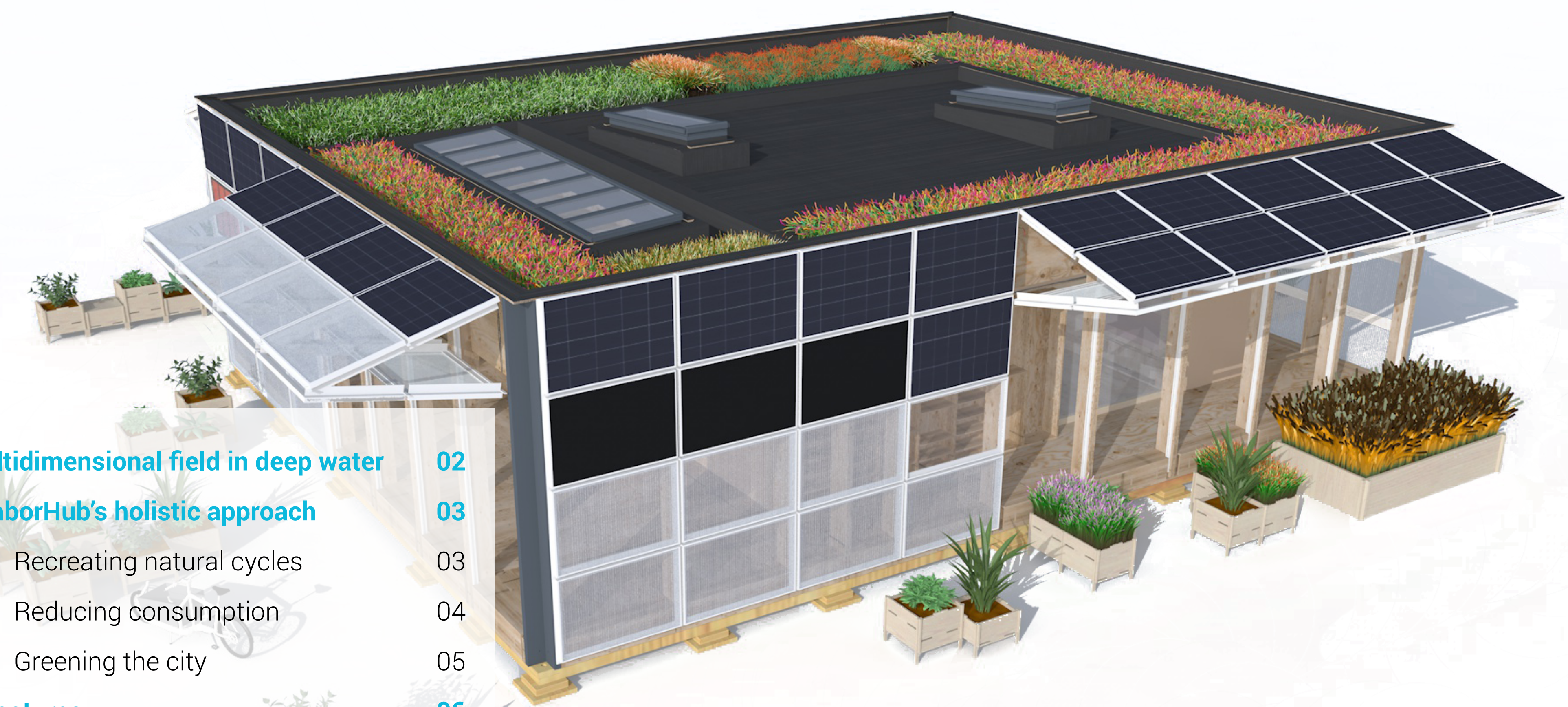
Water management



U.S. Department of Energy Solar Decathlon 2017

Swiss Living Challenge

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A multidimensional field in deep water

The Swiss team believes that the transition towards a more sustainable world through the development of greener technologies has already begun, but that local communities need to play a stronger role as change leaders. The answer to environmental and social challenges faced by Switzerland and the rest of the developed world do not lie in building an energy-efficient single family-house in a residential area. We need more: the NeighborHub. We are convinced that everyone has the means to act, everyone can be responsible, everyone counts.

