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ROOF WATER-FARM. Participatory and Multifunctional Infrastructures for Urban Neighborhoods

Angela Million, Grit Bürgow, Anja Steglich, Wolf Raber

Abstract

Cities and towns all over the world are influenced considerably by infrastructural changes. Decentralized and multifunctional infrastructure systems will be shaping future neighborhoods. Within the debate and practice of infrastructural transformation, the ROOF WATER-FARM research project has a resource cycle approach connecting water infrastructure with food production following the urban development Leitbild of a LoopCity. The paper presents first findings of the ROOF WATER-FARM – funded by the German Federal Ministry of Education and Research (2013-2016) through the national support initiative "Intelligent and multifunctional infrastructure systems for a future urban water management (INIS)." A ROOF WATER-FARM combines water and farming technology, architectural and urban design, and neighborhood development with public participation and education.

Key Words: multifunctional infrastructure, food production, water management, roof farm, LoopCity, neighborhood development, participatory urban design

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Introduction

Existing water infrastructures of supply and disposal in many European cities are at stake. The challenge of maintaining and retrofitting them (Libbe and Beckmann 2010) is accompanied by a number of research initiatives to explore, in theory and built practice, the structural transformations of linear centralized infrastructures towards decentralized approaches, integrated urban water management and design (e.g. DIFU 2013, BMBF 2012, Hoyer et al. 2011, AECOM 2013). A common aim is to promote the efficient usage of water resources to meet the challenges of demographic developments and climate change in order to enhance water security both in supply and disposal. Interdisciplinary and transdisciplinary research is needed to meet the challenge (BMBF 2012:6). This is especially necessary when other challenges are taken into account, such as the linkage of water and food supply (BMBF 2012:11). As water and soil are limited but needed for food production, the development of innovative concepts and technologies is especially searched for in the urban context. The result would be multifunctional infrastructure that links urban water management and food production.

What sounds like a major innovation and an abundance of technology has been practices of combined water and food production in the global South (e.g. millenary traditions of integrated aquaculture farming in Asia and South America). The question is whether this approach can be successfully adapted to European metropolises, their urban development and design, and urban lifestyles. This is explored by the interdisciplinary research project ROOF WATER-FARM,[1] funded from 2013 to 2016 by the Federal Ministry for Education and Research (BMBF) within the program "Intelligent and multifunctional infrastructure systems for a future urban water management (INIS)."[2]

ROOF WATER-FARM[3] researches the production of fresh food in urban settings via hydroponics (water-based plant cultivation) and aquaponics (combined fish and plant culture), while being linked to water treatment technologies for greywater and blackwater, as well as rainwater management. It is an onsite approach combining urban water management with urban farming. The building-integrated combination of water treatment with the production of fish and plants is a spatial- and resource-efficient urban design strategy which uses the spatial potential of buildings' roofs within the city context. A central aspect of the research is also to explore tools and methods to incorporate citizen participation and education to foster a sustainable implementation of the ROOF WATER-FARM.

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[1] ROOF WATER-FARM partners:

- TU Berlin – Department for Urban Design and Urban Development at the Institute of Urban and Regional Planning (ISR); ZEWK kubus – Cooperation Center for environmental issues,
- Fraunhofer Institute UMSICHT
- Nolde & Partner
- Terra Urbana Umlandentwicklungsgesellschaft mbh, inter 3 – Institute for Resource Management GmbH
- Senate Administration for Urban Development and Protection of the Environment, Berlin.

[2] www.bmbf.navam-inis.de

[3] www.roofwaterfarm.com/en/

Research frameworks: From sustainable cities to LoopCities

"Sustainability" and "sustainable development" have been important issues of European urban development for several years. The "German Sustainability Strategy" is of essential importance at a national level. Herein, the central fields of action, targets and 21 key indicators for sustainable development are being formulated. The extent of the actual implementation of sustainable development in its various facets, however, depends, to a large extent, on the actors in politics, government, business, and civil society involved. The cities and, more generally, the urban living environments and spaces are where sustainable action actually manifests itself. Sustainability has increasingly been seen as an overarching mission statement for a steadily growing number of German communities. In relation to this political aim, a national research agenda has been formulated called "Research for Sustainable Development" (FONA). One focus looks at sustainable water management in relation to energy, food, health, and the environment (BMBF 2012). An explicit research program explores the future development of urban water management systems via multifunctional infrastructure (INIS) (DIFU 2013).

Sustainable strategies and research grant programs are based on different guiding principles (German: Leitbilder) for European city development. Many German municipalities have formulated concepts of sustainability or city development strategies with a focus on sustainable development. With these concepts, they have established strategic aims, visions or action programs, explicitly naming them "Sustainability Reports," containing a quantitative and indicator-based monitoring and evaluation of measures on communal levels. Based on the analysis of German municipal sustainability concepts, 14 Leitbilder[4] for sustainable urban development were identified (Grabow and Uttke 2010). One of them is the concept of LoopCities (German: Kreislaufstadt). It focuses especially on resource cycles within the city.

LoopCity is about sustainable urban development and design that increases healthy synergies and interacts feedback cycles within the urban context for essential resources, such as energy, waste, biodiversity, water, food, soil and space, and also knowledge. The aim is to use resources more efficiently and to minimize environmental overreliance (Verbücheln et al. 2013). It is based on a model that wants to organize and develop cities as ecosystems (e.g. Barton et al. 2010, Lyle 1994, Todd and Tod 1993).

The research approach of the ROOF WATER-FARM follows this Leitbild (Fig. 1). It explores the impact of interacting feedback cycles – with a focus on water management and food production – on infrastructures, architecture and urban form, public space, land use and density of the urban fabric, as well as city life. It follows the need to explore (also by informed design) subjects such as mixed use/multiple usage, low tech and high tech solutions, and public participation and education. The interacting resource cycles – thus the hypothesis of the project – lead to architectural and urban designs that rely more on the energetic and water synergies and user engagement than before. Multifunctional infrastructures will have a spatial impact as well as an impact on people's everyday life while using water. It could also alter people's views on how and where food could be produced in inner city contexts.

[4] e.g. Ecological City : Klimagerechte Stadt, Sustainable Mobile City : Nachhaltig mobile Stadt, Compact City : Kompakte Stadt, Cooperative City : Kooperative Stadt, Economic Sustainable City : Nachhaltige Wirtschaft in der Stadt, Social and Integrative City : Soziale und integrative Stadt, Regenerative City : Regenerative Stadt, and LoopCity : Kreislaufstadt.

