and don't have an urban farming function, but show potential.

15. Greenhouse - Interior: Atriums (Wageningen, Netherlands, 1998)



Figure 24. Greenhouse atrium (Gauzin-Müller, 2002, p. 223)

The Forest and Nature Research Institute in Wageningen has three storeys and a plan in the shape of a capital E: the straight laboratory part is positioned to the north and the three linear office blocks, separated by two greenhouse-like glazed atriums of 300 m² each, face the south (Gauzin-Müller, 2002). The internal walls of the offices are 60% glazed to achieve optimum natural lighting. The facades (external and internal) have insulating double glazing, but the glass atrium roofs are single glazed. The atriums, meant as a relaxation area for the researchers, create a variety of atmospheres: one atrium is full of vegetation, the other one is filled with ponds and sculptures. They don't have a goal of food production but play a big role in the energy concept of the building, because in winter sunlight warms the air and heat is stored in the massive structural parts and in summer the gardens are cooled by evaporation from the pools and plants. A system of blinds (like in commercial greenhouses) provides shading in summer and insulation in winter. Electrically operated valves in the roof allow hot air and smoke to naturally disappear, for example for night cooling. According to the SF tool both atriums together can provide about 24 people fruits and vegetables for a whole year, but the necessary circulation areas will lower this potential.

4. Conclusion & Discussion

The last decade agriculture has gained ground within the urban environment and even got integrated into buildings. This research has shown that this has happened in eight different ways: four different parts of a building (plot, roof, facade and interior) and two main farming appearances (open field, greenhouse)

have been merged, with various consequences and effects. This section attempts to display these results, and for this a criteria list has been created (Figure 29) which can be divided in four main topics: technical value (constructability and adaptability of the urban farm), functional value (in and output of the urban farm), social value (the urban farm's influence on people and environment) and architectural value (the urban farm's influence on form and space of the building). Yield comparison has deliberately been omitted, because it doesn't make sense: a bigger field gives a bigger yield and commercial farms logically have a (much) bigger yield than fields.

Besides that, case studies 13, 14 and 15 don't have an agricultural goal. To make it possible for these case studies to participate in the evaluation, the following assumptions have been made:

1. *The horticulture in Boston's greenhouse is replaced by raised food beds.*
2. *The balconies of Saint-Herblain contain raised food beds.*
3. *The green area in the atrium of Wageningen can be seen as a harvesting food field.*

To get a clearer view on the evaluation results in Figure 29, for each topic the results have been translated into the matrix which was created and used during the process. The total average value of all typologies is 2,5, exactly the half of the maximum score a typology can get. When the mean value of a typology is above 2,5 it gets a green mark (positive), when it's below 2,5 it gets a red mark (negative). On the next page the results are shown:

	Plot	Roof	Facade	Interior
Open field	✗	✗	✓	✗
Greenhouse	✗	✗	✓	✗

Figure 25. Overview of the technical values (Own illustration, 2014).

	Plot	Roof	Facade	Interior
Open field	✗	✗	✓	✓
Greenhouse	✓	✓	✓	✓

Figure 26. Overview of the functional values (Own illustration, 2014).

	Plot	Roof	Facade	Interior
Open field	✓	✓	✗	✓
Greenhouse	✗	✗	✗	✓

Figure 27. Overview of the social values (Own illustration, 2014).

In Figure 25 it can be seen that only the facades have a positive technical value. This can be explained due to their relative small scale: no heavy earth planters or big structures, but small lightweight fields and glass structures. Only the Open Field- Plot-

	Plot	Roof	Facade	Interior
Open field	✗	✗	✗	✓
Greenhouse	✗	✓	✓	✓

Figure 28. Overview of the architectural values (Own illustration, 2014).

Raised beds typology can compete (Evaluation: 3) because of its ability to adapt. The rest is below average because their criteria keep each other in balance. For example Plot-Open Field-Allotment gardens has few, simple components, but they are quite heavy and inadaptable (earth) and Interior typologies are small and lightweight but rather complex (LED lighting, irrigation systems) with many parts. To make these typologies more optimal is interesting to investigate further.

The small scale character of the facades doesn't work out well for their social value (Figure 27), where their result is negative. Except from Boston's facade greenhouse, which is located partly on the ground (Evaluation: 4), the facade typologies don't gather people, don't stimulate physical activity or biodiversity and are not easily accessible: in this field facade farming has to develop further, which is a challenge for upcoming designs. The Open Field-Plot and Open Field-Roof typologies have high social values because of their broad offer of meeting places and educational programs. Because they are in open air they also stimulate biodiversity, in contrast to the greenhouse typologies. Also the Interior typologies have a high social value, probably because they are

connected to humans the most. This is only not true for the Shanghai mall (Evaluation: 1), because the concept of the farm is not strong enough: people don't get to work together and the farm is not easy to find. The full score of Pasona Tokyo, where urban farming is integrated maximally, pulls the average up.