The NeighborHub aims, in a larger context, to be a milestone of neighborhood transformation towards a more sustainable society. It is a community house with a socio-technical infrastructure proposing alternatives to residents of a neighborhood by acting on seven driving themes: renewable energy, waste management, mobility, food, choice of materials, biodiversity, and, last but not least, water management.

As one of the seven driving themes addressed by the NeighborHub, water management is a key topic linked to multiple challenges. The over-consumption of water remains the first aspect we think of, even in Switzerland, which is considered as 'Europe's water tower', but there are other underlying concerns. In cities, both water supply and treatment imply considerable energy consumption, as shown in figure 1. This is linked to numerous infrastructures whose maintenance is also costly. Talking more precisely about Wastewater Treatment Plants (WWTPs), these installations are not able to clean wastewater completely. Moreover, they do not valorize the nutrients in it nor return them to their origins, creating resources conflicts.

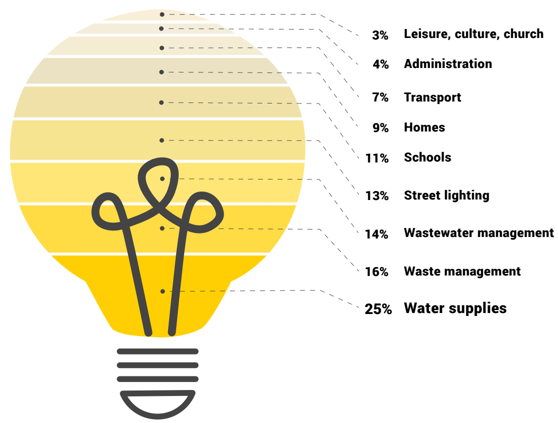


Figure 1: Electricity consumption of a Swiss municipality [1]

Even if these issues are hidden underground in pipes and sewers, they have a direct impact on our lives, with the increasing problem of micropollutants as another example. These substances come from medicines, personal care products, detergents, dyes, food additives or nanoparticles. After use, most end up in sewers and are difficult to detect and treat in WWTPs. They then reach surface water or even groundwater, threatening natural ecosystems and human health. However, there are also other challenges that are more visible, especially on an urban scale.

Nowadays, the building sector increases soil impermeability, which in turn leads to intensified runoff in cities. This disrupts WWTPs, waterways and cities' infrastructures.

As climate change provokes more extreme events, these disruptions are very likely to increase in magnitude. However, extreme events also mean droughts and heat waves, whose consequences are reinforced by the 'urban heat island' effect. Green spaces and biodiversity are indeed neglected and reserved for the city's surroundings, as well as land for food production.

These visible and invisible challenges go beyond what we consider as pure water issues and set water at the center of a multidimensional field. When undertaking water management, we need to consider energy, nutrients, micropollutants, runoff, biodiversity and even food, to manage and reduce our global impact. It is therefore a matter of synergies we have to create and awareness we have to raise.

In this narrative, the Swiss team first presents the general concepts behind its thought processes. With a detailed description of the NeighborHub's key features, we then give citizens concrete alternatives and advice to build more sustainable and self-sufficient neighborhoods without reducing comfort.

NeighborHub's holistic approach

Recreating natural cycles

Ignoring the fact that wastewater is subcategorized into several types, the standard treatment system brings all of them to WWTPs, as shown in figure 2. However, each water has its own characteristics.

Greywater contains household chemicals such as detergents, soaps, shampoos and cosmetics, releasing altogether several hundreds of different micropollutant types. Greywater also contains a slight organic load from kitchen sinks [2] and dishwashers that discharge food residues, oils and fats.

Feces contained in brown water exhibits a high organic and low nutrient load. Water content is 75 %, while the remaining 25 % is dominated by organic matter. Brown water is also characterized by very high levels of pathogens.

Urine contained in yellow water is theoretically sterile, but sometimes contains a few human pathogens. Water content is 95 %, and the rest is mostly organic compounds (of which 50 % is urea) and dissolved salts. Surprisingly, the quantity of dry urine solids is significantly higher than that of feces, 58 vs 41 g/p/d (0.13 vs 0.09 lbs/p/d). Urine represents 1 % of the daily volume of household wastewater. This same urine contains 79 % nitrogen and 47 % phosphorus loads treated by the WWTPs, and also a majority of micropollutants such as pharmaceutical residues [3].

