MASTER IN ADVANCED ARCHITECTURE

2014/15

DESIGN WITH NATURE

50 SHADES OF GREYWATER

BARCELONA

IaaC Institute for advanced architecture of Catalonia

MASTER IN ADVANCED ARCHITECTURE

50 SHADES OF GREYWATER

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01 THE STORY OF GREYWATER

Figure 1a. Watersheds and river systems of Catalonia.
Image Source: Agencia Catalana de l'Aigua: Presentacio de la Demarcacio Hidrografica, Mapa 1.1.2.

Catalonia has always been a water-stressed region, and as its largest city, Barcelona is no exception. Until the 20th century, Barcelona relied almost exclusively on groundwater reserves, as well as surface water from the Besos river. As these sources became depleted and increasingly polluted, around the mid-20th century Barcelona turned to the Llobregat River. But this too was not enough to satisfy the increasing population, so only a few decades later (in 1967), an initiative was made to channel water from the Ter River, about 100 km north of the city. To this day, the Ter-Llobregat system continues to be the main source of water for the Metropolitan Region of Barcelona. Unfortunately, extraction of water from this system borders on overexploitation, and yet the available infrastructural alternatives are few. In 2009, the Llobregat desalination plant, the largest in Europe, went into operation. With a

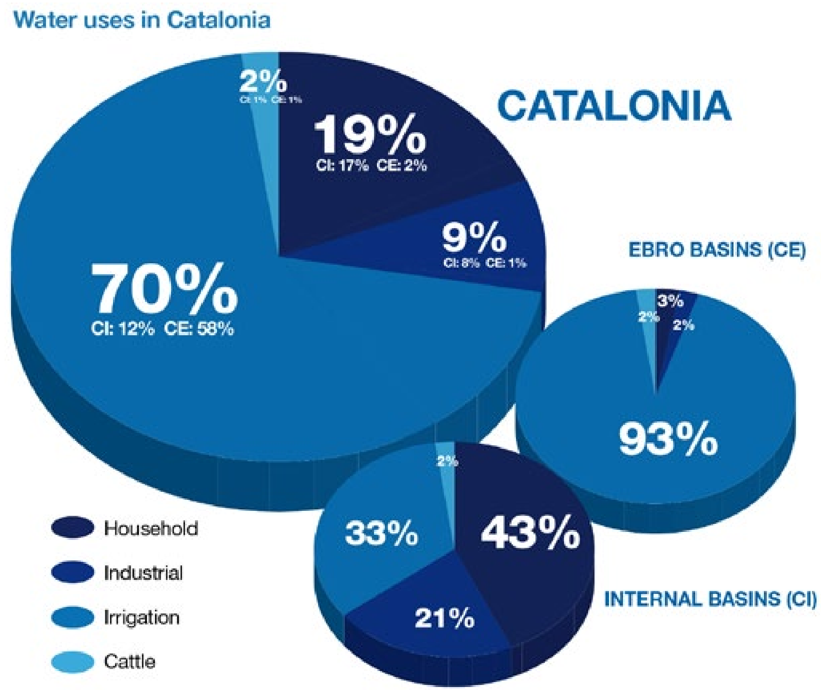


Figure 1b. Water use in Catalonia by industry, 2008.
Image source: ACA – Water in Catalonia, 2008, p 13

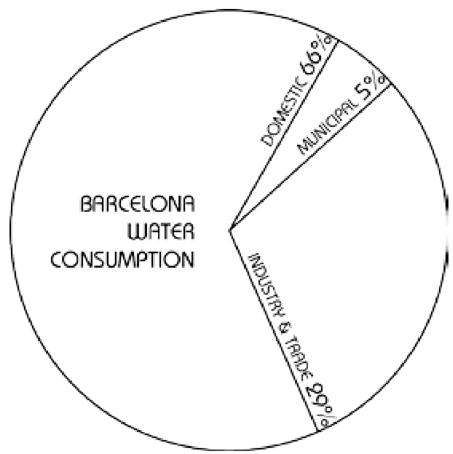


Figure 1c. Water use in Barcelona by industry, 2011.

Figure 1d. Llobregat Water Treatment Facility
Image source: http://www.life-aware.eu/project/aware-demonstration-site/

drinking water output of 200 million L per day, it satisfies only a quarter of Barcelona's water consumption needs.

In 2008, Barcelona suffered a drought severe enough that drinking water had to be imported in order to meet the city's demand. It is predicted that only two years of drought would result in a collapse of the current system. The city already has one of the lowest water consumption rates in Europe. Domestic consumption is less than 120 L per person per day. There are already multiple provisions in place in case of water shortages. However, a certain minimum is always required for municipal water needs, including watering the city's green spaces and parks and cleaning the streets to maintain sanitary conditions. Adding to the strain on the water system is the development of tourism in Barcelona, which has been increasing steadily since the 1990s. The number of tourists that visit the city peaks during the summer months, which happens to correspond with Barcelona's hottest and consequently driest season.

theguardian

Barcelona forced to import emergency water

· Southern regions say move politically biased · Catalonia's reservoirs three-quarters empty

Graham Keeley in Barcelona

Wednesday 14 May 2008 08.40 BST

The tanker Sichem Defender arrived at the port of Barcelona yesterday carrying something far more precious than its usual cargo of chemicals.

Nearly 23m litres of drinking water - enough for 180,000 people for a day - was the first delivery in an unprecedented emergency plan to help this parched corner of Spain ahead of the holiday season.

As the country suffers its worst drought since records began 60 years ago, Catalonia, of which Barcelona is the capital, has been the worst-hit region. After months without adequate rainfall its reservoirs are down to just over a quarter of normal capacity. A year ago they stood at almost double that.

Nationally, reservoirs are around half full with the worst of the summer heat just a few weeks away.

If levels drop to 15% of normal supply the water in the reservoirs is no longer deemed fit for drinking and restrictions on tap water would have to be brought in.

The tanker, which arrived in Barcelona from nearby Tarragona, will be followed by its sister ship Contester Defender tomorrow from Marseille.

At a cost of €22m (£17.5m), six shiploads are to arrive each month for three months, from Tarragona in southern Catalonia, Marseille and Almeria - one of the driest areas of southern Spain.