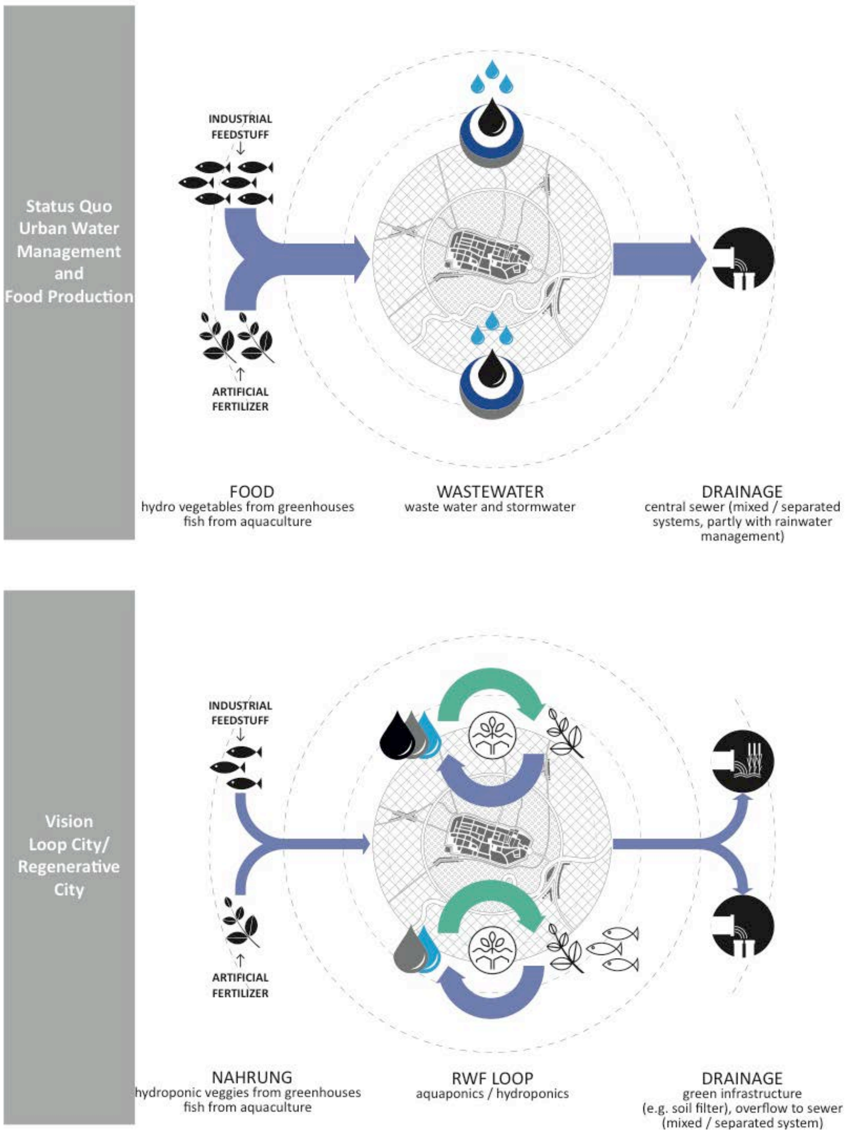

Fig. 1: Research framework of ROOF WATER-FARM: Status Quo versus Leitbild of LoopCity (German: Kreislaufstadt)
Graphics: Felix Bentlin, TUB-ISR, © ROOF WATER-FARM.

Technology development

Benefits of water-farming and blue-green infrastructure technology

Postindustrial cities, such as Berlin, reflect on the contemporary Zeitgeist of local water, food and daily resource provision. Urban farming[5] or urban water initiatives[6] request and develop integrated and decentralized infrastructure designs for basic needs, which necessarily include wellbeing or educational functions and comprise flexible low- and high-tech technologies. Aquacultural farming typologies, such as swimming gardens, fish ponds or types of water-farm greenhouses, thereby become recognized as promising building-blocks and catalysts of water-sensitive cities integrating regenerative design/loop principles (Bürgow 2013). As traditional

[5] e.g. http://prinzessinnengarten.net; http://contemporaryfoodlab.com; http://www.zfarm.de
[6] e.g. http://www.flussbad-berlin.de; http://berliner-wassertisch.net

integrated farm systems[7] (e.g. known from ancient Asian rice-paddy fish-farming or the swimming gardens of the Aztecs in Mexico called *Chinampas*), aquacultural typologies are newly valued as specific *blue-green infrastructures* within contemporary cities (Ibid.). Their multifunctional design due to combined water management and food production can support the transformation process towards the LoopCity.

The benefits of similar *water-farm technologies* facing sustainable aquaculture have been broadly investigated, particularly within the transdisciplinary research field of *Ecological Engineering* (e.g. Steinfeld and Del Porto 2007, Bohemen 2005, Jana 2003, Guterstam and Etnier 1996, Etnier and Guterstam 1991,Todd 1991, Guterstam and Todd 1990).

The combination of fish production, for example, linked to other agricultural livestock and crop production makes aquacultural farming more space-, energy- and resource-efficient due to promising to integrate into urban space (Bürgow 2013). This type of farming reaches a higher productivity compared to contemporary practices of space-extensive organic farming due to using fish manure for fertilization or nutrient-rich water from fish production for irrigation and fertilization (e.g. Hinge and Stewart 1991).

Younger roof-top water-farm concepts[8] are associated with pioneering experiments in ecologically engineered aquaculture greenhouses in North-America in the late-1960s/early-1970s, connecting to keywords such as *Bioshelters, Living Machines* or *Solar Aquatic Systems* (Bohemen 2005b, Steinfeld and Del Porto 2004, Guterson 1993; Todd and Todd 1993, Todd 1991, Todd and Todd 1984). Initial experimental research focused on the design and performance of aquatic ecosystem technologies for solar-based wastewater management within a tropical greenhouse mesocosm under colder climate conditions. The first European pilot water-farm greenhouse – *The Stensund Wastewater Aquaculture* – combining decentralized wastewater management with aquaculture and hydroponic production modules was realized at a Folk College campus in Stensund, the Trosa archipelago community south of Stockholm, Sweden (Guterstam 1996, Guterstam 1991, Chan and Guterstam 1995). The novelty and uniqueness was the integration of the new water-farm infrastructure into a real-life community context and connecting it to the educational program of the school (Bürgow 2013). Based on the case experiences applied, basic scientific research on aquaponic greenhouses showed the quantitative potential regarding nutrient recycling, and space and energy efficiency (e.g. Graber and Junge-Berberovič 2009, Graber and Junge-Berberovič 2008, Staudenmann and Junge-Berberovič 2003, Junge-Berberovič et al. 1999, Rennert 1992), as well as market potential (e.g. Staudenmann and Junge-Berberovič 2003, Junge-Berberovič 2001). Some striking benefits of water-farm technology facing urban needs of sustainable transformation are summarized here (Bürgow 2013):

- Three-dimensional use of (water) space enables higher productivity per square meter.
- About 1 kg of feedstuff is required to produce 1 kg of high-quality fish (e.g. trout), whereas it requires 3 kg of feedstuff for 1 kg of poultry and 10 kg for 1 kg of beef or pork.
- A rule of thumb is that wastewater from 1 kg fish can fertilize 5 kg of vegetables.
- Saving of manure.
- Twofold utilization of water.

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[7] Traditional integrated farm systems have been explored within contemporary Western community and global urban contexts (e.g. Guterstam 1991; Hinge and Stewart 1991, Bocek 1996; Stewart et al. 1991; Jana 2003; Bohemen 2005a, Costa-Pierce 2005).

[8] e.g. http://nysunworks.org/thesciencebarge; http://brightfarms.com; http://lufa.com; http://urbanfarmers.com (20.08.2014).

- No discharge of wastewater and, consequently, no land-based nutrient losses if the remaining fish manure is also recycled, e.g. via combined constructed wetland or productive soil systems.
- Arable land is used effectively. Greenhouse hydroponic systems can reduce agricultural land and water use by a factor of five to ten.
- Hydroponics produces eight to ten times more vegetable foodstuffs in the same area and time.
- Compared to soil-based plant production, hydroponic systems are suitable light-weight roof-top applications.

