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DESIGN WITH NATURE

BIOHYDRO UPCYCLER

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MASTER IN ADVANCED ARCHITECTURE

50 SHADES OF GREYWATER: BIOHYDRO UPCYCLER

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THESIS / FOREWORD

Since the beginnings of capitalism and the industrial age, water has become a victim of humanity's unfortunate cycles. It is no longer free, so to speak, but a commodity with a price and a label, its fate a function of economic and political factors. As with other resources, water is an element to use as we see fit, which has predictably led to a deterioration of respect and consequent degradation of a formerly symbiotic relationship. And since water is the lifeblood of this planet on which we live, our abuse of this most precious element results in negative reverberations through virtually all other ecosystems.

Most of humanity's modern business has adopted a linear cycle of never-ending and ultimately unsustainable growth. From our products to our energy sources, we burn through all that is readily available to power our increasingly demanding lifestyles. Water is no exception - we dam rivers, deplete aquifers, pollute our oceans, and contaminate our groundwater with industrial chemicals and leachates, ignorantly expecting that Mother Nature will take care of what we have so carelessly wasted. Every ecosystem has a saturation point though, and one day we will wake up in a world with no more freshwater and wonder where things went wrong. Of course, in our absence, these ecosystems would have a chance to heal and restore themselves, and the Earth would become whole again. So really, it is we who are in trouble, because once we have damaged the systems that have sustained us for so long, we will not survive.

Our thoughtlessness and inconsideration have carried into the design of the world in which we live today. Our cities, systems, and lifestyles all reflect centralized, linear processes, with ever-decreasing self-sufficiency and resilience. Let us return to water, since it is the central focus of this project. Instead of using water responsibly and practising daily conservation techniques, we have become accustomed to the illusion that there is and will always be a never-ending supply of water. We infuse our water supplies with all varieties of chemicals and toxins without giving a second thought as to where this water is going and whom it is going affect next.

Sadly, this is not entirely our fault. With globalization and increasing urbanization, we are becoming more and more removed from the processes that drive our civilization - the same way that an assembly line worker cannot be blamed for a critical design flaw that occurred in a computer thousands of kilometres away. We are no longer able to see the big picture for what it is - the complexity of the world around us and everything in it is too much for our minds to grasp. Of course, we study abstractly in school the names of oceans and the nature of the water cycle and such, followed by a museum visit to an exhibition about indigenous people and their former way of life - before

us. The trouble is that they still exist, and very much so, yet the exhibition has framed them in history, to be studied as a curiosity and eventually forgotten. And so too do we make this mistake with studies of the biosphere - as though reading a textbook about the water cycle will have an even reasonable effect on our understanding of water in real life.

The reality is that we are in trouble because we have troubled our environment, and there does not exist an easy fix to all the problems we have caused. Unless we make an active effort to learn about these systems as they pertain to our daily lives, one day we will be the fools.

So what is it about water that makes it so special? Well, it moves. It moves through the ground, through the skies, through the river and the oceans, through our bodies and even our minds. As it moves, it changes form and composition, collects elements and depositing compounds, and renews itself. All of this happens au naturel, with the flow.