Already Barcelona's authorities have turned off civic fountains and beachside showers, brought in hosepipe bans, and banned the filling of swimming pools. Schoolchildren are being taught how to save water.

"We are only too aware of the crisis with the water as they have been giving my daughters classes for months on how to save water and only to use what they need," said city resident Begoña Gómez, 43, as she sipped a glass of bottled water. "But we need better management of water by the government."

As the reservoirs across Spain run dry, a "water war" has broken out, with different regions scrabbling for extra supplies.

Figure 1e. Barcelona water shortage bulletin, 2008..
Image source: http://www.theguardian.com/world/2008/may/14/spain.water

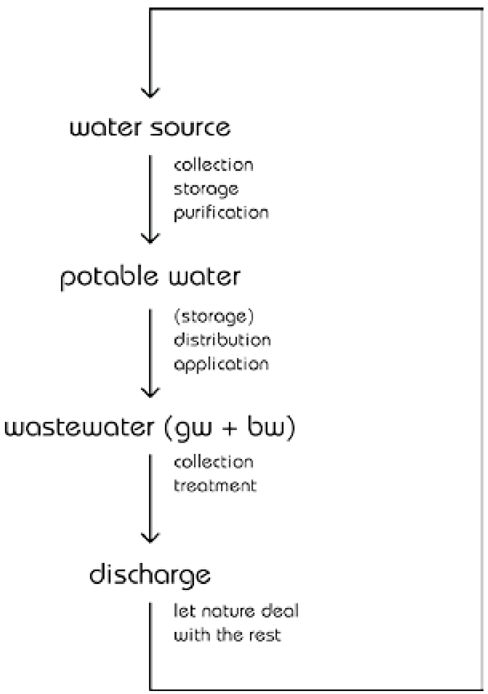


Figure 1f. Linear water system

Although the technology is readily available, the process of treating water is energy-intensive and requires extensive infrastructure. In addition, this water is treated to potable levels, and yet we drink less than 5% of our daily water consumption. Not all activities require such high quality water, and different activities produce different qualities of wastewater. In our current system, high quality potable water goes in, and wastewater comes out as sewage. However, most greywater is still relatively clean before it gets mixed in with blackwater to become sewage. Water is clearly scarce, and yet is it not treated as such. In a region that has already optimized its water use efficiency, the next logical step would be to ask how an existing resource could be reused, and how a linear system could be transformed into a more complex system that disposes of the concept of waste.

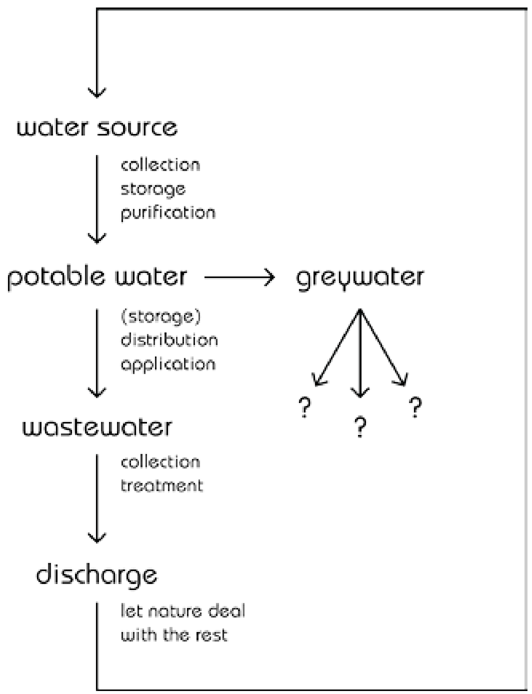


Figure 1g. Linear water system with greywater potential

Can we turn waste into opportunity? What if we could redesign the system to upcycle and reuse greywater?

02 THE STORY OF HEMP

Figure 2a. Industrial hemp crop.
Image source: http://hempourworld.org/wp-content/uploads/2014/07/hemp-farm.jpg

Industrial hemp, or Cannabis sativa, is one of the most promising and yet undervalued crops of today. It is very environmentally beneficial: it can be grown organically, without herbicides or pesticides; it is carbon negative; and it regenerates soils. It grows densely and vertically, and offers high yields with its short growing season of 3-4 months. It is a resilient plant that can adapt to a variety of climates, including that of Spain. France, our neighbour to the north, is in fact Europe's biggest exporter of hemp.

Hemp can be used to produce over 25,000 products. Rope and canvas are made from the raw fibres, while the younger and more refined fibres are suitable for paper and textiles. Hemp hurds can be mixed with other materials to produce building materials, such as insulation and "hempcrete". The seeds can be pressed into oil for use in the food industry, or applied for personal care and cosmetics. All parts of the plant can be used, so nothing goes to waste. This plant holds much potential for cultivation in Spain.

