URBAN FARMING

ETH SUSTAINABILITY SUMMER SCHOOL 2012

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Acknowledgements

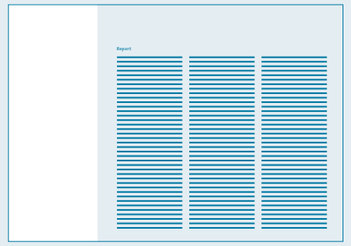
There are a number of people that we would like to thank for their help and contribution to this work.

Urban Farmers, especially Roman Gaus and Mark Durno for making this project possible. MEEZAN, especially Bashar Humeid for the supervision of the case study. The Department of Architecture, especially Nicola Eiffler and Eawag, especially Christian Zurbrügg for their inputs as well as Juanita Schläpfer for the communication training. Frau Gerolds Garten, especially Katja Weber, Marc Blickenstorfer and Patrick Isler for letting us use their site and for the delicious food.

We would also like to thank ETH Sustainability, especially Christine Bratrich, Catherine Lippuner and Lex Schaul who made this project possible.

The Urban Farming Case Study was more than raw facts. That's why this document is more than just a scientific report.

On each page our impressions float in the white space



while the results are presented in blue columns.

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Abstract

Many densely populated areas in arid or semi-arid regions face both water and land scarcity and are therefore highly dependent on imports to ensure food security. Aquaponics, the integration of hydroponics with aquaculture, is highly water efficient and can easily be installed on a flat rooftop. It is therefore a good option to increase urban food production even under conditions of water and land scarcity.

In Amman, the capital of Jordan, aquaponic systems have been successfully implemented by the local NGO MEEZAN. However, these systems depend on external water supplies and are relatively costly. In the context of the ETH Sustainability Summer School 2012, a group of 13 students addressed the task of constructing a simple, low cost aquaponic system which is able to collect and store rainwater and offers sufficient ventilation during the summer. The proposed model is adapted to the local conditions in Amman and opts to improve the current design used by the NGO MEEZAN.

Due to time constraints, the main greenhouse structure was bought in advance. The design efforts of the project therefore focused on the water collection and ventilation system. The latter was realized by including ventilation openings in the greenhouse plastic cover and by providing a shading cloth to cover the greenhouse during the hot summer months. Rainwater is collected by a gutter, which was sewn onto the plastic cover. The water is then collected in PET-bottles and led via a tube to storage tanks inside the greenhouse.

The above mentioned aquaponics system has not been tested yet, but estimates indicate that the proposed system is far less dependent on external water sources than the system used so far by MEEZAN. Furthermore, simple calculations show that a relevant share of the fish and vegetables consumed in Amman could be produced in rooftop aquaponic farms. The payback period is estimated to lie between two and four years, depending on the outputs that are produced in the aquaponic farm.
Aquaponics is therefore seen as a possibility to significantly improve the food security within cities like Amman.

The major parts of the greenhouse have already arrived on site and now need to be shuffled into order. As soon as the wooden grow bed is water proofed, it will rest on the reused international bulk containers (IBC). Will one can still smell the energy drink that used to be shipped within, they will function as water reservoirs and fish tank.

In the very beginning, we visited the Urban Farmer‘s box, where salad, basil and tomatoes are already growing in an aquaponic system. Mark and John analyze the quality of the produced salad that will be eaten for dinner at the Seed City garden, where our greenhouse stands today and hopefully produces the same quality of vegetables and fish.

Urban Farming

In 2008, for the first time in history, more than half of the world’s population lived in urban areas. By 2020, 75% of all urban dwellers will live in cities in the developing countries of Africa, Asia and Latin America. The rapid urbanization goes along with a rapid increase in poverty and food insecurity [Baudoin and Drescher 2008].

According to van Veenhuizen (2006), Urban Farming (UF) has the potential to increase food security andreduce urban poverty. Urban agriculture can be defined as the growing of plants and the raising of animals within and around cities and towns. It includes a variety of production systems, ranging from subsistence production and processing at household level to fully commercialised agriculture [van Veenhuizen 2006]. Thereby, UF helps to transform cities from being only consumers of food and other agricultural goods into relevant producers [Smit and Nasr 1992]. It is estimated that at least 15% of the global food output is produced in cities [Pauli 2012]. Apart from fostering food security, UF reduces the energy demand along the food supply chain, e.g. by reducing the transport distances between producers and consumers of food. Short transport distances furthermore reduce food losses: In developing countries, 10 to 30 per cent or more of post-harvest losses are caused by long transport distances, poorly maintained trucks, lack in cold storage etc.[FAO 2005]. Other advantages of UF are the provision of jobs and the contribution to urban ecology [Baudoin and Drescher 2008].

Urban agriculture has existed for a long time. At many different places in the world there are long traditions of farming within and at the edge of cities. Ancient civilizations developed creative ways to produce food and manage land and water in urban areas.

A well-known example for a city that was self-reliant in food in the 16th century is Machu Pichu [Smit 2002, Smit et al. 2001]. Before “modern” urban sanitation systems came up in the latter 19th century, urban agriculture was the principal treatment and disposal method for urban wastes. Food was brought by donkey cart to the markets and in turn, the city’s wastes were delivered to rural and urban fields [Smit et al. 2001]. In Europe, a decline in urban agriculture started in the late 19th century and accelerated after World War II. In the 1970s and 1980s, a resurgence of agriculture in European cities began and there is now a new interest in community gardens.

It is obvious that water was omnipresent during the case study. Above, Lea and BinBin are testing the throughput of the rainwater collection system while watering the vegetables in the garden, and below Francis and Mel are observing the fish in the Aquaponics Lab at the ZHAW Wädenswil.

In developing countries, urban agriculture became also increasingly common during the last half of the 20th century due to unreliable food supply chains and a persistent urban hunger [Smit et al. 2001].