In order to meet contemporary needs of decentralized and flexible integration of water and food technologies into existing urban spaces, ROOF WATER-FARM applies the benefits mentioned and goes a step further. It links established technologies of building-integrated water management and water-reuse with aquaponic or hydroponic production of food on urban rooftops.

3.2 Roof Water-Farm modules and process-technological variants

ROOF WATER-FARM, through its modular *blue-green design*, strives for mutual life-support in the sense of a "co-housing and co-working of man, fish and plants."[9]
The aim of applied research is to test the combination of new modular technologies for the safe treatment of building-related water flows (greywater, rainwater, blackwater) and its reuse for water-based food production via aquaponics or hydroponics. In respect of this, the research partners developed flexible modules of blue-green infrastructure for integrated water and farm management. The development of individual and combined water treatment components enables site- and user-specific applications and shows possibilities of spatial transferability to different building types as well as to different neighborhoods.

At the technological level, ROOF WATER-FARM searches for alternatives to using drinking water and artificial fertilizer by meeting the high transport and energy expenditures of urban food production and supply with the development of local loop technologies. In brief, one can say that ROOF WATER-FARM combines water treatment (blue) with farm production (green).

Regarding *the blue*, two main water sources from the building are in focus for local irrigation:

- Greywater (from showers, sinks, kitchen, washing machines) and/or
- Rainwater (from roof-tops).

Additionally:

- Blackwater (from toilets)

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[9] e.g. Studio assignment, Master class of Urban Design and City and Regional Planning, Winter Semester 2013/2014, TU Berlin: *Participatory Blue-Green Infrastructure*, lead by Million (née Uttke), Steglich, Bürgow – http://urbandesign.staedtebau.tu-berlin.de/lehre/ma-srp-ud, http://www.roofwaterfarm.com/en/news/ (18.08.2014)

is used as a basis of liquid fertilizer production for local fertilization of plants with necessary nutrients and minerals, mainly nitrogen, phosphorous, potassium (NPK), which should meet the standards of a commercial fertilizer.

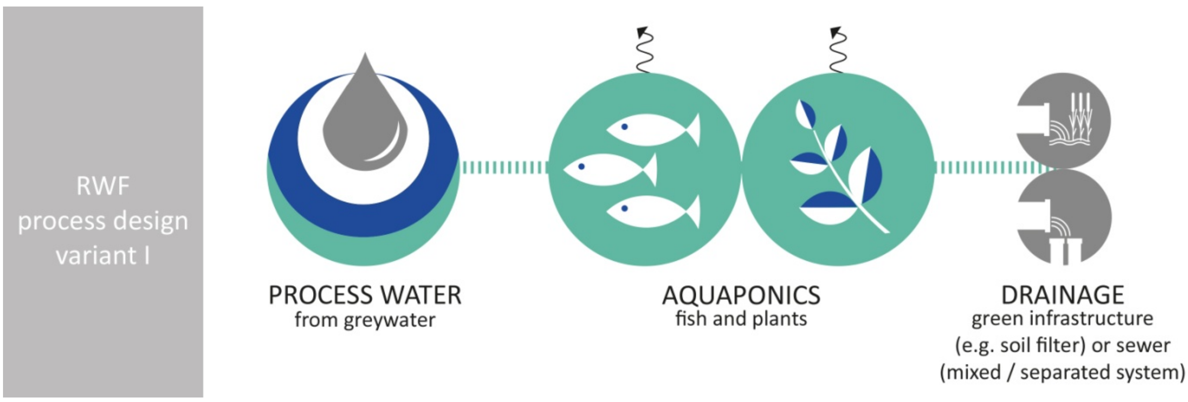
The quality aim for irrigation water is to meet EU bathing water standards via applying the latest modular technologies, such as MBBR (Moving Bed Bio Reactor) for greywater or standard mechanical pre-treatment (filter systems) for rainwater. A new membrane technology is tested for the unique approach of liquid fertilizer production out of blackwater. Accordingly, ROOF WATER-FARM has contributed a technological module regarding the shortage of phosphorous, which has been recognized as a much scarcer resource compared to fossil oil (e.g. Gerling and Wellmer 2005), and is mined, to a great extent, through socially and ecologically questionable methods, such as in Africa (e.g. Schuh 2009).

Regarding *the green*, the ROOF WATER-FARM concept investigates two main water-farming types:

- Aquaponics (fish and plants) and
- Hydroponics (plants).

Depending on the structural preconditions of the building and the users' needs, those water-farm types are lightweight compared to soil-based farming systems and, therefore, more suitable to apply to the surfaces of buildings (roofs, facades).

When combining *the blue* and *the green*, ROOF WATER-FARM investigates four ROOF WATER-FARM variants. It explores two optional water sources for irrigation combined with the two water-farming types along with the appropriate process technology. This makes four ROOF WATER-FARM (RWF) variants (RWF) in total (Fig.2). These variants can be adapted according to the specific building typologies and their water production (e.g. pattern of daily water use: Is there greywater production or not?) as well as the needs of the users (e.g. which products are liked?) (4.3.).