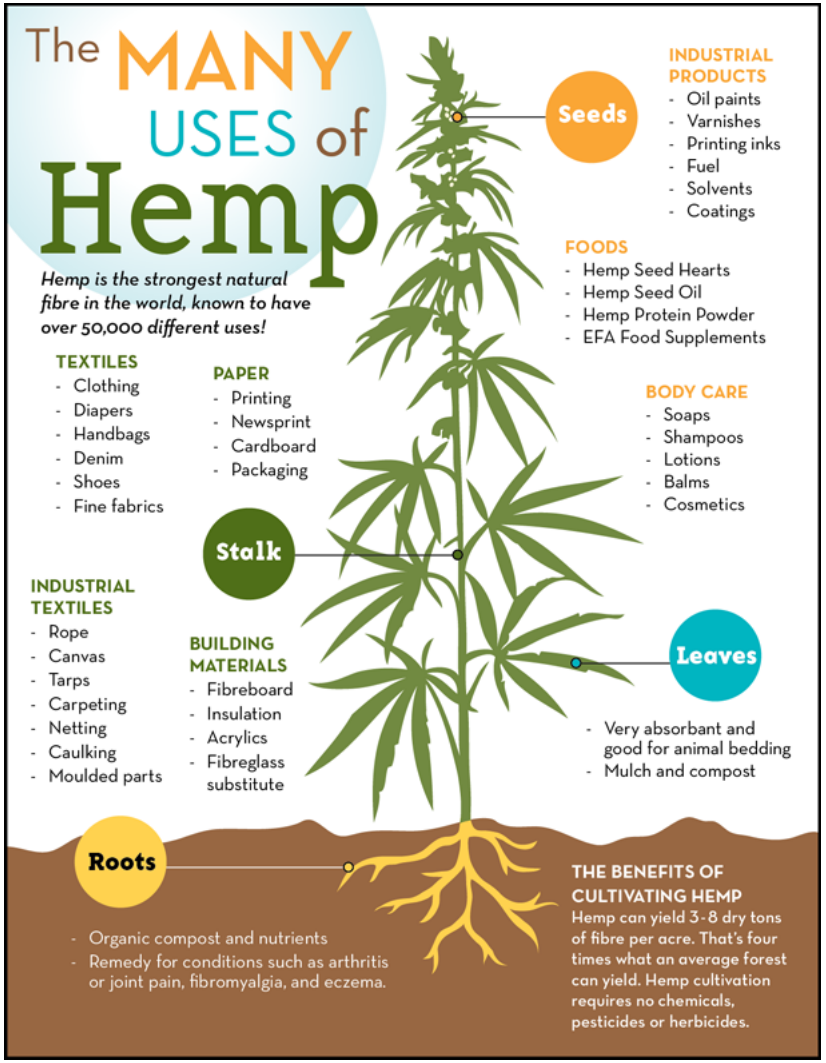


Figure 2b. Hemp uses infographic.
Image source: http://canadahempfoods.com/wp-content/uploads/2014/07/Uses_of_Hemp.png

03 THE STORY OF EIXAMPLE

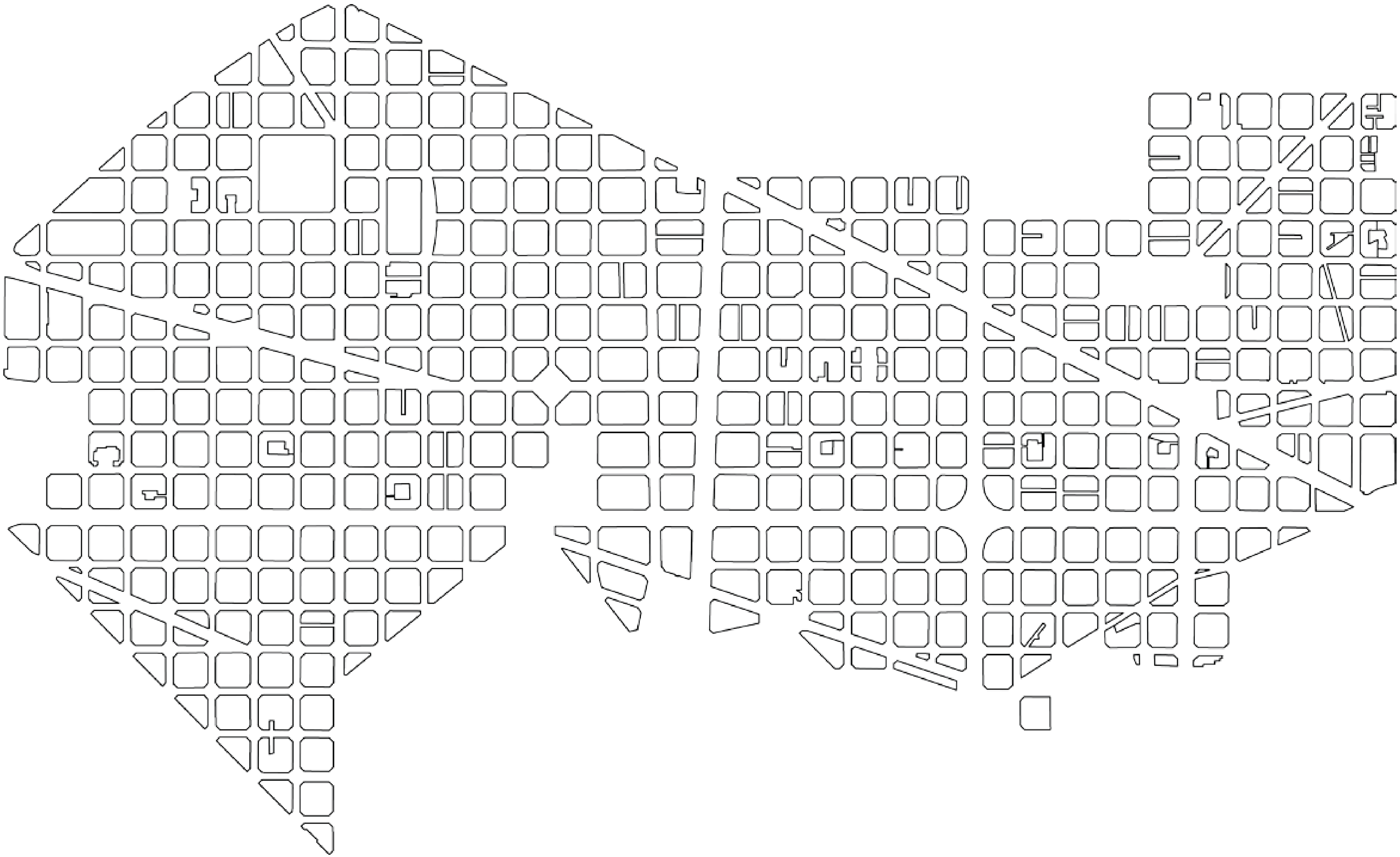


Figure 3a. Barcelona's Eixample neighbourhood as it is today.