Urban Farming can be realized in many different ways. The most traditional form of urban agriculture is the standard, ground level farm or garden. Backyard and community gardens are two examples of this form of urban agriculture. A different form of UF that tackles the problem of limited open space within cities is rooftop gardening. Apart from producing agricultural goods, green roofs help retaining storm water and lower ambient air temperature [Gittlerman 2009]. A distinction between ground level and rooftop farming considers where UF takes place. A second possibility to classify different types of UF is by focussing on what is being produced. The main components of UF are horticulture, animal husbandry and forestry as well as aquaculture [FAO 2001]. In the case of horticulture, a further differentiation can be made between farming with and without soil. When no soil is used, plants can be grown in non-soil organic matter, water solutions (hydroponics), air (aeroponics) or in other media [Smit et al 1996]. Some of these elements can also be combined. The combination of soil-less vegetable growing (hydroponics) and fish farming (aquaculture), for instance, is referred to as aquaponics [FAO 2012].

Aquaponics

In aquaponics, fish and plants are grown in one integrated system [Hillyer 2007]. Even though, there are several examples of successful aquaponic systems, the science of aquaponics is still in the early stage [Goodman 2011].

At the University of the Virgin Islands, a commercial-scale aquaponic unit has been developed. There, Dr. James Rakocy (who is sometimes referred to as the father of U.S. aquaponics) spent 30 years in developing and promoting aquaponics [Aquaponic Source 2010]. The system at the University of the Virgin Islands has four fish rearing tanks with a volume of almost 7800 litres each and a hydroponic growing area of 214 m^2. It is capable of producing approximately 5000 kg of tilapia fish and 1400 cases of lettuce or 5000 kg of basil per year [Rakocy et al. 2006].

Other systems have been implemented in Australia, Canada, Saudi Arabia, Israel and other parts of the world [Rakocy 2012, Savidov 2005, Al-Hafedh et al. 2008, Gooley and Gavine 2003]. It is estimated that there are around 1500 aquaponic systems in the United States. However, most of these systems are operated at the hobby and backyard level [Rakocy 2012].

ADVANTAGES AND DISADVANTAGES OF AQUAPONIC SYSTEMS

There are several advantages of the aquaponic system compared to a traditional farming system. As compared to conventional farms, aquaponic systems are highly water efficient: they use less than 50% of the water needed for normal soil farming. In addition, two agricultural outputs (fish and plants) can be obtained from a single input (fish food). Aquaponic systems are quite easy to operate and can be realized in a variety of scales: systems can be as small as an aquarium covered by a tray of plants or very large with many production units [Rakocy 2012]. Harvesting is easy and a high-density crop production is possible [FAO 2012]. A major advantage of aquaponic systems is that crops are less susceptible to soil-borne diseases [Rakocy et al. 2006]. Due to the low water requirements and the possibility for high-density crop production, aquaponic systems may provide fresh and local food even in areas with limited water and land resources.

A challenge for aquaponic systems may be the fact that pesticides pose a threat to fish and should therefore not be used for pest and disease control on aquaponic plant crops. Similarly, therapeutics for treating fish parasites and other diseases may be absorbed and concentrated by plants and should therefore not be used. Instead, nonchemical methods of integrated pest management such as resistant cultivars, predators, physical barriers and traps must be used. The prohibition of chemicals for pest and disease control in aquaponic systems makes crop and fish production more difficult [Rakocy et al. 2006]. Fish density needs to be limited which makes the fish production more expensive. However, the abdication of chemicals ensures an environmentally sound agricultural practice.

Jordan

In Amman, the capital of Jordan, the local NGO MEEZAN has successfully implemented aquapoinc systems on rooftops. Jordan is located in the Mediterranean region, about 80 km to the East of the Mediterranean Sea [UNFCCC 2010] (Figure 1).

Figure 1: Map of Jordan

Climate: The Jordan climate is characterized by hot dry summers and rather cool wet winters. Precipitation falls from October to May, but about 75% of precipitation is concentrated in the winter season (December to March) [WHO 2012]. More than 80% of Jordan's area is arid and receives less than 200 mm annual precipitation [AARDO 2007]. In Amman, the average annual rainfall is 255 mm (data from 1970 to 2002 for Amman Airport station) [Al Mahamid 2005].

Water resources: Compared with other countries in the Middle East, Jordan has scarce water resources [WHO 2012]. Jordan's fresh water resources are, on a per capita basis, among the lowest in the world (135 m^3 per capita and year for all uses) [AARDO 2007]. At present, there are major concerns about the use of non-renewable water resources and the exploitation of groundwater for irrigation [UNDP 2012]. Climate change is expected to increase temperatures and water scarcity in Jordan in the coming years [WHO 2012]. Climate change models show a significant decrease of the annual discharge for the Jordan River, which serves as the main source of irrigation water in the Jordan Valley [UNFCCC 2010, Trondalen 2009].

Amman: More than 2 million people live in Amman, Jordan's capital. Reflecting the geography of the region and the rapid growth of the city itself, a major issue for Amman is the supply of potable water. Amman receives around 50 % of its water from the Jordan Valley. 98 % of households in Amman are connected to the water supply network, but since 1987, water supply has been rationed [Potter et al. 2009].

Agriculture: Jordan's agricultural area sums up to around 2.7 % of the total area. 70 % of the agricultural area is non-irrigated, but except for few areas in the northern and western highlands, rainfall amounts and climatic conditions do not support good rain-fed agriculture. While trees and field crops are mainly cultivated in non-irrigated systems, most vegetables are grown in irrigated agriculture. The irrigated area is mostly located in the Jordan Valley. For irrigation purposes surface water is transported via the King Abdullah Canal. Within a limited area in the southern part of the valley, groundwater is used [AARDO 2007].

Population: In 2010, Jordan's population was estimated at about 6 million. The share of the urban population increased from 70 % in 1980 to 83 % in 2004 [DoS 2010]. In 2008, poverty in Jordan was estimated at 13.3 %. Although the number of the urban poor is higher, the vulnerability to poverty and food insecurity are seen to be greater in rural areas [UNDP 2010].