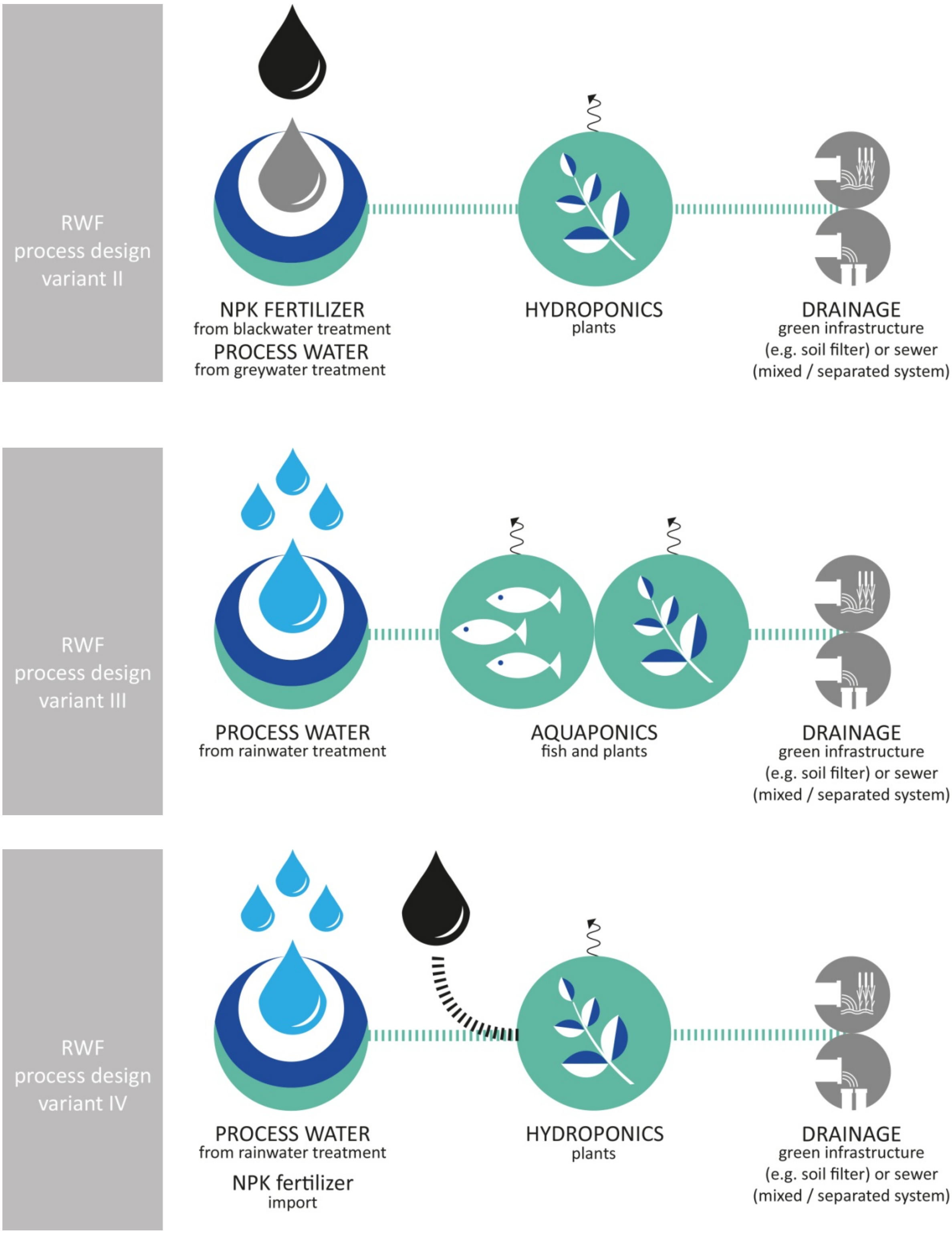


Fig. 2: RWF-variants combining building-integrated water-reuse and water-farming investigated in ROOF WATER-FARM
Graphics: Felix Bentlin, TUB-ISR, © ROOF WATER-FARM.

ROOF WATER-FARM variants focusing on AQUAPONICS (fish and plants)

- RWF variant I: reuse of greywater via treatment and transformation into process water (EU bathing water quality) for the cultivation of fish and building-related reuse (toilet flushing); the plants are fertilized via the nutrient-rich water from fish production
- RWF variant III: usage of rainwater from the roofs for fish production; the plants are fertilized via the nutrient-rich water from fish production

ROOF WATER-FARMING variants focusing on HYDROPONICS (plants)

- RWF variant II: reuse of greywater via treatment and transformation into process water (EU bathing water quality) for the cultivation of plants and building-related reuse (toilet flushing), safe usage of domestic blackwater and transformation into a liquid fertilizer; the fertilization of plants is adjusted via the crop-specific mix of the fertilizer with the process water
- RWF variant IV: usage of rainwater from roofs for the cultivation of plants, safe usage of domestic blackwater and transformation into a liquid fertilizer; the fertilization of plants is adjusted via the crop-specific mix of the fertilizer with the process water.

Roof Water-Farm testing site

The first ROOF WATER-FARM pilot plant was realized in Berlin-Kreuzberg and docked on to the existing decentralized water management infrastructure of Block 6 in the spring of 2014 (Fig. 3). The integrated water concept at Block 6 in Berlin-Kreuzberg was originally developed as a project of the International Building Exhibition 1987, further researched as a model project of the Experimental Housing and Urban Development Program financed by Federal and State funds until 1993, and finally, optimized and redesigned in 2006/07. Since the project's start, domestic wastewater produced by the tenants of Block 6 has been separated into the two flows: greywater and blackwater. The comparatively low-nutrient grey water from bathtubs, showers, washbasins, washing machines, and kitchens is separated via a second water supply pipe. Since 2006/07, the grey water of ~ 250 tenants has been treated mechanical-biologically towards EU bathing water quality in a separate water-processing house and reused to flush toilets and irrigate tenants' gardens. Rainwater from 2,350 m^2 of roof surface area and 650 m^2 of sealed (paved or build-up) open space is discharged into the former constructed wetland. The microclimate improves via the evaporation by the plants. After heavy rain events, excess water can infiltrate time-delayed via an adjacent trough.

The project ROOF WATER-FARM extends the existing water reuse concept and uses the treated greywater (bathing water quality) for the production of fish and plants in the new greenhouse. Another innovative feature is the use of blackwater (from the toilets) and its hygienically safe transformation into a liquid fertilizer. The further development of the water treatment and food production technologies will be visible and tangibly available for people to experience in the water-processing house and the water farm greenhouse: Greywater becomes process water for the irrigation and production of fish and plants (aquaponics, hydroponics), blackwater becomes a liquid fertilizer for the hydroponic cultivation of fruit and vegetables. The hygienic quality is examined and irrigation water, fish and plants are tested according to relevant micro-pollutants. The ROOF WATER-FARM pilot plant delivers further process-technical data, such as for cost-benefit and life-cycle analyses or for investigating product quality and productivity of the technology.

Fig. 3: Greenhouse in the courtyard of Block 6.
Photo: © ROOF WATER-FARM

The greater vision of blue-green infrastructures similar to the ROOF WATER-FARM pilot-plant in the compact urban context is to design urban water and food production flows according to loop principles. As a result of starting from the technological scale applied at single buildings, the harvesting of fresh fish and food, literally from roof down to the river, can become a reality, whereby influencing the city-wide context.

City, Neighborhood, Building Sites: From Technology to Space

The urban context calls for flexible and architecturally integrated applications, which, on the one hand, increase the quality of life and ideally create new livable urban spaces and, on the other hand, provide infrastructure services for different sectors, exploiting space in a multifunctional and participatory way. The project chooses the city of Berlin as a mirror for infrastructural innovation which shows how decentralized technology could transform the urban realm. The research about the diffusion of ROOF WATER-FARM technologies into the urban texture focuses on three spatial levels: the city of Berlin, city quarters and neighborhoods, and the individual building sites.

City of Berlin

The research focus on identifying theoretical potentials for application of ROOF WATER-FARM concepts on available rooftops in Berlin is based on previous research into building-integrated farming in Berlin, e.g. *Zero Acerage Farming Z-Farm*,[10] and studies in other Western cities, such as New York City (Ackerman et al. 2012). A geographical information system (GIS) is used to analyze parameters, such as roof top dimensions, inhabitants, (waste-)water flows, resource metabolism, and building typologies (according to uses and social life). They are generated from geodata and statistics from the City of Berlin.[11] If these underlying datasets with preliminary figures on material flows are merged, city-wide application potentials according to the characteristics of the four different ROOF WATER-FARM variants/concepts can be derived (3.2). The map of potential ROOF

[10] http://www.zfarm.de (20.08.2014)
[11] Senate of Berlin, Department for Urban Development and Environment and Statistical Office for Berlin-Brandenburg

WATER-FARM applications focusing on flat rooftops in Berlin shows and visualizes the distribution of the innovative technologies in the urban realm. Due to the building-specific availability of the resources required, the four variants have different characteristics in their spatial diffusion potentials, e.g. aquaponics with treated greywater (Fig. 4).