Eixample is the brainchild of Ildefons Cerda. Following the demolition of the walls of the Old City of Barcelona, a plan was needed to expand the city and connect it with Gracia and other surrounding towns and villages. In 1859, a competition was held to develop such a plan. Cerda approached the challenge from a logical perspective. Having studied the cramped and unhealthy conditions of the Old City, his goal for Eixample was to create living spaces that received adequate light and ventilation, as well as to provide ample green space for its citizens. He worked with a square grid to create a modular layout with housing blocks of similar characteristics. He oriented the blocks NW-SE so that all apartments would receive an approximately equal amount of sunshine during the day. The streets are a minimum of 20 m wide with half of that width intended for pedestrian use. The building heights were originally not to exceed the width of the street, allowing plenty of light to penetrate down to the streets.

Although monotonous, Cerda's original design was undoubtedly a carefully considered approach to urban planning. Unfortunately, due to predictable politics and economic reasons, Cerda's original plan was significantly altered. Nevertheless, the Eixample remains a district of unrealized potential.

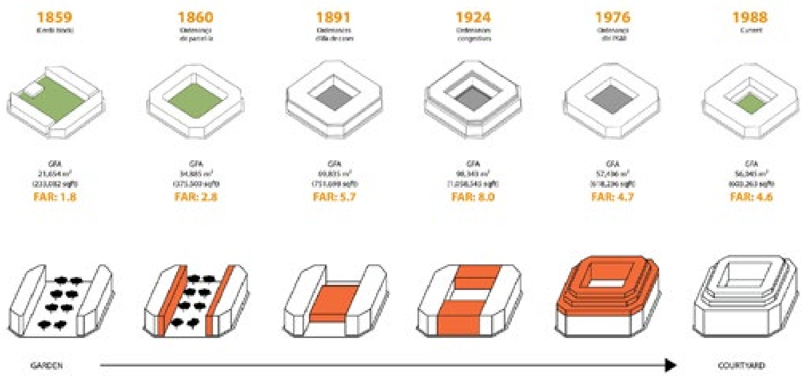


Figure 3e Evolution of the original Eixample block.
Image source: http://projectivecities.aaschool.ac.uk/portfolio/yuwei-wang-barcelona-block-city/

Figure 3b. Eixample from above, satellite view.
Image source: http://i.widelec.org/38jv.jpg

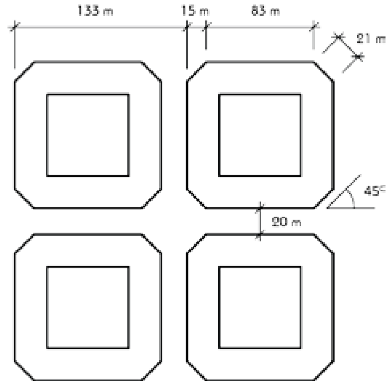


Figure 3c. Eixample dimensions.

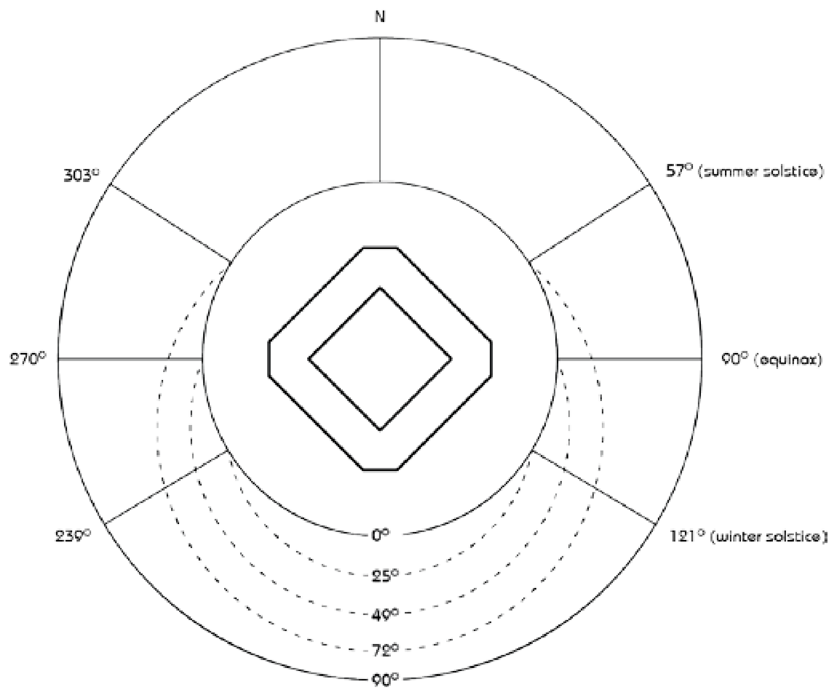


Figure 3d. Eixample sun path and light distribution.

04 THE NATURE OF SYSTEMS

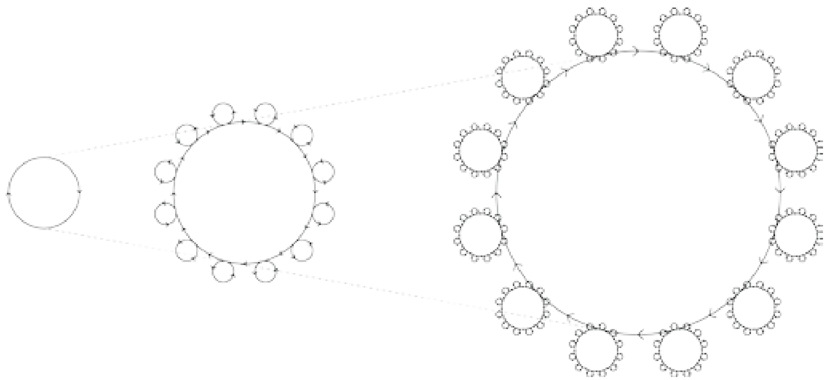


Figure 4a. Simple cycle vs. fractal cycle.

In nature, processes reflect a fractal geometry. Each level reveals an additional layer of complexity: from the scale of the Earth, to the biome, to the ecosystem, to the niche, and so on. Moving from the global to the local to the microscopic, one notices similarities as well as differences, but at all of these scales there is something going on. The water cycle is similar. On a global scale, one observes the movement of water as it evaporates from the oceans and then condenses over land, eventually moving back to the oceans either along the surface or through the ground. However, at each point of the water cycle, "mini" water cycles are also occurring. Not only that, but the water also becomes a part of other cycles, such as the carbon cycle, the life cycle, the agricultural cycle. As the water moves between various systems, its physical and chemical composition changes, and so does its application or usabilility.