Knowing these facts, we decide to adopt a different strategy for each kind of water: to treat or valorize it in the best way possible. It is indeed a mistake to mix, independently of their quality, greywater, brown water, yellow water and even sometimes rainwater in the same sewerage system. Such a way of thinking is equivalent to our past waste management and clearly neglects the advantages linked to separation.

In the NeighborHub, we take advantage of blackwater, since it contains precious resources such as carbon, nitrogen or phosphorous that are worth recycling. Some WWTPs already do this, however the sewerage needed is not only very costly in terms of infrastructure and grey energy, but also reaches its capacity limits due to demographic growth and urbanization.

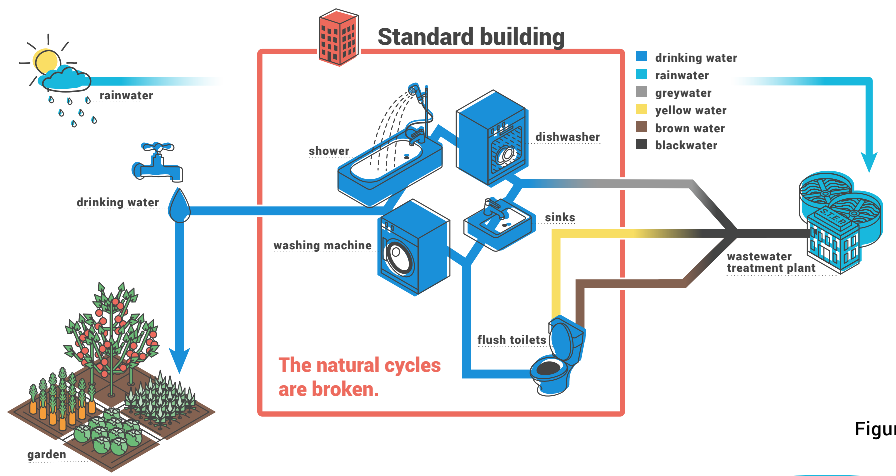
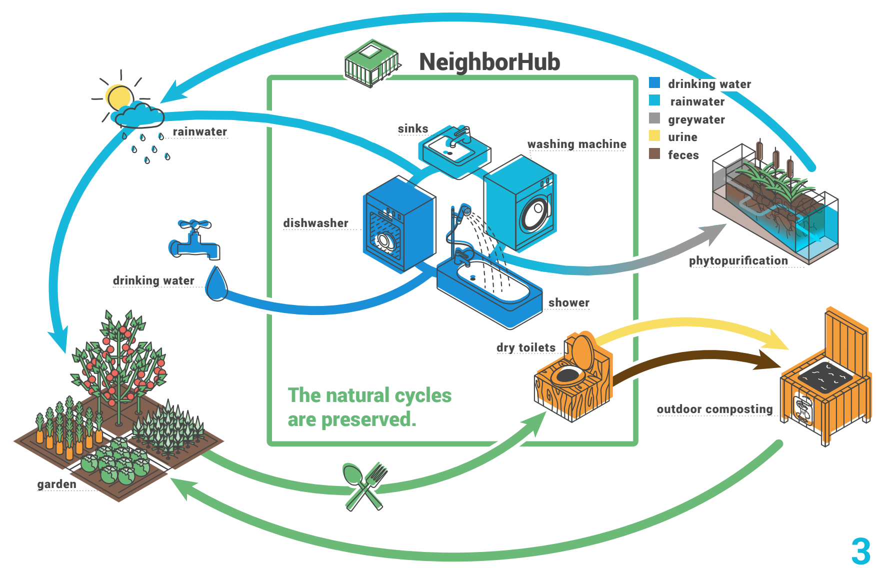


Figure 2: Today's water management

Figure 3: NeighborHub's water management



For these reasons, we prefer no-pipe processes, which makes us independent of the conventional centralized system.

To efficiently recover the above-mentioned resources, specific on-site sanitation systems are chosen for each wastewater type. For the NeighborHub, nature is our source of inspiration to design these systems. Blackwater is valorized through dry toilets, recreating the natural cycle of carbon and nutrients with the creation of valuable compost. Greywater is treated by phytopurification and then reinjected into the environment, recreating the natural cycle of water on a large scale, to which we are also linked as we collect rainwater on our roof for relevant purposes. Indeed, we insist on matching water quality to the appropriate usage.