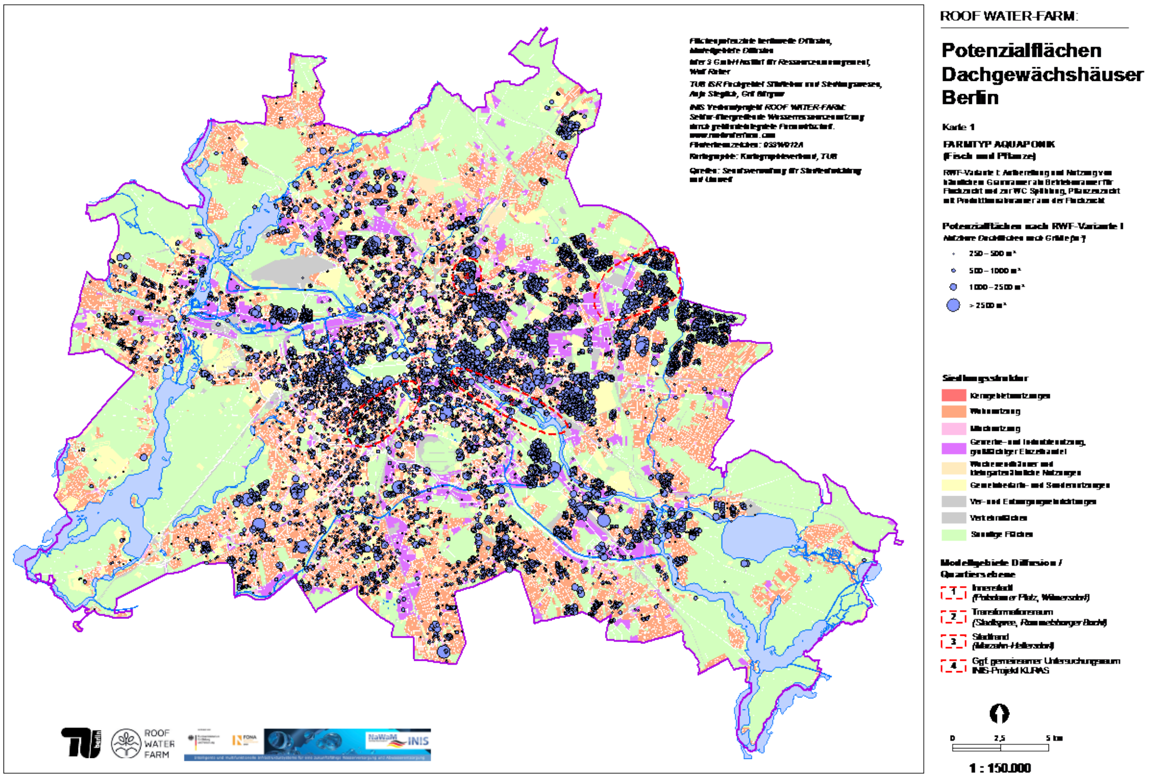


Fig. 4: Map of ROOF WATER-FARM variants with their different characteristics in their spatial diffusion potentials, e.g. aquaponics with treated greywater.
Source: ROOF WATER-FARM, Database: Senate of Berlin, Department for Urban Development and Environment and Statistical Office for Berlin-Brandenburg.

The results of the citywide analysis also exhibit the diversity of building typologies within the 900 km^2 city boundaries of Berlin. Only 13% of the 536,000 individual buildings included have flat roofs larger than 50 m^2 and, therefore, contain a theoretical usage potential. However, the analysis also showed that these potential buildings, which represent 45% (4,423 ha) of the total building area in Berlin, are mainly large buildings with many inhabitants, housing 57% of the 3.4 million Berlin inhabitants. Sixty-five percent of "potential" buildings are represented in the building typology "residential," derived from the automated cadastral register of Berlin.
Analyzing the four ROOF WATER-FARM variants reveals that the variants using rainwater instead of greywater have larger overall area potential in Berlin. This is due to the fact that buildings with few or no inhabitants (hence, low waste water production), such as factories, institutions or supermarkets, are also suitable. Applying a conservative preliminary production footprint of 25 kg of vegetables per m^2 and 15 kg of fish per 1 m^3 tank (surface area 1.2 m^2) and year, the following alternative of production potentials could be identified throughout Berlin:

- up to 165,000 tons of vegetables and 14,000 tons of fish per year with greywater use;[12]
- up to 299,000 tons of vegetables and 10,000 tons of fish per year with rainwater use.[13]

Regarding the multi-functionality of ROOF WATER-FARM, potential consequences for the water sector are currently under analysis. In addition to savings for irrigation water, fertilization, cooling, and transportation in comparison to conventional production elsewhere, the potential impacts on the urban water sector are being examined. Therefore, the assumption that excess purified greywater may be used for flushing toilets in buildings with ROOF WATER-FARM variants operating with greywater was included in the GIS simulation. Thereupon, the analyses calculated savings of 16% of total domestic drinking water consumption in Berlin and 23% less domestic wastewater to be treated in municipal wastewater treatment plants. Furthermore, collection and use of rainwater by ROOF WATER-FARM has the potential to disconnect up to 14% of the total sealed area in Berlin, which would be a significant contribution and relief for the central stormwater management infrastructure. Central water infrastructure is heavily challenged by climate variations and protection claims for urban water bodies though the European Water Framework Directive in many European cities.

City Quarters, Neighborhoods
Case study areas within the city of Berlin were chosen by criteria such as:

- location and dynamics of development, e.g. density, migration balance, new construction, demand for redevelopment,
- building form and use, mapping of the building prototypes defined, and
- social setting, e.g. income, property ownership and housing rent, social services offered.

According to these criteria, three model areas were selected that serve as potential diffusion areas of the ROOF WATER-FARM technology: 1) *Inner City Berlin* (Potsdamer Platz, Wilmersdorf), 2) *Areas of Transformation, Inner Void* (Spreestadt, Rummelsburger Bucht) and 3) *Border Areas* (Marzahn-Hellersdorf). These model areas are interpreted as prototypes for distinctive dynamics, stakeholder networks and significant urban form that are common within European cities.
Within the research process, the criteria analysis in the model areas evolves into the description of spatial characteristics and spatial scenarios. This creative research and design process is based on GIS data about rooftop dimensions related to potential water flows and resource metabolism (4.1). Characteristic building typologies and uses, social life and urban design merge with the different features/variants of ROOF WATER-FARM technology. Potential user profiles will simulate the *cultural dimension* of building-integrated reuse of water and food production and the decentralized resource metabolism related to, for example, typical processing and trade structures, maintaining and monitoring structures, local investment, local harvesting, and consumption as social and technical challenges. The research team will develop a *technique of network-mapping* as an innovative tool for planning and design, which shows/creates the potential resource metabolism on the district level and describes the necessary planning and

[12] If considering an annual requirement of fresh vegetables/fruit of 68.7 kg per person (Gesellschaft für Konsumforschung 2009), 2.4 million people could be theoretically supplied. If considering an annual need of fresh fish of 5.2 kg per person (Gesellschaft für Konsumforschung 2012), 2.7 million people could be theoretically supplied.
[13] Consequently, 4.3 million people could be theoretically supplied with fresh vegetables/fruit or 1.9 million people with fresh fish.

design steps and the narratives to its realization. Different user profiles (video/audio), collages and images (drawings, renderings) will give impressions about stakeholders' motivation, cultural challenges and urban design.