Food security: Jordan is the most food insecure Middle Eastern nation [Wilson and Bruins 2005]. Generally, ensuring food security requires adequate quantities of food available at all times within a region, either produced locally or procured from outside markets. In the case of Jordan, most cereals are imported, while vegetables, poultry, eggs and fruits are mainly produced within the country. Jordan is a net importer of food. As water and land suitable for agriculture is scarce, Jordan's potential for food self-sufficiency is limited even if the best farming technology was available [UNDP 2010].

Urban Farming: Historically, Amman and its suburbs have been known for their production of agricultural goods such as olives, grapes, apples and pomegranate. However, when the urbanization increased land and water resources got more scarce [Al Jundi 2008]. But nevertheless, crop and livestock production within the city continues. It is expected that urban farming will positively affect the standard of living in Amman [CIHEAM 2001].

The aim of the case study is to improve and document the building process of a greenhouse for the organization MEEZAN from Jordan. The pictures on this page show Bashar during the building process of the first freedom machine in Amman, built on one of the many rooftops of the capital of Jordan [Alnimer 2012].

In order to accomplish the task of creating the project within just 9 days, we split into groups. The building group took care of the actual assembly of the greenhouse. Here, Laura is adapting an international bulk container (IBC) while Marco and Stefan are assembling the metal frame structure.

System Description

In aquaponic systems, the combination of hydroponics and aquaculture within a closed-recirculating system, nutrient-rich effluent from fish tanks is used to fertilize and irrigate hydroponic production beds (Figure 2). Plant roots and rhizobacteria remove nutrients from the water and thereby prevent the nutrients from building up to toxic levels in the fish tanks. Thus, the waste products of one biological system (fish excreta, algae and decomposing fish feed) are used as nutrients for a second biological system. After the water has been cleaned in the hydroponic beds it can be re-circulated back into the fish tanks [Diver 2006]. The fish, plants and bacteria need an adequate level of dissolved oxygen. By aerating the water, the level of dissolved oxygen should be maintained at least at 5 mg/l [Rakocy 1997].

A major concern in aquaponic systems is the removal of ammonia, a metabolic waste product excreted by the fish. Unless it is removed, ammonia will accumulate and reach toxic levels. The removal takes place through the process of nitrification, in which ammonia is oxidized to toxic nitrite in a first step and to relatively non-toxic nitrate in a second step. Nitrifying bacteria grow as a film (biofilm) on the surface of inert material or adhere to organic particles. Aquaponic systems have used biofilters as a substrate, i.e. sand, gravel, plastic media or other materials with large surface areas for the growth of nitrifying bacteria. The efficiency of the nitrification process is affected by the pH. It is optimal at pH values ranging from 7 to 9, whereas most hydroponic plants grow best at a pH of 5.8 to 6.2. The pH furthermore affects the bioavailability of nutrients, especially of trace metals. Micronutrients such as iron, manganese, copper and zinc are less available to plants at a pH higher than 7. By maintaining the pH of an aquaponic system close to 7, a compromise between nitrification and nutrient availability can be reached [Rakocy et al. 2006].

Fish production

Several warm-water and cold-water fish species are adapted to recirculating aquaculture systems, including tilapia, trout, perch, arctic char, and bass [Diver 2006]. Most freshwater species that can tolerate crowding (including ornamental fish) will do well in aquaponic systems [Rakocy 2012]. However, tilapia is the fish species most commonly cultured in aquaponic systems. Tilapia tolerates fluctuating water conditions such as pH, temperature, oxygen, and dissolved solids [Diver 2006].

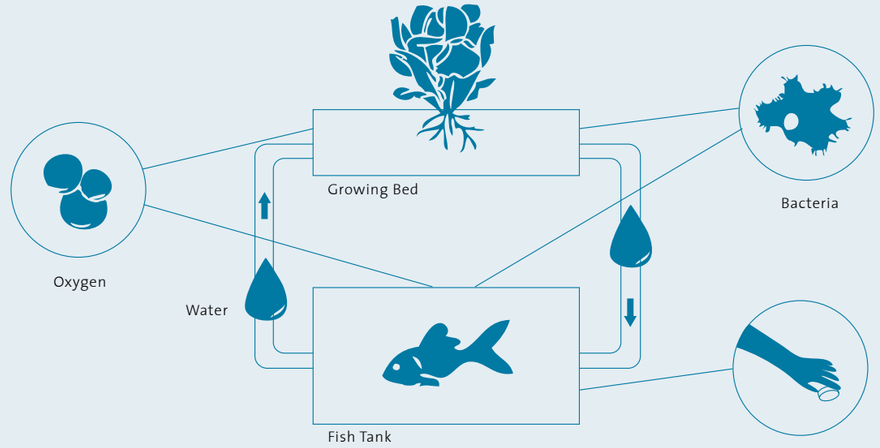


Figure 2: Schematic representation of an aquaponic system. Source: FAO. 2012

There are three basic methods of fish management [Rakocy 2012]:

1. Sequential rearing: Several age groups of fish are raised in the same rearing tank. When one group of fish reaches marketable size, it is harvested and an equal number of fingerlings are immediately restocked in the same tank. Problems with this system include stress for the remaining fish during the periodic harvests.
2. Stock splitting: Fingerlings are raised at very high densities and the fish population is periodically split in half as the carrying capacity of the rearing tank is reached. Unless a swim-way is installed between the tanks, the moves can be very stressful on the fish.
3. Multiple rearing: With multiple rearing units, the entire population is moved to larger tanks when the carrying capacity of the initial rearing tank is reached.

It is generally recommended to maintain the carrying capacity in aquaponic systems below 60 kg/m³ [Rakocy 2012].