Consequently, a coherent and cyclic system is created, as shown in figure 3. We are convinced that our approach optimizes water management, but also preserves natural processes, which are at the very heart of our reflections.

Reducing consumption

Dry toilets save a considerable amount of drinking water: 29 % of the Swiss daily average consumption, i.e. 41 L/d/p (11 gal/d/p) [4]. However, it is not the only significant factor in the NeighborHub. The use of efficient devices and new technologies has a positive impact on both the quantity of water and the energy related to hot water production, without reducing the user's comfort.

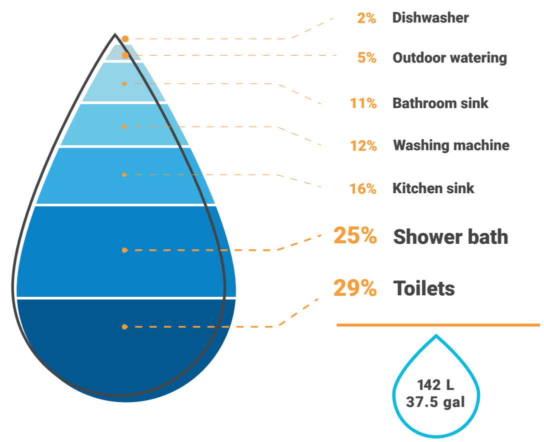


Figure 4: Switzerland's domestic daily water consumption [4]

Domestic water can be separated into two groups. The first gathers water flows controlled by automatic machines, such as a washing machine or dishwasher. As a consumer, the choice of products for home appliances using water is one of the more simple actions which can be performed to reduce water consumption.

The second group is made up of water flows controlled by the user, such as shower, bathroom sinks and kitchen sinks, and which represents half of the average daily consumption in Switzerland.

These volumes are heavily dependent on the behavior of the users themselves, but can be influenced by the selection of low-flow taps and shower heads.

Another way to preserve water, and thus energy, is to design a water management system with the integration of smart metering, which is rare on a household scale. To integrate this concept, it is important to find and act specifically on the appliances that are most energy and water intensive. In the NeighborHub, they are identified through a scientific approach, which encourages the creation of a consumption model, a material flow diagram and a sensitivity analysis [5]. This helps decide the placement of the meters and other smart devices. The aim is to achieve optimized monitoring, in opposition to a costly installation of numerous flow meters all around the house measuring everything at the same time.

Besides monitoring, communication is the other key aspect of smart metering. The goal is to cleverly communicate with the users, without being too intrusive. In this sense, the NeighborHub would give information about the impact of their actions in the building, but also advice about when to use certain commodities. Smart metering follows the 'learning by doing' principle with an integrated design.

Greening the city

In the concrete jungle of our cities, the impermeability of the ground is a major concern. One solution is to vegetate parts of the town. This drastically reduces the runoff and stormwater peaks. Indeed, from a waterproof surface with a runoff coefficient of 1, re-vegetation decreases this value between 0.1 and 0.5, lowering the flow rate by at least 50 % [6]. Moreover, residues of polluted rainwater are filtered by the ground instead of ending up in surface water.

Vegetation can be integrated on roof tops which are generally impermeable and represent 20 % of the built surface of Switzerland. Drawing on this, the city of Basel recently decreed that all new flat roofs must include vegetation. Following this trend, we integrate a green roof on the NeighborHub, the advantages of which go beyond simple water retention.

Green roofs also create a natural resistance to overheating by playing a buffer role. This contributes both to the decrease of urban heat islands in cities and to the insulation of buildings. The latter are also better protected, as vegetation limits UV impact on roofs, thus increasing their lifetime [7].

Moreover, from an environmental point of view, green roofs act as a trap for microparticles, which are absorbed by plants, decreasing smog and thus increasing air quality [8]. Clearly, greening the surroundings of the NeighborHub and, more generally, the streets of our cities further improves the air quality.

The development of these green pathways provides, for a number of birds, plants and insects, an ecological niche in the greyness of the concrete. It leads to a great improvement in fauna and flora, especially insects which, as pollinators, are key players in plants' development [9].