Building site layout and architectural design

On the building and site scale, the transferability of the ROOF WATER-FARM concept will be proven via a process-technical and architectural upscaling for different building typologies (residential, educational, commercial, accommodational/hotel, social, and cultural, including industrial transformation buildings). Thereby, the different RWF variants are exemplarily applied to the individual building typology, e.g. a residential building could apply rainwater or greywater reuse (RWF variants I to IV), whereas a school building might face the application of rainwater use (RWF variants III and IV), as usually not enough greywater is produced (Fig. 5). Within the research process, these different building typologies will be examined alongside exemplary prototype building studies and evolved to ROOF WATER-FARM building passes, mirroring the transferable aspects at the building level, e.g. significant resource metabolism (greywater, blackwater, rainwater), constructive form, use, and key actors within the transformation.

The feasibility, guidelines for operation and maintenance, and cost-benefit analyses are elaborated and complemented by potential risk analyses. The project partners develop models for commercial and non-commercial operation and product marketing, and develop communication and training media for the different actors and users.

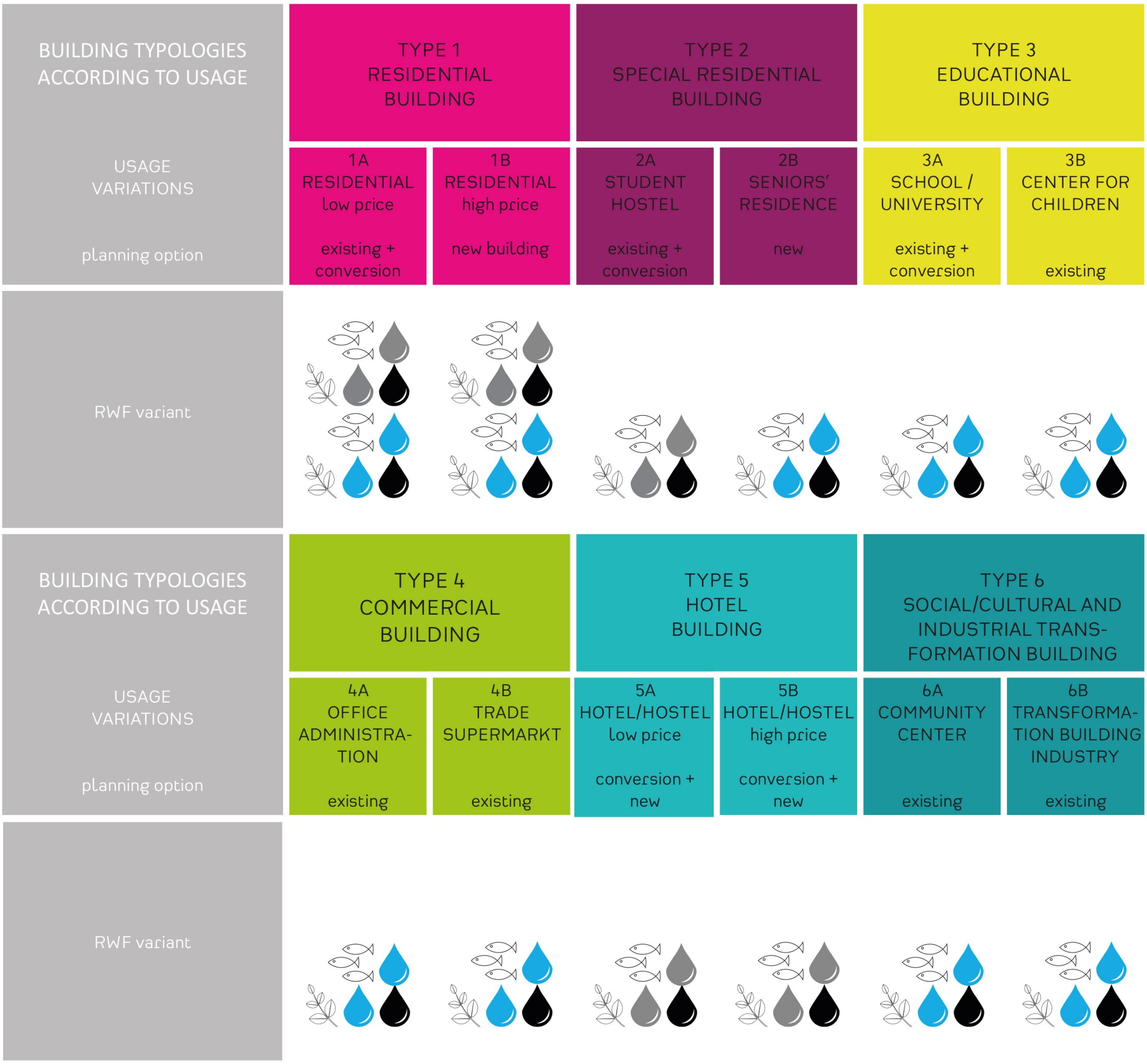


Fig. 5: ROOF WATER-FARM variants and their application to buildings
Graphics: Felix Bentlin, TUB-ISR, © ROOF WATER-FARM.

Following intermediate insights from both the ROOF WATER-FARM pilot test-site after the first six months of operation and the first typological building study, the following can be derived for a residential building prototype case:

- WATER demands can easily be met if greywater is used, because it contributes 70% to the total wastewater in private households: assuming 100 liters of total wastewater, 70 liters are grey and 30 liters are black. If using rainwater from roofs, e.g. for aquaponics, theoretical calculations show that additional treatment of tank flushing water from fish production is most often necessary; otherwise, the water demand cannot be met for the total rooftop greenhouse space. Therefore, an additional module for the treatment of wastewater from fish tank flushing should be integrated to better meet water demands.
- ENERGY demands, particularly in the colder seasons, are critical and need to be investigated according to the individual project site, since it contributes to the overall

feasibility of the system. Synergistic potentials, such as through using excess heat from the building or technical infrastructure in the local neighborhood, should be examined.

- PRODUCTS such as carp species, salad and strawberries showed good performance, whereas e.g. peppers are more sensitive. If opting to meet the food needs of people living "under the roof," the type of products grown varies strongly depending on the rooftop space available and the number of floors in the building (the higher the building, the more people need to be supplied).

Public participation and education

The potential implementation of the ROOF WATER-FARM concepts does not only require functioning technologies, but also needs to consider the acceptance and requirements of the potential operators, users and customers (e.g. urban developers, investors, building owners, city administration, urban water works, urban farmers, residents). It has been shown within the research project that it is fruitful to communicate the applied research in a transparent and continuous manner from the beginning – e.g. via website, social media,[14] guided tours, and events on the pilot site.

Fig. 6: One of the ROOF WATER-FARM campaign photos
Photo: Marc Brinkmeier, © ROOF WATER-FARM.

Aiming for a diversity of target groups and research process-related communication, the research team is working with different formats for user participation and acceptance for the technology within the urban population. Interviews and different user profiles (video/audio), and a web and communication campaign (Fig. 6) will help to involve a diversity of potential actors in the research and communication process. Events, guided tours and hands-on-workshops involve potential users directly into the research process and support the team with target group-specific questions and needs. Techniques of network-mapping and narrative scenarios (4.2.) will evolve into

[14] www.facebook.com/roofwaterfarm (18.08.2014)

practical guidelines and user-related learning elements for different target groups (design/planning, education and everyday life).