Plant production

Most plant species can grow in an aquaponic system but only a few have been tested and proven to be economically viable [Jones 2002]. In general, culinary herbs will generate the highest level of income per unit area and per unit time [Rakocy 2012]. It must be considered that the fish feed ultimately determines the fertilizers given to the plants. Since commercial fish feed blends are not available with variable nitrogen-phosphorous-potassium ratios plants used in large-scale operations must have constant nutrient needs during their entire life cycle. Some suitable crops for aquaponic systems that require high nitrogen levels at all life stages are lettuces, mints, culinary herbs and medicinal herbs. Fruiting crops such as tomatoes and peppers are less suitable for aquaponic systems as they need high nitrogen levels at the beginning of their life cycle and low nitrogen and high phosphorous and potassium levels for good fruit development [Jones 2002]. Other factors that influence plant growth are the intensity and daily duration of light and the water temperature, which is far more important than air temperature for hydroponic plant production. The optimal water temperature for most crops is around 24°C [Rakocy et al. 2006].

Feeding rate ratio and component ratio

The feeding rate ratio is the amount of feed fed to the fish per day and square meter of growing bed. It should be used to determine the ratio between fish and plants. Generally, feeding rate ratios range from 60 to 100 g/(m²day) [Rakocy 1997].The ratio of the volume of fish tank water to the volume of hydroponic media is known as component ratio. Common tank:bed ratios range around 1:2 but ratios as high as 1:4 are sometimes employed. Factors such as fish species, fish density, feeding rate and plant species may change the value of the appropriate component ratio [Diver 2006]. Another key factor is the ratio of daily feed input to plant growing area. If this ratio is too high nutrient salts will accumulate and may reach phytotoxic levels. If, on the other hand, the ratio of daily feeding rate to plants is too low, nutrient supplementation will be necessary in order to prevent the plants from developing nutrient deficiencies. As a rule of thumb 60 to 100 g of fish feed per square meter of plant growing area per day should be used [Rakocy et al. 2006].

The roll out group was in charge of documenting the construction process in order to make it reproducible but also of internal communication. Karol here discusses the water collection system with Francis and the choices made by the ventilation group with Mel.

Objective

In the context of the ETH Sustainability Summer School 2012 at ETH Zürich, a team of 13 students from 12 different academic disciplines and 8 different countries spent two weeks in a case study designing and building a simple, low cost aquaponic system. The system had to be adapted to the situation in Amman, where the local NGO MEEZAN has already started to implement aquaponic rooftop farms. The founder of this NGO, Bashar Humeid, and a member of the ZHAW spin-off company UrbanFarmers, Mark Durno, supervised the project. The current system of the MEEZAN rooftop farm includes basically a greenhouse, a fish and a sump tank, a grow bed and an airlift pump. These elements were used as a basis for the new system.

The goals of the project were as follows:

- the costs of the entire system should not exceed 2000 CHF (based on costing at source in Jordan);
- the system's size should not exceed 20 m^2;
- the greenhouse structure should allow to collect and store rainwater and it should offer sufficient ventilation during the summer.

Given the relatively short timeframe of the project, the main greenhouse structure was ordered in advance. It had to be built up but no designing and no analysis concerning the materials best suited for such a greenhouse had to be performed. The biggest challenges thus were to design a system to harvest precipitation and to ventilate the greenhouse.

System Overview

The aquaponic farm built during the ETH Sustainability Summer School 2012 includes a greenhouse with a projected area of 18 m^2 (3m x 6m), four 1000 litres international bulk containers (IBC), one sump tank (plastic barrel), a wooden grow bed (1.22m x 4m) and an airlift pump. One IBC is used as a fish tank; three serve as water storage tanks. A plastic foil covers the greenhouse structure. As growing medium, expanded clay aggregate is used. The airlift pump has two purposes: First, it circulates the water through the system and second, it aerates the aquaponic system and thereby supplies the fish, bacteria and plants with oxygen. The water is pumped from the fish tank to the grow bed where it is distributed evenly through a series of pipes. The grow bed is inclined so that the water drains into the sump tank, which in turn recirculates the water back to the fish tank. The sump tank is incorporated in the fish tank.

For a detailed description of the building procedure, reference is made to the instruction manual that is being edited.

The project was based in "Frau Gerlods Garten", a recently opened outdoor bar and restaurant. Later, the greenhouse has been moved to its final destination SeedCity, a community garden at the ETH Science City Campus.

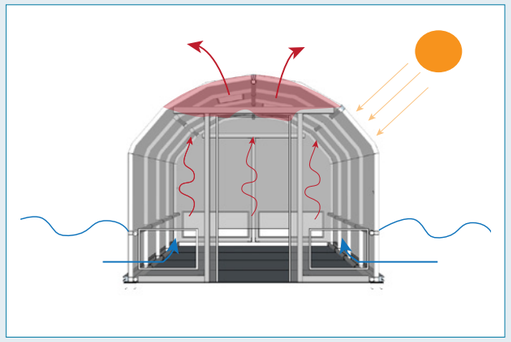


Figure 3: Summer. Ventilation.

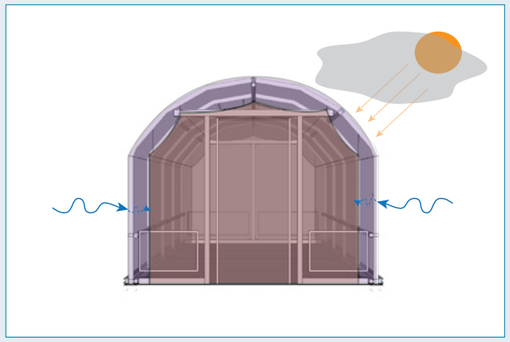


Figure 4: Winter. Extra Insulation Layer.

Ventilation

A ventilation system had to be designed in order to keep humidity and temperature in the greenhouse within an appropriate range. Different aspects influencing the climate inside the greenhouse were considered:

1. Ventilation: The greenhouse has ventilation holes at the top and in the back. When it gets too hot inside the greenhouse, the door and the ventilation holes can be opened to permit airflow (Figure 4). The ventilation holes are covered with mesh to prevent insects from entering the greenhouse.
2. Shading: Another critical component of summer cooling in the greenhouse is shading. A dark green mesh was cut to size and can now be attached with clips to the greenhouse plastic. Shading must occur on the outside of the greenhouse because otherwise hot air will be trapped between the shade cloth and the inner side of the greenhouse plastic.
3. Insulation: An idea to maintain a warm temperature within the greenhouse during the winter months was to attach an additional plastic layer to the inside of the greenhouse. Thereby, the volume of air in the greenhouse that requires heating would be reduced and warmed up air between the two layers of plastic would act as a buffer between the cold outside and the warm inside.
4. Another component that needs to be considered when thinking about the climate within the greenhouse is the water storage volume. The greater the amount of stored water, the larger the thermal mass and the smaller the temperature fluctuations within the greenhouse.