In the same vein, urban food production answers to the colossal energy and environmental costs of food product transportation. Providing access to local and seasonal fresh food in the center of the neighborhood increases the energy efficiency of the food production cycle. It also raises awareness on sustainable food consumption and cultivation.

More than urban organic farming, we use a permaculture approach. We judiciously choose appropriate species to favor symbiosis and resilience. As each plant has different functions, multiplying these roles helps the local ecosystem to develop well: each plant assumes also the task of others, reducing the probability of failure.

It is the same on a community level. Working together and helping people realize that everyone counts develops life in the neighborhood. The NeighborHub uses this social approach to connect citizens and multiply their functions. Just as the Incredible Edible apply this concept to unite people in gardening activities [10], so we fill the empty roadsides with community gardens. This unites different generations and cultures on a common topic creating a tremendous opportunity to forge social links in the neighborhood.

Figure 5: Incredible Edible gardens in New York © Informaction.info

Pursuing the same goal, the NeighborHub, with its activities and workshops, is the ideal place to enable the concentration of ideas from different domains and to facilitate the creation of local initiatives on a neighborhood scale.

Our concept of smart vegetation goes beyond its key role of retention and environmental gains. It contributes to urban qualitative transformation, creating local hobbies and increasing the comfort of citizens, as there is less need to leave suburbia in order to avoid pollution and enjoy a healthier environment [11].

Our key features

On-site natural treatments

As stated earlier, conventional toilets waste a lot of water and are connected to a sewerage system whose efficiency is poor in terms of energy, cost and nutrient valorization. We have therefore designed and built our own dry toilets system which eliminates the use of water and separates urine and feces at source in order to produce two kinds of compost.

Our dry toilets consist of a wooden unit with two containers. The top one is a rotating tub and houses a hemp medium inhabited by earthworms (*Eisenia fetida*). We use this amazing creature to reproduce what it does best naturally in the ground: mixing, aerating and structuring the soil. This vermicomposting process greatly reduces the volume of feces and also mineralizes it into easily-available nutrients. To avoid a surplus of water which can lead to unpleasant smells, the lower box collects the percolate which comes from the upper compost medium.

To balance the worms' needs (C/N ratio) and also to further avoid unpleasant smells, we add some hemp after each usage. This blocks the enzyme transformation of organic nitrogen to ammonia, the source of bad smell. Toilet paper can also be thrown into the toilets, to be eaten by the earthworms.

Urine is redirected into a bale of straw placed in a wooden box outside the building. Once again, straw helps prevent odors and keeps the nitrogen in an organic state. The composting process starts in the box and produces a nitrogen- and phosphorous-rich compost, different from the dry toilets' vermicompost.

The straw and earthworm media are designed so that, after 3-4 months, they are replaced by fresh materials to restart a new cycle. They are then transfered outside to pursue their natural transformation into compost. This resting period takes approximately 18 to 24 months as pathogens and micropollutants are killed through a long oxidation process using oxygen from the air [12]. To close the loop, the compost is afterwards used for gardening, as shown in figure 6.

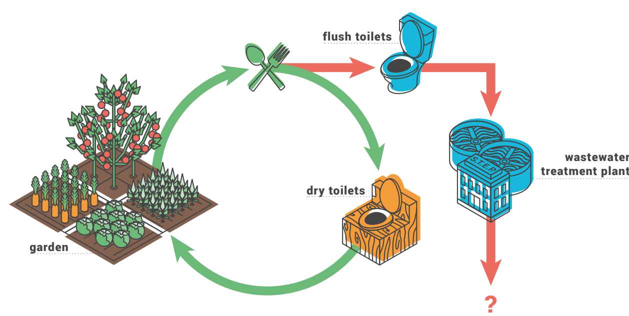


Figure 6: Closing the loop

In Switzerland, this kind of installation is gradually being integrated into innovative houses and small buildings, and has encountered a certain success. For example, 150 L (40 gal) of vermicompost are produced each year per flat of 4 people in the Cressy building in Geneva (CH). As the dry toilets' input corresponds to 2,000 L (528 gal) (urine, feces and wood chips), an impressive reduction factor of 20 is observed [12].