Simple linear systems (usually man-made) lack the fractal structure of natural systems. The water cycle of the city lacks the diversity or the complexity of the water cycle of the earth, and its only relevant label is "potable" or "waste". How could we reimagine cities as self-sufficient, closed-loop systems? And how could we reimagine the cycle of water within these new cities?

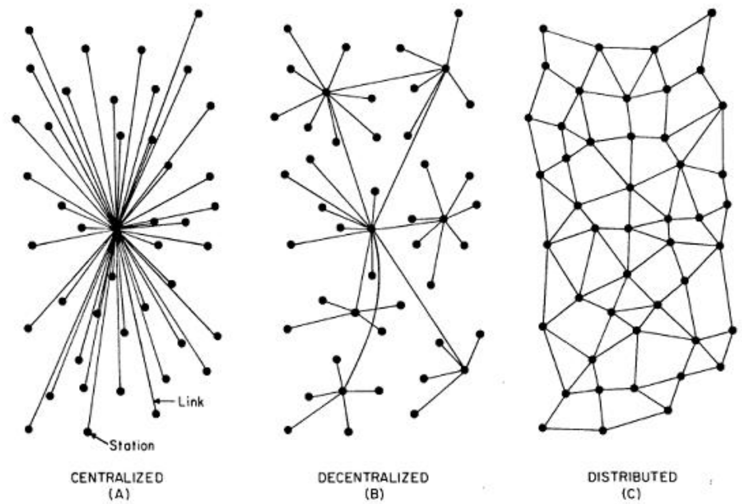


Figure 4b. Centralized, decentralized, and distributed networks.
Image source: On Distributed Networks Communications, by Paul Baran, 1964, p 2

We have also designed our cities and systems according to centralized or decentralized principles. The water within our cities is collected, treated, and stored at a few select nodes which are equipped with the knowledge and systems to deal with it. However, this organization is not only inefficient, but also highly vulnerable. Distributed networks would offer much greater self-sufficiency and resilience. Can we rethink the distribution of municipal water in terms of new network systems?

Figure 4c. Microbial Home project: Methane digester and larder.
Image credit: Philips Design

The microbial home has served as inspiration for this project. An experimental endeavour by Philips Design, it is an attempt to create a cyclical domestic ecosystem, designed towards self-sufficiency in the home. The outputs of one process act as the inputs for another, eliminating the concept of waste altogether. This project demonstrates that it is possible to combine multiple processes to create a larger and more complex interconnected system - the same way that pieces of a puzzle join together to form a bigger picture.

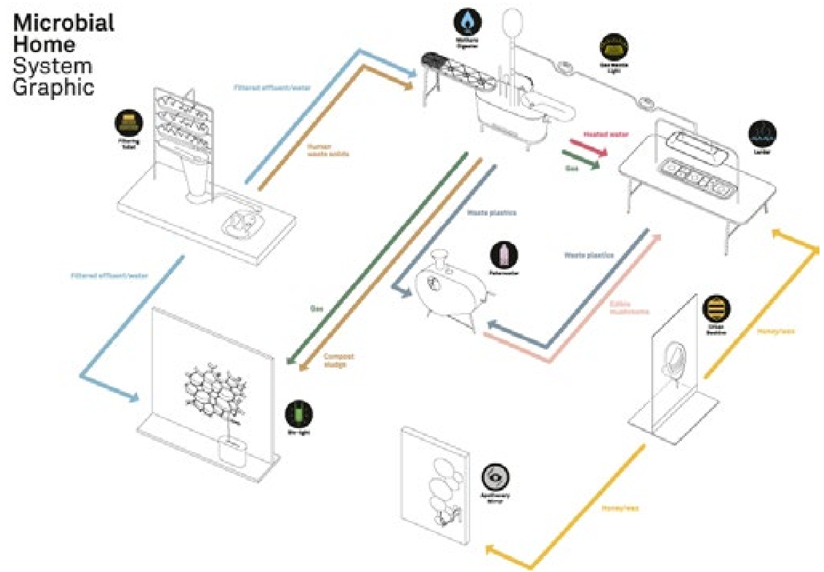


Figure 4d. Microbial Home project: System graphic.
Image credit: Philips Design

05 THREE STORIES AS ONE

Combining the three stories, we arrive at the following scheme:

Tapping into a readily available and reliable resource (greywater) to enable a system of vertical farming (hemp) grafted onto an ideal urban fabric (Eixample).

The underlined words are important because they highlight key defining parameters of the design approach:

Reliability: The advantage of such a proposal within an urban context is that the design can be predicated on the assumption that there will always exist a supply of water. Therefore, any activities that rely on this supply can be safely planned ahead of time.

Verticality: The nature of cities is that they are dense and offer limited space in the horizontal plane. The design must therefore take advantage of space available in the vertical dimension.

Grafting: Perhaps most importantly, the design should take into consideration the existing urban topology and conditions, and present an improvement which is realistic and applicable to the present.

Greywater intended for reuse must be of a certain minimum quality, depending on its desired application. For irrigation purposes, the crop to be grown would be the determining factor of water quality. Crops intended for human consumption would require much higher quality greywater and therefore a more intensive treatment process to remove toxic compounds such as hormones, heavy metals, or other contaminants otherwise dangerous to human health. This is yet another reason why hemp would make an excellent fit as an urban crop.

Outgoing greywater would have to be tested in situ. For this, flow-through sensor cells could be installed into the existing plumbing. These would be able to measure the quality of greywater as it flows through the pipes on its way out from each residence. Of course, it would not be possible to perform tests requiring special lab equipment or extra time. However, flow-through sensors could provide more than enough useful data, including readings about greywater pH, salinity, turbidity, and temperature. These parameters would be enough to determine whether the greywater is suitable for its intended purpose.