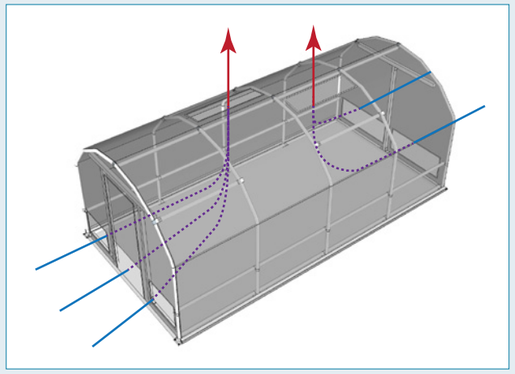


Figure 5: The Ventilation System.

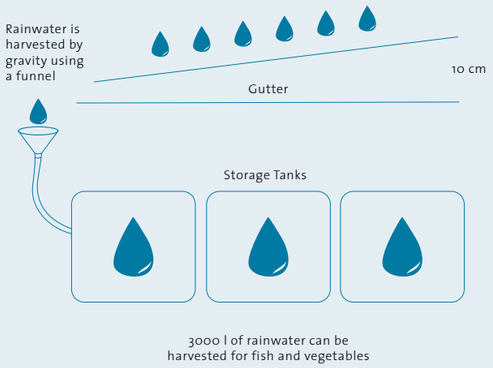


Figure 6: A Schematic representation of the rainwater harvesting system.

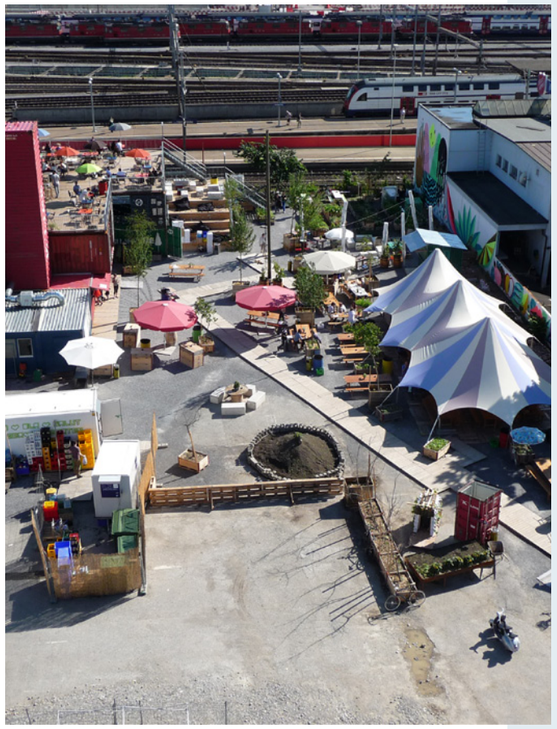
Water harvesting

Due to the severe water scarcity Jordan is – and will be – facing, one of the main goals of the project was to design a system to harvest rainwater. The solution which was found to this problem is illustrated in Figure 6 and includes several components:

1. Rainwater collection: The principal idea was to attach a gutter on each side of the greenhouse to collect the rainwater that falls on the greenhouse plastic. For this purpose, a separate piece of plastic foil was sewn onto the main plastic foil of the greenhouse to form a gutter. It was reinforced by long pieces of wood (water collection system). The gutter is inclined so the water flows to the back part of the greenhouse where it is caught in PET-bottles and channelled through pipes into the last IBC-tank inside the greenhouse.
2. Storage tank connection: The three water storage tanks were connected at the bottom of the tanks in order to prevent stagnation of water. The IBC-tanks were positioned in such a way that their outlet was at the bottom and could be used for interlinking the tanks by pipes.
3. Transporting the water from the storage tanks to the sump tank: The outlet of the third IBC tank can be used to remove storage water manually and put it into the sump tank. This will have to be done whenever water within the aquaponic system is lost through evapotranspiration and needs to be replaced. If no or not enough storage water is available, an external water source has to be available to top up the water level.

Different scales of precision were important on site. While for the construction group, cm's was good enough, Elena and BinBin – in charge of the actual sewing – needed to address mm's. Another example for reusing standard products is the use of the PET bottle as a connector between the roof and the pipe for rain water collection.

Our building site seen from the FREITAG tower. A new kind of public space for Zurich – Frau Gerholds Garten. It opened its doors a few days before the construction of the greenhouse began. A colorful place where occasionally also students and film crews meet.



Discussion

Water and land resources within the city of Amman are limited. However, aquaponic systems require little water and allow for high-density crop production and may therefore provide fresh and local food even under such difficult circumstances. The system that was built during the ETH Summer School 2012 has two main advantages compared to conventional greenhouses:

The constructed greenhouse is able to collect and store rainwater (the storage capacity of the three IPC tanks is < 3000 litres). The aquaponic system is therefore less dependent on external water sources. If a mean annual rainfall amount of 250 mm (see page 5) and a rainfall collection area of 18 m^2 are assumed, 4.5 m^3 (4500 litres) of water could be collected per year. This calculation represents a rough estimate. It does not account for any water losses e.g. due to splattering nor does it consider that the actual collection area is a little bit smaller than 18 m^2 (as the gutter was built at a height where the greenhouse structure is already curved). Furthermore, an average rainfall intensity was assumed for the calculation which could easily exceed the actual amount of precipitation for a given year by a factor of two. Nevertheless, the rainwater harvesting system definitely makes the aquaponics more resilient to water scarce conditions. If the stored water volume exceeds the water requirements of the greenhouse, some of the rainwater can be used for domestic purposes.