With the web campaign and the process-related communication tools, the research team wants to offer appealing elements to engage and enable a broad field of actors into the process of infrastructural development and urban design. With the pilot site, the research team has a tangible small-scale example of the technology, which exemplifies different aspects, e.g. hygiene questions, harvest potentials, concrete noise, smell and taste, questions of design and materiality, monitoring and maintenance efforts and costs.

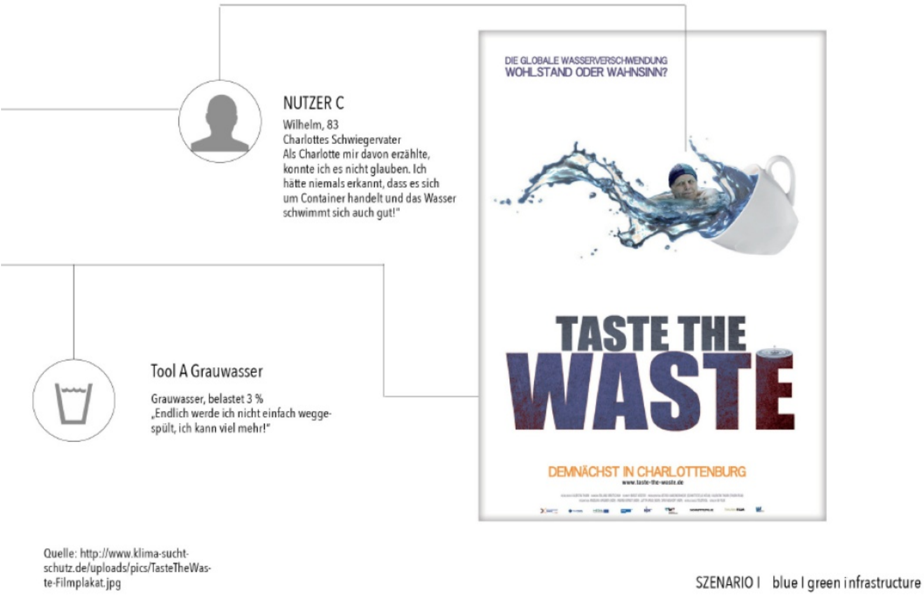


Fig. 7: Student campaign encouraging greywater recycling in Berlin-Charlottenburg, produced within the Master class of Urban Design and City and Regional Planning at the TU Berlin: Participatory Blue-Green Infrastructure[15]
Graphics: Fabian Becker, Jürgen Höfler, Tim Nebert, TUB-ISR

In the winter term 2013/2014, TU Berlin students from the MA Urban Design and MA Urban and Regional Planning, joining the Master Course *Participatory Blue-Green Infrastructure*[16] at the Dept. for Urban Design and Urban Development, Institute for Urban and Regional Planning (ISR) discovered the application of ROOF WATER-FARM for a self-selected building typology. The task was to visualize the transformations of urban form and uses along with the implementation of blue-green infrastructure modules envisioned. The studio work included coping with building-specific water flows, and daily and seasonal product and resource flows. The students were motivated to reflect on the different living spaces and living worlds. They envisioned new ways of cooperation between human and living ecosystems in the sense of a co-housing and co-working of man, fish and plants (3.2). Starting on the building scale, the idea was to weave the concept into the city.

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[15] http://urbandesign.staedtebau.tu-berlin.de/lehre/ma-srp-ud, http://www.roofwaterfarm.com/en/news/ (18.08.2014)
[16] http://urbandesign.staedtebau.tu-berlin.de/lehre/ma-srp-ud, http://www.roofwaterfarm.com/en/news/ (18.08.2014)

Last but not least, the task was to design communication and learning strategies striving for the participation of various actors. They should be motivated and enabled to realize and manage blue-green infrastructures from the scale of a building to a neighborhood.

Conclusion

ROOF WATER-FARM researchers look at water and farming technology, architectural and urban design, neighborhood development, public participation, and empowerment. Three spatial research scales (city, neighborhood, building site) are analyzed to clarify the potential of the diffusion of the technology into the urban realm and to visualize that potential as different building-, district- and actor-related innovations. Atmospheric changes/transformation within the urban texture, e.g. rooftops with greenhouses, infrastructures for harvesting, processing and storage, marketing and consumption opportunities, will be visualized. The challenge of this research is to think of this concept from the scale of a single water pipe to the scale of a city.

Within the Leitbild of LoopCity, the ROOF WATER-FARM project derived from explicitly focusing on water resource cycles and their interface with food production. If it develops further as part of food planning and production within the city, the ROOF WATER-FARM concept will need to take into consideration other resource cycles and infrastructure sectors (e.g. energy) and infrastructure services (e.g. leisure, education). If multifunctional infrastructures such as ROOF WATER-FARM become part of the city, it will increase the multifunctionality of urban space. Thereby, green open space will also include new infrastructural services and, consequently, also become revalued as green or blue-green infrastructure. This impact will be spatially seen, felt and lived by urban citizens. Accordingly, tools and formats of participation, education and enabling are needed to foster public acceptance and implementation of ROOF WATER-FARM technologies, designs and products. The diversity of technology enables site- and user-specific adaptations. In addition, new operation models and changing responsibilities from design to managing the new infrastructures need to be developed and tested. This will start a cultural change process reaching beyond the current, primarily technological understanding, such as in the context of *Smart Cities*. The refreshing and provocative ideas of the TU Berlin students produced a wide range of input for serious discussions about implementation of multifunctional infrastructure. They will be reflected by further research in the next step of the ROOF WATER-FARM project.

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References

Ackerman, K., Plunz, R., Conard, M., Katz, R., Dahlgren, E., Culligan, P. (2012): The Potential for Urban Agriculture in New York City, Growing Capacity, Food Security, & Green Infrastructure, Urban Design Lab, The Earth Institute, Columbia University

AECOM (Ed.) (2013): Water sensitive Urban Design in the UK. Ideas for Built Environment Practitioners. London: CIRIA

Barton, H., Grant, M., Guise, R. (2010): Shaping Neighborhoods for Local Health and Global sustainability. 2nd Edition. London and New York: Routledge

BMBF Federal Ministry of Education and Research (2012): Funding priority “Sustainable Water Management” NaWaM within the framework programme on “Research for Sustainability Development.” Bonn: BMBF

Bocek, A. (1996) Introduction to Polyculture of Fish: Water Harvesting and Aquaculture for Rural Development. [online]. Auburn University, Alabama, USA

Bohemen, H. von (Ed.) (2005a) Ecological Engineering: Bridging between Ecology and Civil Engineering. Boxtel: Aeneas Technical Publ.

Bohemen, H. von, (2005b) Green Machines (“Living Machines”) for Processing Wastewater. In: Ecological Engineering: Bridging between Ecology and Civil Engineering, edited by H. von Bohemen, 73–78. Boxtel: Aeneas Technical Publ.