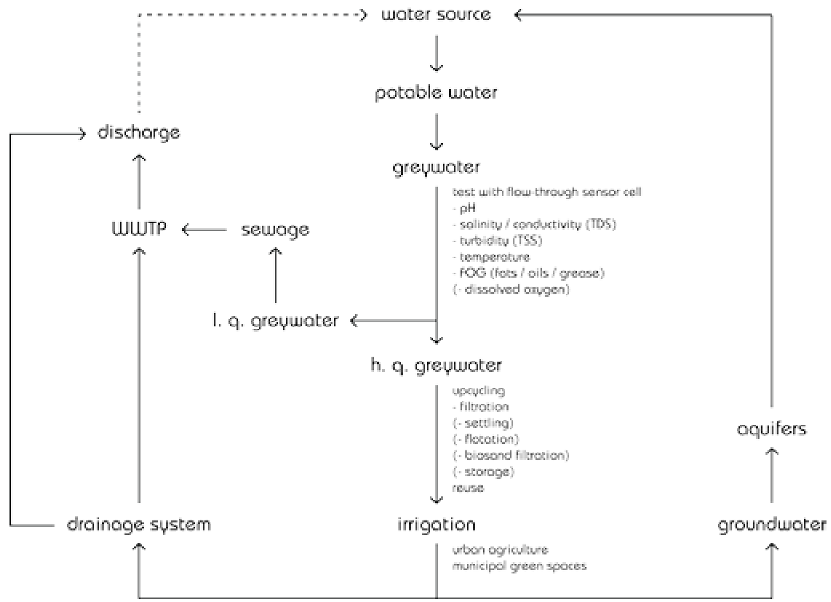


Figure 5a. The greywater cycle.

Distributed networks pose spatial and economic challenges with regards to water treatment options, another limiting factor to the potential greywater applications. The dense nature of the city, in particular the Eixample district, would preclude any massive interventions, and the existing buildings have not been designed with in situ water treatment or storage in mind. Greywater of insufficient quality would have to be diverted to Barcelona's wastewater treatment plant where it could be upcycled with more intensive and extensive processes unavailable in a residential setting.

However, it is important to remember that most greywater sources are already relatively clean, so the percentage of greywater that could be reused without an intensive treatment and filtration process would already be quite high. In fact, greywater tends to be rich in nitrogen and phosphorus, as well as other elements, making it a valuable nutrient source for landscaping and agriculture irrigation. A greywater reuse scheme would reduce pressures on the environment by reincorporating nutrients from the waste stream into agricultural soils and crops in a manageable and distributed manner.

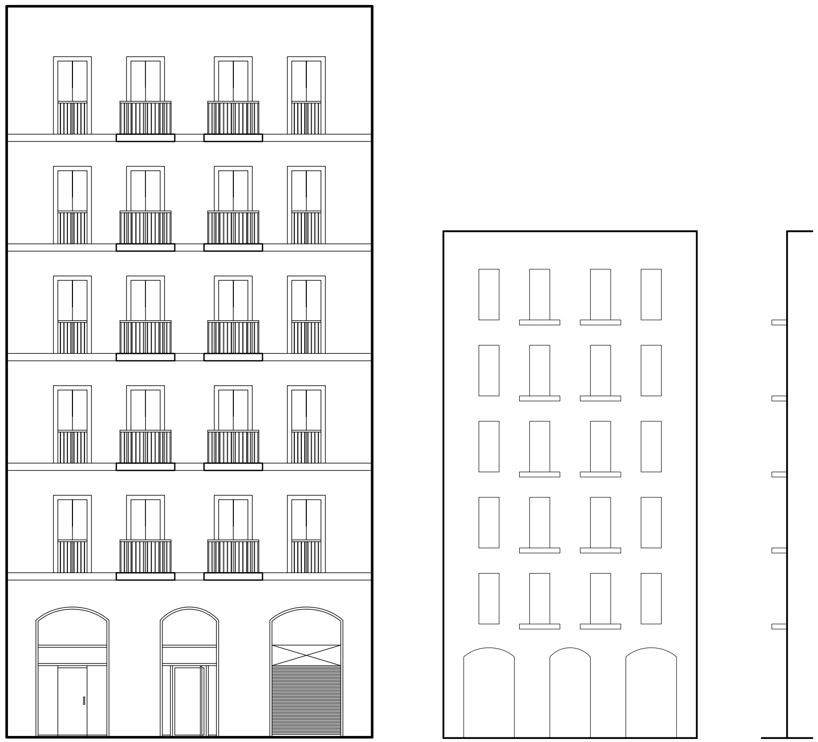
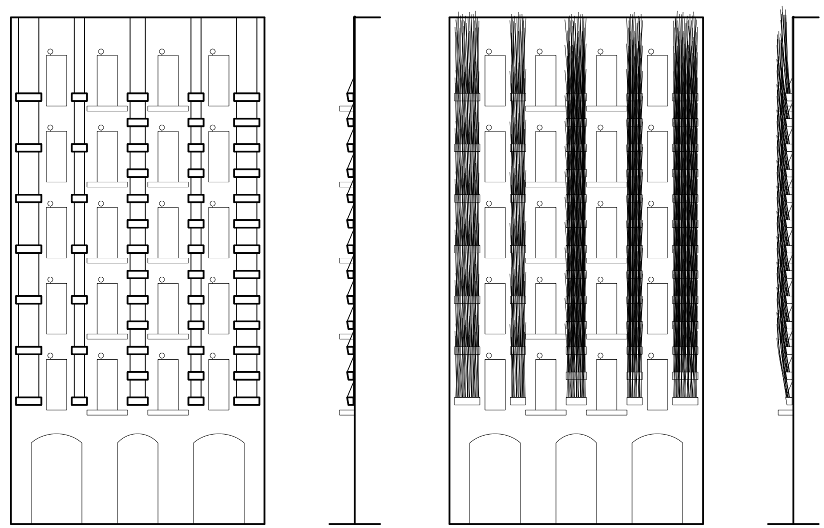


Figure 5b. Vertical growing scheme.

The image on the left shows a generic building typical of the Eixample typology, in this case 10 m wide by 20 m high. Buildings are a minimum of 20 m in height, with a ground floor and five or more stories above it. Newer buildings may have larger windows, but the majority have openings that may lead to a small exterior balcony. Balconies may be individual or horizontally continuous.