The greenhouse can be ventilated and shaded with simple mechanisms, which helps to keep the system affordable.

As the aquaponic system built during the ETH Summer School has not yet been in operation, a rough estimation of the expected fish and vegetable production yield is presented at this point: As mentioned, feeding rate ratios ranging from 60 to 100 g/(m^2day) are common. Not all the fish feed is converted into fish biomass. In the case of Nile tilapia, 1.7 kg of fish feed is needed for every kilogram of fish biomass growth (feed conversion ratio = 1.7). In the case of red tilapia, the feed conversion ratio is 1.8 [Rakocy et al. 2004]. With a grow bed of 4 m by 1.2 m and assuming a mean weight of 50 g for the fingerlings and 600 g for the harvested fish, the number of fish reared per year can be determined as follows:

$$\frac{0.08\ kg_{ff}}{m^2_{gb}\ x\ d} \cdot \frac{365\ d}{a}\ 4.8\ m^2_{gb}\ \frac{0.6\ kg_{bm}}{1.75\ kg_{ff}} \cdot \frac{1\ fish}{(0.6\text{-}0.05)\ kg_{bm}}$$

= 87 kg fish/a

ff: fish feed
gb: growing bed
bm: biomass

Outputs	Price	Scenario 1	Scenario 2	Scenario 3
Tilapia	5.20 CHF/kg	87 kg/a	87 kg/a	87 kg/a
Tomato	0.46 CHF/kg	192 kg/a	96 kg/a	96 kg/a
Parsley	3.25 CHF/kg	0 kg/a	43.2 kg/a	43.2 kg/a
Heating	56.30 CHF/month	none	none	5 months/a
Payback Period		**3.7 years**	**2.7 years**	**2.2 years**

Table 1: Price and yield for different outputs of an aquaponic system and payback time for three scenarios.

With an average weight of 600 g per fish this gives 145 fishes per year. Using the average global per capita fish consumption of 17 kg per year [OECD 2012], the aquaponic system is able to produce enough fish for 5 people.

Similar calculations can be done for the vegetable production. In the case of lettuce, roughly 29 plants can be grown per square meter and a growing period of three weeks can be assumed [Rakocy 2012]. In our system with 4.8 m^2 this gives approximately 2400 lettuce plants that can be harvested per year. A study performed in Alberta reported yields of around 50 kg per square meter and year for Swiss chard, 40 kg/(m^2a) for tomatoes and 18 kg/(m^2a) for spinach and parsley [Savidov 2004].

The ultimate vision of the Jordanian NGO MEEZAN is to have an aquaponic system on all the rooftops in Amman. A very rough calculation can provide an idea of the role aquaponics could play under such circumstances in supplying food for Amman: For that purpose, the following assumptions are made

- Number of houses in Amman: 323'400 [Johansson and Ouahrani 2009]
- Population of Amman: 2.17 million [Potter et al. 2009]
- Fish consumption per person and year (global average): 17 kg
- Tomato consumption per person and year (average in Amman): 50.3 kg [Dababneh et al. 2011]
- Grow bed size: 4.8 m^2
- Number of aquaponic systems: each house, i.e. 323'400
- Cultivated crop: tomato only
- Tomato yield in aquaponic system: 40 kg/(m^2a) [Savidov 2004]

In this imaginary situation, an average number of 6.7 people would live in one house and share an aquaponic rooftop farm. Under the given assumptions, 76% of the fish and 57% of the tomatoes consumed in Amman could be harvested from rooftop aquaponics. Of course, also other crops than tomatoes are consumed and could be grown. This simple calculation should just give a picture of the impact aquaponics could have on the food security of Amman.

In order to determine the payback period of the aquaponic system, Bashar Humeid, the founder of the Jordan NGO MEEZAN, was asked to estimate the current prices for tilapia, tomatoes and parsley in Amman (see Table 1) [Humeid 2013]. To convert his price indications from Jordanian dinars and Euros to Swiss Francs, rates of exchange of 1.25 CHF/€ and 1.3 CHF/JOD were used. Assuming the before mentioned yields of 40 kg/(m^2a) for tomatoes and 18 kg/(m^2a) for parsley [Savidov 2004] and a total cost of the system of 2000 CHF, the payback period is 3.7 years for a system producing tomatoes only (scenario 1) and 2.7 years for a system where exclusively parsley is cultivated (scenario 2). The aquaponic farms built by MEEZAN use excess heat in the greenhouse during the winter season in order to heat the house. In near future, electricity prices will rise in Amman (as subsidies will be withdrawn), so that 56 CHF/month can be saved by using the greenhouse for heating purposes [Humeid 2013]. Cultivating 50% tomatoes and 50% parsley and using the greenhouse to heat the house during wintertime gives a payback period of 2.2 years (scenario 3, Table 1).

The Middle East belongs to the regions with the highest levels of urbanization in the developing world [Smit et al. 2001]. Therefore, urban agriculture could play a very powerful role in the food production of these countries. As demonstrated with a simple calculation, aquaponics have the potential to become a relevant source of food in cities like Amman. A major advantage of the aquaponic system presented in this report is its ability to collect and store rainwater. Even if rain provides no constant source of water, it's use reduces the pressur on water bodies, which are used for irrigation purposes in conventional agriculture. In Jordan, climate change is expected to change precipitation patterns in such a way that surface water availability decreases and water scarcity increases [WHO 2012]. This makes an efficient agricultural water use, which can be provided by an aquaponic system, even more important. Therefore, aquaponic systems can be seen as part of the solution to the problem of limited food self-sufficiency in urban areas such as Amman, where space and water resources are scarce.

References

AARDO 2007: Jordan Accession to WTO: Impact on Agricultural Sector, Research Study, New Delhi, Afro-Asian Rural Development Organization

Al-Hafedh Y, Alam A; Beltagi M S (2008): Food Production and Water Conservation in a Recirculating Aquaponic System in Saudi Arabia at Different Ratios of Fish Feed to Plants, Journal of the World Aquaculture Society, Vol. 39, No. 4, 510-520

Alnimer O (2012): Freedom Machine Video.