Bürgow, G. (2013): Urban Aquaculture – Water-sensitive transformation of cityscapes via blue-green infrastructures. Doctoral dissertation thesis and disputation. Technische Universität Berlin. Publication 2014

Chan, A., Guterstam, B. (1995) Stensund Wastewater Aquaculture: A Small-Scale Model for Sustainable Water Resource Management in Urban Areas. In: J. Niemczynowicz (Ed.) (1995) Integrated Water Management in Urban Areas: Searching for New, Realistic Approaches with Respect to the Developing World: 315–328. Proceedings of the International Symposium, UNESCO-IHP, September 1995. Lund, Sweden

Costa-Pierce, B., Baker, D., Desbonnet, A., and Edwards, P. (2005) (Eds.) Urban Aquaculture. Oxford: CABI International

DIFU Deutsches Institut für Urbanistik (2013): Intelligente und multifunktionelle Infrastruktursysteme für eine zukunftsfähige Wasserversorgung und Abwasserentsorgung Vorstellung der Verbundprojekte: Ziele, Projektpartner und geplantes Vorgehen. Bonn: BMBF

Etnier, C., Guterstam, B. (Eds.) (1991): Ecological Engineering for Wastewater Treatment: Proceedings of the International Conference at Stensund Folk College, Sweden, March 24-28, 1991. 1st ed. Gothenburg, Sweden: Bokskogen

Gerling, J. P., Wellmer, F.-W. (2005): Wie lange gibt es noch Erdöl und Erdgas? Chemie unserer Zeit 39: 236–245

Gorgolewski, M., Komisar, J., Nasr, J. (2011): Carrot City: Creating Places for Urban Agriculture. 1st ed. New York: Monacelli Press

Graber, A., Junge-Berberovič, R. (2008): Wastewater-fed Aquaculture, Otelfingen, Switzerland: Influence of System Design and Operation Parameters on the Efficiency of Nutrient

Incorporation into Plant Biomass. In: J. Vymazal (Ed.) (2008) Wastewater Treatment, Plant Dynamics and Management in Constructed and Natural Wetlands: 299–310. 1st ed. Netherlands: Springer Verlag

Graber, A., Junge-Berberovič, R. (2009): Aquaponic Systems: Nutrient Recycling from Fish Wastewater by Vegetable Production. In: Desalination 246: 147–156

Grabow, B., Uttke, A. (2010): Leitbilder Nachhaltiger Stadtentwicklung. Von der Lokalen Agenda zur Nachhaltigkeit als strategischem Rahmen. PLANERIN 6_10: 22-25.

Guterson, M. (1993): Living Machines: Putting human waste back in its place: at the bottom of the food chain. Context – A Quarterly of Humane Sustainable Culture 35: 37

Guterstam, B., Todd, J. (1990): Ecological engineering for wastewater treatment and its application in New England and Sweden. Ambio 3: 173–175

Guterstam, B. (1996): Demonstrating ecological engineering for wastewater treatment in a Nordic climate using aquaculture principles in a greenhouse mesocosm. Ecological Engineering 6: 73–97

Guterstam, B., Etnier, C. (1996): The Future of Ecological Engineering. In: J. Staudenmann, A. Schönborn, and C. Etnier (Eds.) (1995) Recycling the Resource: Proceedings of the Second International Conference on Ecological Engineering for Wastewater Treatment, School of Engineering Wädenswil – Zürich, September 18 – 22, 1995: 99–104. Zürich-Uetikon: Transtec Publications

Hinge, J., Stewart, H. (1991): Solar Wastewater Treatment in Denmark: Demonstration Project at “Danish Flokecenter for Renewable Energy.” In: C. Etnier, and B. Guterstam (Eds.) (1991) Ecological Engineering for Wastewater Treatment: Proceedings of the International Conference at Stensund Folk College, Sweden, March 24–28, 1991: 181–187. Gothenburg, Sweden: Bokskogen

Hoyer, J., Dickhaut, W., Kronawitter, L., Weber, B. (2011): Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future. Berlin: Jovis

Jana, B. B. (Ed.) (2003): Sustainable Aquaculture: Global Perspectives. Binghamton, NY: Food Products Press

Junge-Berberovič, R., Staudenmann, J., Todt, D. (1999): Wastewater-fed Aquaculture in Temperate Climates: Optimizing the Recycling Rates via Primary Production. In: B. Kløve, C. Etnier, P. Jenssen, and T. Mǽhlum (Eds.) Managing the Wastewater Resource: Ecological Engineering for Wastewater Treatment, Ås, Norway

Libbe, J., Beckmann, K. (2010): Infrastruktur und Stadtentwicklung: Technische und soziale Infrastrukturen – Herausforderungen und Handlungsoptionen für Infrastruktur- und Stadtplanung. Berlin: Deutsches Institut für Urbanistik

Lyle, J. T. (1994): Regenerative Design for Sustainable Development. New York, NY: Wiley

Million (née Uttke), A., Steglich, A., Bürgow, G. (2013/2014): Participatory Blue-Green Infrastructure, Master class of Urban Design and City and Regional Planning, Winter Semester 2013/2014, TU Berlin. [online] http://urbandesign.staedtebau.tu-berlin.de/lehre/ma-srp-ud, http://www.roofwaterfarm.com/en/news/ (18.08.2014)

Rennert, B. (1992): Simple Recirculation Systems and the Possibility of Combined Fish and Vegetable Production. In: Progress in Aquaculture: Proceedings of 4th German-Israeli Status Seminar, October 30-31, 1990, GKSS-Forschungszentrum Geesthacht, Germany. edited by EAS Spec. Public., 91–97. EAS Spec. Public.

Schuh, H. (2005): Ohne Phosphat läuft nichts. [online] http://www.zeit.de/2005/23/N-Phosphatkrise/komplettansicht (18.08.2014)

Staudenmann, J., Junge-Berberović, R. (2003): Recycling nutrients from industrial wastewater by aquaculture systems in temperate climates (Switzerland). Journal of Applied Aquaculture 13: 67–103

Steinfeld, C., Del Porto, D. (2004): Growing away wastewater: Constructed ecosystems that clean wastewater. Onsite Water Treatment 1: 44–53

Steinfeld, C., Del Porto, D. (2007): Reusing the Resource: Adventures in Ecological Wastewater Recycling. Concord, Mass.: Ecowaters Books

Stewart, H., Chan, G., Hinge, J. (1991): Energy Budget for a Polyculture-based Wastewater Treatment System. In: C. Etnier, and B. Guterstam (Eds.) (1991) Ecological Engineering for Wastewater Treatment: Proceedings of the International Conference at Stensund Folk College, Sweden, March 24–28, 1991:181–187. Gothenburg, Sweden: Bokskogen

Todd, J., Todd, N.J. (1984): Bioshelters, Ocean Arks, City Farming: Ecology as the Basis of Design. San Francisco: Sierra Club Books.

Todd, N. J., Todd, J. (1993): From Eco-cities to Living Machines: Principles of Ecological Design. Berkeley, California: North Atlantic Books.

Verbücheln, M., Grabow, B., Uttke, A., Schwausch, M., Gassner, R. (2013): Szenarien für eine integrierte Nachhaltigkeitspolitik – am Beispiel: Die nachhaltige Stadt 2030 Band 2: Teilbericht “Kreislaufstadt 2030.” Dessau-Rosslau: Umweltbundesamt