Removing the details, one can see that the openings account for only about half of the facade's horizontal dimension, which leaves a fair amount of facade space that is vacant or not in use. This leaves a lot of room for the application of a vertical scheme.



Cables are suspended from the roof of each building, from which planters can then be hung. These planters would be pre-seeded with hemp, while fertile soil could be used from the compost generated from the city's organic waste. The spacing of the planters could vary, with a minimum of 1 m distance (= 3 planters per floor) to allow adequate growing room for the hemp, which can reach a height between 2 and 4 metres, depending on the species.

The growing season for industrial hemp starts in late April or early May. Hemp grown for its fibres could be harvested 10 to 12 week after planting. Alternatively, hemp grown for the seeds would take between 16 and 18 weeks to fully mature, although the fibres would be older and stiffer by this time. Planters could be removed together with the hemp and then taken to a central location for harvesting and processing. All components would be reusable.

06 ENGAGING THE USER

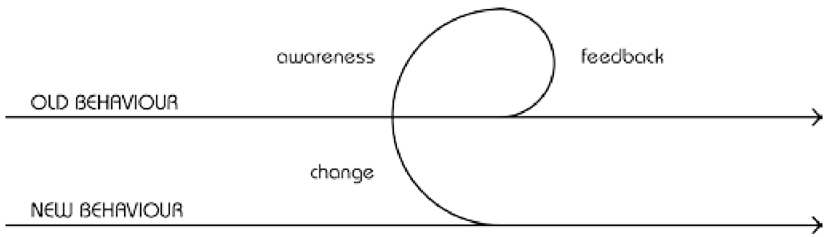


Figure 6a. The feedback cycle.

A greywater reuse proposal is nothing without its users. Due to the aforementioned limiting factors in such a proposal, the main strategy for reusing greywater would be for citizens to directly reduce contamination of their water supplies. This would be difficult to achieve without feedback about their water use patterns and consequences.

Greywater reuse initiatives in the past have not been successful for various reasons. Figures 6b and 6c demonstrate a direct reuse approach with no feedback and limited to no human involvement. Such a solution is purely technical and fails to address the deeper underlying issues. The projects in figures 6d and 6e offer feedback through interaction on a simple, emotional level, and in this way are more successful in conveying the issue at hand. However, these projects are more authoritarian, and deliver their message through negative reinforcement. It would be more useful to engage the user in a more positive and educational manner.

Figure 6b. W + W Toilet Sink.

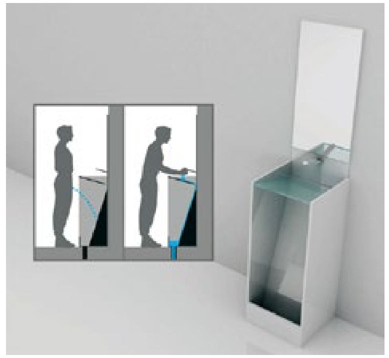


Figure 6c. Eco Urinal.

Figure 6d. Green Warrior shower curtain.

Figure 6e. Poor Little Fishbowl sink.

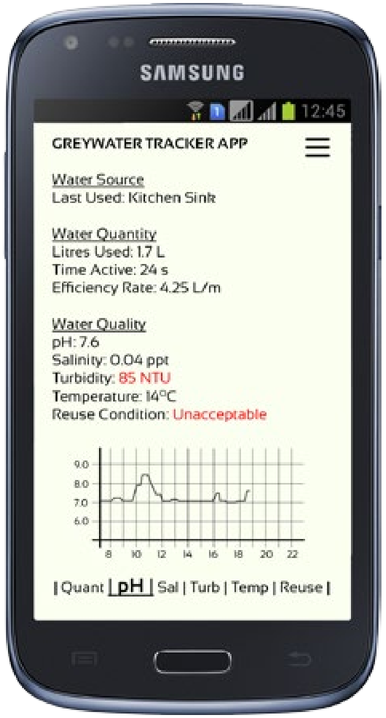


Figure 6f. Mobile app interface.

Detailed information could be obtained from the flow-through sensor cells installed in the outgoing plumbing. These would measure water quality parameters such as pH, salinity, turbidity, and temperature. Water use stats could be relayed in real time through a mobile or online app.

The challenge here would become one of translation: How could specific scientific data be interpreted by the user? The average citizen is probably unfamiliar with the technicalities of water quality. For this reason, a feedback system would have to act as both educator and interpreter.

The following list provides an explanation and interpretation of water quality characteristics of domestic greywater:

pH
Explanation: A chemical measure of the acidity and basicity of the water supply.
Acceptable range: 6 to 8.5
Consequences: Too low or high pH can harm plants, pollute the groundwater supply, and create conditions otherwise unsuitable for life.
Interpretation: Rely on mechanical rather than chemical cleaning methods; switch to organic cleaners and detergents; be more economical with laundry.

Salinity
Explanation: A chemical measure of the total concentration of all dissolved salts in the water. This is related to conductivity and can be measured by water's capability of passing electrical flow.
Acceptable maximum: 0.5 ppt
Consequences: High salinity can dehydrate plants, and corrode underground infrastructure.
Interpretation: Avoid disposing of concentrated saline solutions, especially when cooking.

Turbidity
Explanation: A physical and easily visible indicator of water quality which includes all particles suspended or finely mixed, but never dissolved, in the water.
Acceptable maximum: 55 NTU
Consequences: Turbid waters may clog pipes, or encourage bacterial growth and microbial pollution, especially from organic material.
Interpretation: Use physical filters for drains to remove larger solids, be mindful of products that would increase turbidity (especially surfactants).

Temperature
Explanation: A physical measure of how hot or cold is the water.
Acceptable maximum: 40°C
Consequences: In addition to using up energy, hot water can inhibit plant respiration and photosynthesis, increase solubility and thus toxicity of certain compounds (including heavy metals and salts), and create conditions for increased microbial growth.
Interpretation: Use colder water for laundry and dishwashing, limit temperature or volume of hot water during showers and baths.