Aquaponic Source (2010): Interview with Dr James Rakocy, Father of Aquaponics: Part 1, The Aquaponic Gardening Blog, http://theaquaponicsource.com/2010/09/07/interview-with-dr-james-rakocy-father-of-aquaponics-part-1, 20.09.2012

Bailey D S, Rakocy J E., Cole W M, Shultz K A (1997): Economic Analysis of a Commercial-Scale Aquaponic System for the Production of Tilapia and Lettuce, University of the Virgin Islands

Baudoin W and Drescher A (2008): Urban Agriculture for Sustainable Poverty Alleviation and Food Security, Rome, Food and Agriculture Organization of the United Nations, available at http://www.fao.org/fileadmin/templates/FCIT/PDF/UPA_-WBpaper-Final_October_2008.pdf

CIHEAM (2011): Urban Agriculture in the Mediterranean, Watch Letter No. 18, International Centre for Advanced Mediterranean Agronomic Studies

Dababneh B F, El-Quadah J M, Al-Bakheit A A (2011): Nutritional Status and Obesity among Adults of Amman and Al-Balq'a Governorates, American Journal of Agricultural and Biological Sciences 6 (3): 339-347

Diver S (2006): Aquaponics – Integration of Hydroponics with Aquaculture, National Sustainable Agriculture Information Service (2006), available at http://www.aces.edu/dept/fisheries/education/documents/aquaponics_Integrationofhydroponicswaquaculture.pdf

Ezilon (2009): Jordan Map – Physical Map of Jordan, www.ezilon.com, 27.12.2012

DoS (2010): Jordan Population and Family Health Survey 2009, Amman, Department of Statistics, available at http://www.dos.gov.jo/dos_home_e/main/linked-pdf/pop_2009.pdf

FAO (2001): Urban and Peri-Urban Agriculture, A briefing guide for the successful implementation of Urban and peri-urban Agriculture in Developing Countries and Countries of Transition, 1. Edition, Rome, Food and Agriculture Organization of the United Nations, available at http://www.fao.org/FCIT/docs/briefing_guide.pdf

FAO (2005): Farming in urban areas can boost food security, Rome, Food and Agriculture Organization of the United Nations, available at http://www.fao.org/newsroom/en/news/2005/102877/index.html,

FAO (2012): Urban agriculture in the Gaza Strip through vertical gardens and aquaponics, factsheet, Food and Agriculture Organization of the United Nations, available at http://www.fao.org/fileadmin/templates/FCIT/PDF/Fact_sheet_on_aquaponics_Final.pdf

Goodman E R (2011): Aquaponics: Community and Economic Development, Master Thesis, Massachusetts Institute of Technology

Gooley G J and Gavine F M (2003): Integrated Agri-Aquaculture Systems, A Resource Handbook for Australian Industry Development, RIRDC Publication No. 03/012

Gittlerman M (2009): The Role of Urban Agriculture in Environmental and Social Sustainability: Case Study of Boston, Tufts University

Hillyer C D (2007): Is aquaponics the agriculture of the future?, Inform, Vol 18, Numb 2, 83-83

Humeid B (2013): Personal communication, 26.01.2013

Johansson E and Ouahrani D (2009): Climate Conscious Architecture and Urban Design in Jordan. Towards energy efficient buildings and improved urban microclimate, Housing Development & Management and the Royal Scientific Society

Jones S (2002): Evolution of Aquaponics, Aquaponics Jornal, Volume VI, No. 1

Al Jundi R (2008): Multi stakeholder Policy Formulation and Action Planning for Urban Agriculture, Gender Analysis and Marketing: The Case of Amman, Jordan, American University of Beirut

Al Mahamid J (2005): Integration of Water Resources of the Upper Aquifer in Amman-Zarqa Basin Based on Mathematical Modeling and GIS, Jordan, Freiberg Online Geology (2005)

OECD (2012): Fish – OECD-FAO Agricultural Outlook 2011-2020, http://www.oecd.org/site/oecd-faoagriculturaloutlook/fish-oecd-faoagriculturaloutlook2011-2020.htm, 7.10.2012

Pauli G (2012): Next Generation of Urban Agriculture, Blue Economy, Case 97

Potter R B, Darmame K, Barham N, Nortcliff S (2009): "Ever-growing Amman", Jordan: Urban expansion, social polarisation and conemporary urban planning issues, Habitat International 33, 81-92

Rakocy J E (1997): Ten Guidelines for Aquaponic Systems, Aquaponics Journal, issue no. 46, 14-17

Rakocy J E, Bailey D S, Shultz R C, Thoman E S (2004): Update on tilapia and vegetable production in the UVI aquaponic system, University of the Virgin Islands, available at http://ag.arizona.edu/azaqua/ista/ista6/ista6web/pdf/676.pdf

Rakocy J E, Masser M P, Losordo T M (2006): Recirculating Aquaculture Tank Production Systems: Aquaponics – Integrating Fish and Plant Culture, Southern Regional Aquaculture Center, Publication No. 454

Rakocy J E (2012): Aquaponics – Integrating Fish and Plant Culture, in: Tidwell J (Ed.): Aquaculture Production Systems, John Wiley & Sons, Inc.