Research on this topic is being carried out by biologists, but also by architects, students and other individuals who are motivated to change. Even if there are various biological aspects to be aware of, the main issue concerning dry toilets remains the change in our habits and therefore the breakdown of certain psychological barriers. This is why we first worked with a housing cooperative and an independent biologist on a prototype, before designing and building our integrated dry toilets module, which guarantees a high level of comfort to the user.

With no black and yellow water in the NeighborHub, only greywater from the kitchen and bathroom sinks, the shower, the dishwasher and the washing machine needs to be treated. This water has a low pollutant load, so does not necessarily require much treatment. We therefore also use a nature-inspired technology recognised by sanitation experts: phytopurification. This consists of a rectangular basin filled with gravel of different diameters and covered by reeds, as shown in figure 7.

Even if gravel helps to mechanically filter greywater, the main agent is the roots of the reeds. They form a well-developed system containing a lot of bacteria capable of decomposing organic matter and mineralizing phosphorus and nitrogen. These nutrients are then made available to the reeds.

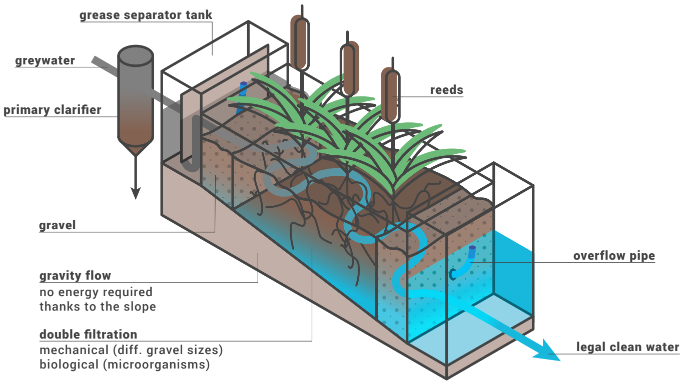


Figure 7: Phytopurification diagram

In the NeighborHub, greywater first travels through a primary clarifier, for the deposit of solids, then through a grease separator, to finally enter the phytopurification basin. These tanks are positioned under the floor of the semi-outdoor space, easily accessible and properly integrated to the architecture.

As phytopurification is a natural system, we only use environmentally-friendly products to wash clothes and dishes in the NeighborHub. It is the only constraint of this easy-to-maintain treatment unit.

As for dry toilets, some phytopurification units already exist in Switzerland and have demonstrated that their output concentrations respect the legal norms in terms of pollutants. They can therefore be connected to rainwater sewerage or to a river, in order to close the natural cycle.

Local food production

Another phytopurification is integrated in the NeighborHub, but this time as part of a bigger process called aquaponics. This system valorizes the effluent of aquaculture by creating a collaboration between several actors: fish, via their excrement, supply ammonia which is transformed by bacteria into nitrate to feed the plants [13].

Once an equilibrium is reached, the advantages are numerous. Aquaponics is an independent system and, consequently, does not need much maintenance. The only input is the fish food which is twice valorized by feeding also the plants. Productivity is 2 to 5 times greater than conventional agriculture, while the water saving is about 90 % [14]. The absence of in-soil culture problems, such as pathogens, soil structure and salinity, simplifies care and labor. Moreover, plants do not need other fertilizers and the yield is optimized.

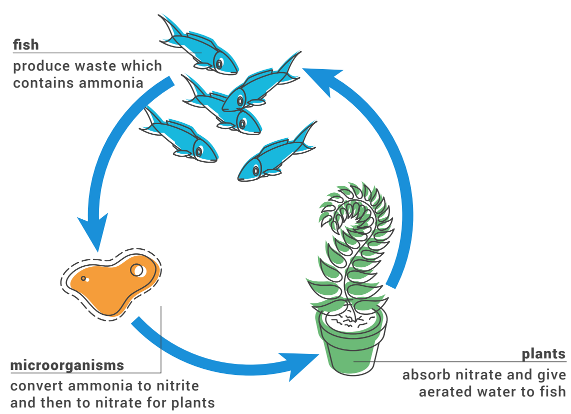


Figure 8: Aquaponics diagram

We integrate 3 aquaponics units to produce fish and vegetables. Each unit has 24 net pots for plants and starts with 4 kg (8.8 lb) of fish. With perfect conditions of pH and temperature, and assuming we grow only lettuces, we could produce two plants per day. Obviously, this is not enough to supply food for the neighborhood, but it inspires and motivates people to grow their own supplementary fresh food.