FOG (Fats, Oils, Greases)
Explanation: A hydrophobic , organic substance of less density than water, either in free/floating or emulsion form.
Ideal maximum: None
Consequences: Oils and grease are one of the main reasons for clogged plumbing, they increase hydrophobicity of the soil and inhibit water uptake by plants, and they are generally toxic to plant and aquatic systems.
Interpretation: Dispose of FOGs appropriately, sort liquid wastes as you would solid wastes.

Users would be able to learn about the outcomes of their behaviours in real time, and become more mindful about their impacts on the quality of their water and its effects in the bigger picture. Gradually, this feedback would encourage responsible behavioural practices, and users' percentage of reusable greywater output would increase.

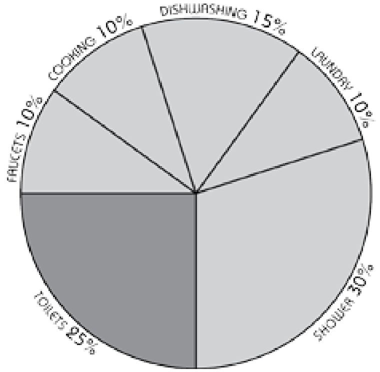


Figure 6g. Barcelona citizen's average daily water use by category.

So exactly how much greywater might be available for reuse? The average daily water consumption of a citizen of Barcelona is 120 L. Since a quarter of this produces blackwater, the maximum possible daily greywater output is 90 L per person. Let us assume that, at least for starters, only a third of this greywater would be deemed as reusable for irrigation purposes. Going by the 2014 population count of the Eixample district (263,500 residents), this would result in just over 7.9 million L of reusable greywater every day. The total area of the Eixample district is 7.48 km^2, while a typical Eixample block has an area of 17,769 m^2. This translates to roughly 626 residents per block, who would output close to 19,000 L of greywater on a daily basis.

To determine how much greywater would be needed for irrigating the vertical hemp gardens, I first calculated the exterior perimeter of a Eixample block - 416 m. Only about half of this is vacant facade space. However, all the buildings are different, and about half of them are not suitable for vertical farming due to continuous balconies, ribbon windows, or irregular facades. This would leave about a quarter of the original perimeter per block, or 100 m. I set the width of the planters at 20 cm. At an average of 16 planters that can be hung vertically along the available facade space, this ensures about 320 m^2 of growing space per block.

Hemp requires about 700 mm of precipitation per growing season. Averaged over 90 days, this translates to about 8 mm of water per day. For a 320 m^2 growing area, this equates to about 2560 L per day.

While a Eixample block outputs 19,000 L of high quality greywater per day, only an eighth of this would be needed for urban agricultural purposes. Since greywater of any quality harbours microbial growth, it should not be stored for more than 24 hours. How could the remaining greywater be harnessed within this time?

Up to 6% of Barcelona's total water consumption is for municipal purposes, or about 5 billion L per year. About half of this water is used to water the city's trees, parks, green spaces - that's 7 million L per day. To recall, a third of greywater reused for the Eixample district would generate 8 million L per day - enough to satisfy the city's green space irrigation needs.

At this point, two interesting changes occur. For one, a former waste is reimagined as a valuable resource, and suddenly there is a surplus of water, enough to satisfy a significant portion of the city's municipal water needs. But the second change is much more interesting. Since the municipal water needs are now directly dependent on greywater output from its users, a new relationship develops between the citizens and their city - that of the nurturer and the dependant. The wellbeing of the city relies on the responsibility of its people, who in turn gain a direct understanding of the consequences of their actions. As Barcelona establishes itself as a producer, its citizens will increasingly realize the socially, environmentally, and economically positive consequences of their actions, further reinforcing a more sustainable and self-sufficient model of urbanism through small yet effective lifestyle choices.

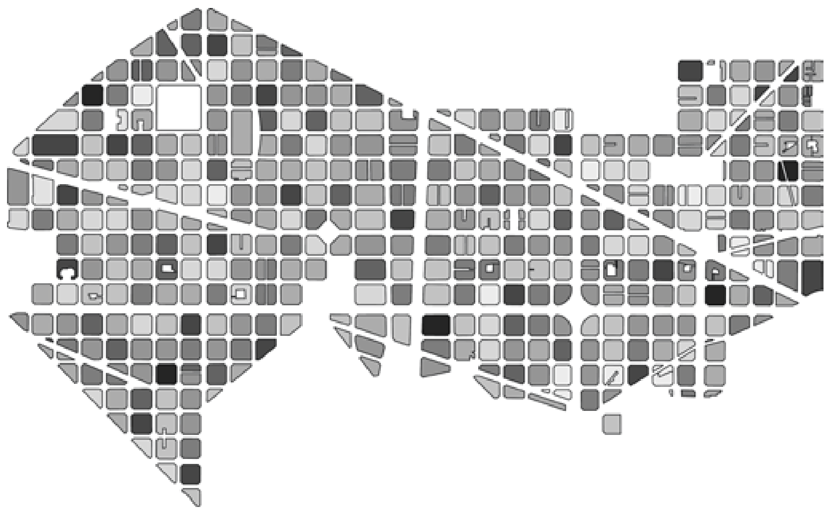


Figure 6h. The Eixample greywater challenge.

Figure 6i. Indicator lights in the night.

Feedback alone is not enough to mobilize people to action. There must be incentive, whether intrinsic or extrinsic. It would be impossible to account for every individual, since everyone has different priorities. Some might respond to social imperatives, others to economic incentives; still others might only be obligated by legal rule. The system would have to take this into account.

This proposal prefers to take a more positive approach to the issue of water use by focusing on the benefits and opportunities of greywater reuse. Figure 6h imagines a scenario in which the Eixample blocks (about 300 of them) are in healthy competition with each other to see who can produce the most abundant supply of reusable greywater.

The beauty of data is that it can be shared and visualized. Figure 6i demonstrates the idea of an indicator system which publicly displays which apartments are outputing which quality of greywater. While this may serve as a mere curiosity for some, it is a simple yet powerful tool for generating social accountability. With the help of a feedback interface, citizens would not only become informed about their water use patterns, but also become versed in the language of water. This would create the opportunity for a more concrete dialogue within the community and gradually reconnect the people with their city in a meaningful and synergistic way.

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