The functional values (Figure 26) also keep each other in balance: no case study has a score higher than 3. Commercial farms like Singapore and Vancouver for example produce a low amount of waste and use a low amount of resources, but they don't deliver many types of food and aren't flexible: they are very specialized and good in the production of just a few vegetables. Open fields on plot or roof produce a lot of types of food and are flexible, but relatively need a lot of resources, relatively produce a lot of waste and have a risk of attacks from

pests and insects. Greenhouse typologies overall have a high architectural value (Figure 28), except the Greenhouse-Plot which doesn't contribute to the building exterior, interior and routing inside the building. For the same reasons Open Field-Plot typologies also have a low architectural value. The only Open Field typologies which have a high architectural value are Chicago, London and Tokyo. In Chicago the roof farm has been made as transparent as possible, with the large skylights and the surrounding glass corridors. In Tokyo the farms play a big role in the interior and the living wall on the facade has a strong expression towards the exterior.

Figure 29. Evaluation of the 15 case studies with 20 criteria (Own illustration, 2014). Note 4 means that criteria 5 of the Technical Value for greenhouse typologies only is applied on their interior, not on the greenhouse structure itself.

Criteria Case Study	PLOT		ROOF			FACADE		INTERIOR		PLOT	ROOF		FACADE		INT
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13. ¹	14. ²	15. ³
1. The urban farm consists of relatively few components.	yes	yes	no	no	no	yes	no	no	no	no	no	no	no	no	no
2. The components are relatively small and lightweight.	no	no	no	no	no	yes	yes	yes	yes	no	no	no	no	yes	no
3. Connections between components are relatively simple.	yes	yes	yes	yes	yes	yes	no	no	no	no	no	no	yes	yes	yes
4. Maintenance and harvesting requires relatively little effort.	no	no	no	no	no	yes	yes	yes	no	yes	yes	yes	no	yes	no
5. The urban farm can relatively easily change shape/area. ⁴	no	yes	no	no	yes	yes	yes	no	no	no	no	yes	yes	yes	no
Technical value	2	3	1	1	2	5	3	2	1	1	1	2	2	4	1
1. The urban farm delivers relatively many types of food.	yes	yes	yes	yes	yes	no	no	no	yes	no	no	yes	yes	no	yes
2. The urban farm needs a relatively small amount of resources.	no	no	no	no	no	yes	yes	no	no	yes	yes	no	no	no	no
3. The urban farm produces a relatively small amount of waste.	no	no	no	no	no	yes	yes	yes	no	yes	yes	no	no	yes	no
4. The user can easily change the grown types of food.	yes	yes	yes	yes	yes	no	no	yes	yes	no	no	yes	yes	yes	yes
5. The urban farm has no risk of externally caused contamination.	no	no	no	no	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Functional value	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
1. The urban farm is easily accessible, when on plot.	yes	yes	no	no	no	no	yes	no	yes	yes	no	no	yes	no	yes
2. The urban farm stimulates people to interact.	yes	yes	yes	yes	yes	no	no	no	yes	no	no	yes	yes	no	yes
3. The urban farm stimulates physical activity.	yes	yes	yes	yes	yes	no	no	no	yes	no	no	no	yes	no	yes
4. The urban farm has an educational program.	yes	no	yes	yes	no	no	no	yes	yes	yes	no	yes	yes	no	no
5. The urban farm stimulates the biodiversity.	yes	yes	yes	yes	yes	no	no	no	yes	no	no	no	no	no	no
Social value	5	4	4	4	3	0	1	1	5	2	0	2	4	0	3
1. The urban farm has an effect on the building exterior from streetview.	no	no	no	no	no	no	yes	no	yes	no	yes	yes	yes	yes	yes
2. The urban farm has an effect on the building exterior from high view.	no	no	yes	yes	yes	no	yes	no	yes	no	yes	yes	yes	yes	yes
3. The urban farm has an effect on the building interior.	no	no	no	yes	no	yes	yes	yes	yes	no	no	no	no	yes	yes
4. The urban farm has an effect on the routing outside the building.	yes	yes	no	no	no	no	no	no	no	yes	yes	no	yes	no	no
5. The urban farm has an effect on the routing inside the building.	no	no	yes	yes	yes	no	no	yes	yes	no	no	yes	yes	yes	yes
Architectural value	1	1	2	3	2	1	3	2	4	1	3	3	4	4	4
Average value	2,5	2,5	2,3	2,5	2,3	2,3	2,5	2,0	3,3	1,8	1,8	2,5	3,3	2,8	2,8

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