Savidov N (2004): Evaluation and Development of Aquaponics Production and Product Market Capabilities in Alberta, Ids Initiatives Fund Final Report, available at http://www.dfo-mpo.gc.ca/science/enviro/aquaculture/acrdp-pcrda/projects/reports-rapports/ca/CA-04-01-001.pdf

Savidov N (2005): Evaluation of Aquaponic Technology in Alberta, Canada, Aquaponic Journal, issue no. 37

Smit J and Nasr J (1992): Urban agriculture for sustainable cities: using wastes and idle land and water bodies as recources, Environment and Urbanization, Vol 4, No. 2

Smit J, Ratta A, Bernstein J (1996): Urban Agriculture, an Opportunity for Environmentally Sustainable Development in Sub-Saharan Africa, Building Blocks for Africa 2025, Paper No. 11, World Bank

Smit J, Nasr J, Ratta A (2001): Urban Agriculture Yesterday and Today, Chapter 2 in: Urban Agriculture. Food, Jobs and Sustainable Cities, Urban Agriculture Network

Smit J (2002): Community-Based Urban Agriculture as History And Future, City Farmer, Canada's Office of Urban Agriculture, available at http://www.cityfarmer.org/comutybased.html

Trondalen M (2009): Climate Changes, Water Security and Possible Remedies for the Middle East, United Nations World Water Assessment Programme, Paris

UNDP (2010): Food and Nutrition Security in Jordan towards Poverty Alleviation, Project document, United Nations Development Programme, available at http://www.undp-jordan.org/uploads/projects/pd_1293615331.pdf

UNDP (2012): Food Security in Jordan, United Nations Development Programme, http://www.undp-jordan.org/index.php?page_type=projects&project_id=58&cat=1, 23.09.2012

UNFCCC 2010: National Environmental and Economic Development Study for Climate Change, Jordan National Report, United Nation Framework Convention on Climate Change, available at http://unfccc.int/files/adaptation/application/pdf/jordanneeds.pdf

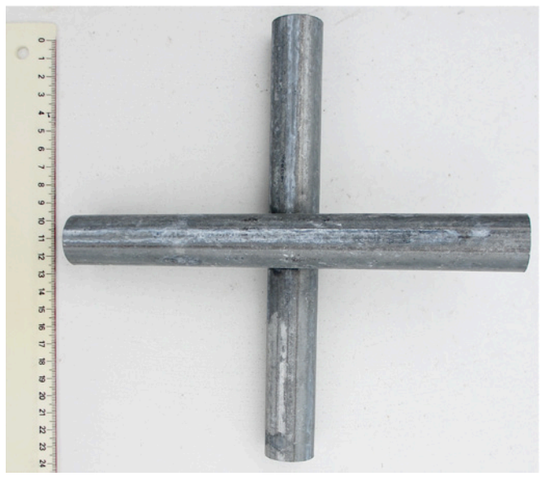
Van Veenhuizen R (2006): Cities Farming for the Future. Agriculture for Green and Productive Cities, International Institute of Rural Reconstruction and ETC Urban Agriculture

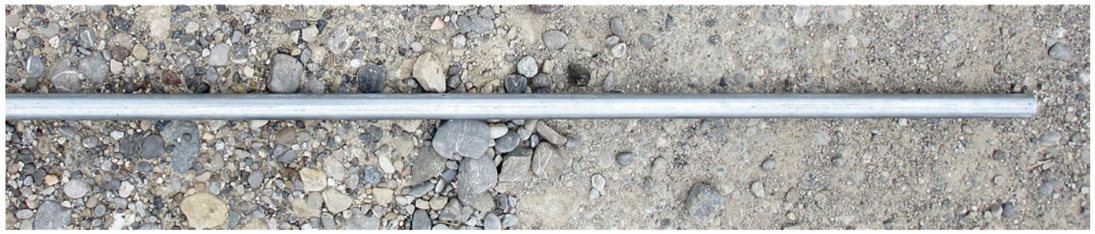
WHO (2012): Climate Change Adaptation to Protect Human Health, Jordan project profile, World Health Organization, http://www.who.int/globalchange/projects/adaptation/en/index5.html, 17.09.2012

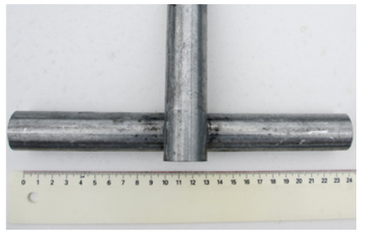
Wilson J P and Bruins H J (2005): Food Security in the Middle East since 1961, in: Hamdy A, Monti R. (Ed.): Food Security under Water Scarcity in the Middle East: Problems and Solutions, Options méditerranéennes, Series A: Mediterranean Seminars, Number 65, Centre International de Hautes Etudes Agronomiques Méditerranéennes

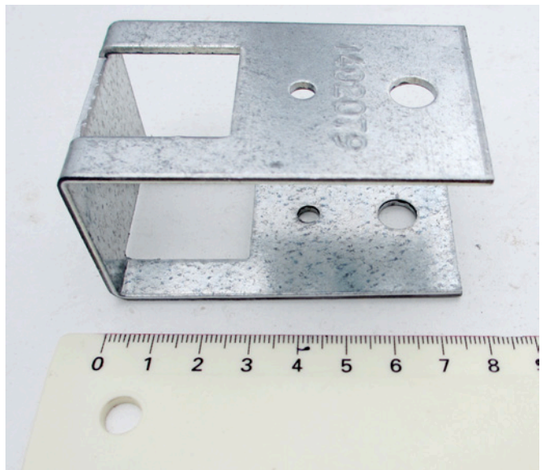
And we made it, in just 9 working days, us 13 students and 3 coordinators finished building a functioning aquaponics green house, including locally grown salad seedlings, proudly displayed by Kate.

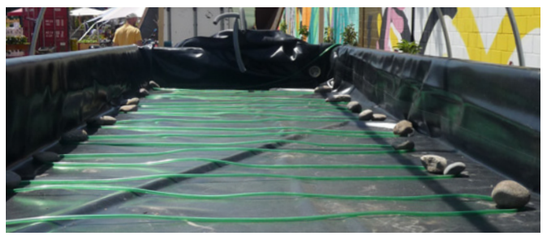
From the many bits and pieces that hold this project together, here a few of the most fotogenic ones. If you want to build one yourself, all are widely available in hardware, gardening, sewing or aquarium stores.











Imprint

Publisher
ETH Sustainability
Lead
Catherine Lippuner
Scientific Report
Lea Eymann
Illustrations
Karol Yanez, Francis Liesting
Design and layout
Lex Schaul
Photos
Francis Liesting, Kate Hofman

March 2013

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