The NeighborHub indeed has the task of sensitizing the public and recreating local food production cycles. This is achieved, inter alia, with aquaponics, but also with our own compost production. Moreover, we aim to set up 'Do It Yourself' gardening activities where people create their own garden with old objects, giving them a second life. This enables citizens to appropriate the NeighborHub's common space and to experiment later at home. Generally, smaller plants, such as aromatic plants, are more suited to this kind of gardening.

To promote the accessibility of urban gardening, we provide wooden boxes of different heights, so disabled persons, children and the elderly are required to make the least effort. The boxes are transportable and rearrangeable. In each box, we grow different species of vegetables or berries to produce advantageous partnerships with a permaculture approach. For example, carrots are planted with onions because both their smells repel the parasites that attack the other.

Rainwater management

As much as the plants and the vegetation around the NeighborHub, our green roof contributes to biodiversity and water retention. It is situated above the semi-outdoor space, as well illustrated on the cover page of this document.

For the installation in Denver, our team is collaborating with an American company to prepare and deliver the roof plants in numerous small modular trays (see figure 9). This enables us to benefit from an easy assembly and disassembly of the building, and more importantly, to ensure a second life of the green roof. Indeed, the University of Colorado Denver is also collaborating with us and plans a great future for our modules after the competition.

With these modular trays, a sedum of grasses is installed at the beginning. It is then observed that the local ecosystem colonizes the roof and, after several months, modifies the primary vegetation. At the end, the roof is home to only indigenous plants.

Concerning water retention, with a total surface of 72 m^2 (770 ft^2) and a soil depth of 10 cm (4.25 in), the NeighborHub's roof has a runoff coefficient of 0.4. If we take the 2016 total precipitation in Fribourg as a reference [15], our green roof prevents a considerable volume of water from going into the WWTP. This contributes to WWTPs' proper functioning and saves both useful water and energy linked to treatment.

On the central part of the roof, a surface of 60 m^2 (646 ft^2) is dedicated to rainwater harvesting [16]. The collector, which has a useful volume of 600 L (160 gal), is sized according to average precipitations in the city of Fribourg with a 10-day reserve.

On the one hand, the tank supplies the washing machine with softer water to preserve the life expectancy of the appliance and reduce the amount of detergent needed [17]. According to its specifications, our washing machine consumes on average 45 L (12 gal). With approximately 220 cycles per year, using rainwater saves 9,900 L (2,615 gal) of drinking water, provided that the tank is well managed.

On the other hand, the reservoir provides rainwater to a sink in the semi-outdoor space of the NeighborHub, which is then used for watering the garden and for other activities that do not necessarily require drinking water. We estimate the need for 1,200 L (317 gal) per year for the NeighborHub's vegetation, the roof being autonomous. As a consequence, the NeighborHub saves precious drinking water, replacing it with available 'free' rainwater which can then be used in certain appliances.

When the rainwater reservoir is empty, a pump called Aquator, automatically switches to 'drinking water' mode, providing the appliances with water from the grid. However, to avoid this unwanted situation, the user is informed on the current reservoir level and on the expected water availability for the coming days based on weather forecasts.

Figure 9: Liveroof Standard modules

Smart metering

As discussed above, the rainwater collected on the roof is stored in the rainwater tank. We equip the latter with 4 floats positioned at different heights that monitor the approximate remaining volume: 20 %, 40 %, 60 % and 80 %. We are also connected to weather forecasts giving precipitation predictions. On this basis, an algorithm is being developed to determine the number of possible washing machines according to the amount of rain predicted in the next two days and the level of water in the reservoir. The users would thus access advice to optimize water consumption through the NeighborHub's tablet.

The choice of our home appliances has been conducted with great thought, in order to reduce water consumption with little effort. The taps from the toilet and bathroom sinks not only have a very little flow rate (5.7 L/min - 1.3 gal/min), but also have a mechanism that encourages the user to use cold water. However, we still insist on connecting both hot and cold water to give the user the choice.

We performed a material flow and a sensitivity analysis to identify the fluxes which have a great impact on the whole system's input and output. We place flow meters in smart locations according to fluxes with high variability: the cold water of the kitchen sink, the cold water of the shower and the outer tap. In addition, the overall water consumption and the rainwater consumption are monitored. The measurements are collected and stored in a database. We use them in an algorithm that calculates other specific volumes such as the hot water of the kitchen sink faucet or the dishwasher.

The algorithm then determines the daily and monthly consumption of total water but also the contribution of each appliance. Our goal is to show those values on our tablet to sensitize the users, following the 'learning by doing' principle.

Figure 10: Amphiro's principle © Amphiro

We add an Amphiro to the shower hose, a small device that measures water and energy consumption. Its screen depicts a cartoon polar bear on an ice sheet which slowly melts the longer the user spends in the shower. An optional smartphone application enables him to follow his own consumption and compare it with that of his friends. Studies have proved that this playful device systematically makes people spend less time in the shower, even indifferent users [18].

Hot water management

The NeighborHub's primary goal is to reduce the amount of water consumed. If appliances contribute to energy saving it is even better. It is an active choice to favor the compromise towards saving water.

It is therefore interesting to mention a few devices on the topic of hot water management. Joulia Inline 3P is a heat exchanger placed under the shower tray. It pre-heats the cold water from 10 to 25 °C (50 to 77 °F) thanks to the energy stored in wastewater. Since our shower head has a small flow rate of 5.7 L/min (1.3 gal/min), it maximises the efficiency of the exchanger (25 %). This device reduces energy consumption without reducing users' comfort.

A thermodynamic boiler stores the hot water produced by solar energy and a heat pump complement if necessary. Our three 'Do It Yourself' thermal solar panels (4.8 m^2 in total - 43 ft^2) have a 90° inclination to smooth the yearly hot water production and cover 35 % of our yearly consumption in Fribourg (75 % of our consumption in Denver in October). To avoid having to wait for 30 seconds until hot water comes, a recirculation pump provides direct hot water to more distant points of the house. It is however only turned on at some relevant moments during the day. Moreover, the dishwasher is supplied only by the hot water from the boiler, reducing the effort of its internal heating system and improving energy efficiency.

Sustainable water management

The NeighborHub enables its users to consume 50 % less water than a conventional house in Switzerland. This goal is not only achieved thanks to its dry toilets and efficient devices. With its smart communication and its experimentation role, the NeighborHub raises awareness and empower the users, encouraging them to be actors and adopt sustainable lifestyles. A mix of high and low tech devices are well integrated in the interior and exterior architecture, being part of the engineering design, home life and comfort.

Adequate usage of rainwater and separate treatment avoids having complex reuse and reclamation processes. Our no-pipe system and on-site treatments favors natural cycles and preserves resources. These solutions are already existing, effective and safe, having positive consequences on the environment and human's health and comfort.

The plants are selected to benefit on environment and biodiversity, to treat water naturally, to increase human comfort in cities and to optimize food production alternatives. The range of plants is wide to answer our several smart vegetation goals and for the NeighborHub's function of showing alternatives, enabling experimentation and creating social initiatives.

The influence of the NeighborHub is huge as it triggers change in the surroundings, acts to sensitize people on sustainable gestures and educate the next generation. Therefore it is interesting to place the building in a broader urban approach.

A phytopurification system with several buildings has a positive scale factor. It is also interesting to group dry toilets compost maturation, rainwater harvesting and smart metering. These local treatment facilities on the neighborhood scale are part of a hybrid transition system of urban water management (UWM) consisting of decentralized systems integrated in a centralized traditional approach [3]. To achieve this, there is a need for innovation in regulatory models with the support of regulation parties and policy makers. A holistic and transdisciplinary approach is key to tackling the complexity of water management.

Other experimental settings such as the NeighborHub are thus crucial to ensure robustness, cost-effectiveness, social acceptance and wide applicability of alternative technologies. On the subject of economic feasibility, numerous Swiss water infrastructures need improvement, renovation or even replacement, the cost of which totals several hundreds of billions of francs. This money can be invested in more sustainable local solutions.

This will help the hybrid transition system to grow, in which the NeighborHub claims to be a key player tackling the numerous challenges related to sustainable water management.

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