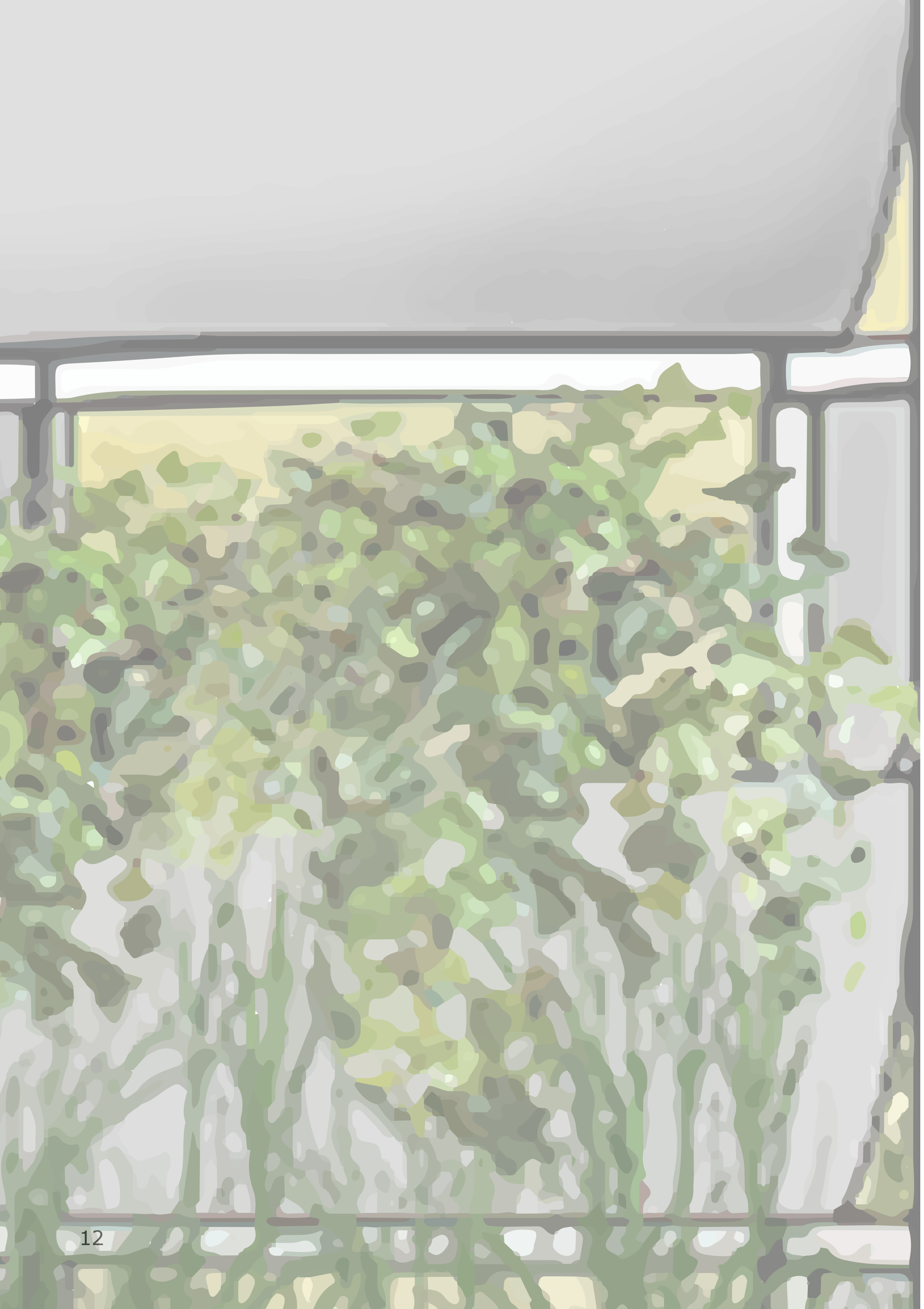
And then we come along and decide that we need the water to be where and when we are at our convenience, in order that we can irrigate our crops and water our lawns and take our 15-minute showers - and steaming hot ones, too. This mentality of bending nature to our wills is not a healthy one. Of course, we have always shaped our surroundings, but there is a difference between working with nature vs. having nature work for us. When we are not working with nature, we are working against it, employing brute force to achieve what was never meant to happen. For example, if we examine our treatment of wastewater, it is a beast of a process with a multitude of steps that attempt to purify sewage, a truly undesirable concoction of, well, everything. We must separate the solids and the fats and oils for the liquid (which must also be disposed of separately), pass this through anaerobic and aerobic reactors and various biochemical treatments, then continue with the removal of organics, nitrogen, and phosphorus, and finally disinfected with chlorine or similar. Meanwhile, there are probably still traces of undesirable chemicals - toxins and hormones and so on - in such minute quantities that they will most likely stay in our water supply for decades to come. And of course this man-treated water will almost certainly never taste as good as water freshly melted from a glacier. So why go to all the trouble in the first place?

As our world complexifies, there is greater availability and unpredictability of chemicals that find their way to our water supplies, and this is an issue we have yet to tackle. The ironic thing is that somewhere out there, nature is already working its magic to create the next bacteria which will take our waste and process it into usable form. This is not an invitation to continue freely in our callous ways, but an observation that at the end of the day, our understanding and appreciation of natural processes are decidedly absent.

So where do we go from here? Well, in the 1980s, a man named John Todd pioneered what he called living machines, or eco-machines, to address the issue of deteriorating water quality. They are based on natural wetlands - nature‘s so-called kidneys due to their water purification processes. Eco-machines range in complexity depending on the size of the machine and the wastewater that needs to be processed - from just a few plant species to an entire ecosystem rich with plants, algae, zooplankton, snails, fish, and many other species. These systems are very effective at breaking down and recycling nutrients, elements, and other contaminants, removing them from the water and converting them into living biomass.

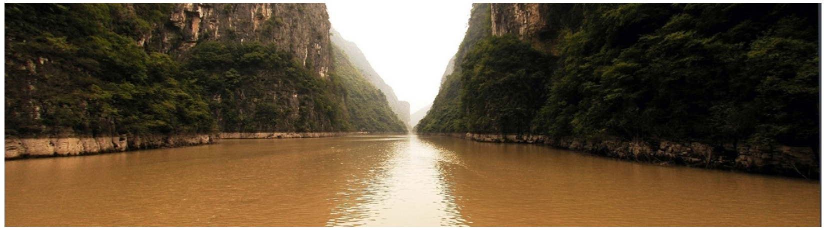
Why hasn‘t such a model been widely adopted? Most likely because the brute force ideology still prevails. Industrial wastewater treatment methods, although crude, are currently faster and can treat much larger volumes of water - volumes that we consume on a daily basis. Demand maintains the status quo - for business and so too for water. But another reason we have not turned to nature is because it‘s challenging. Biology and chemistry as pure subjects are difficult enough to master on their own, and to gain an adequate understanding of an ecosystem even as small as one of John Todd‘s eco-machines can take a lifetime of study and research.

So we are left with the question of wastewater - damaged water that, if given the choice, we would probably leave to its own devices, but that we ultimately have to deal with, for better or for worse. Since the topic of wastewater is quite broad, I have chosen to address specifically the issue of greywater at a domestic scale - how we can rethink the nature of greywater and turn waste into opportunity.



01 AN INTRODUCTION

Water is the lifeblood of this planet. Since the industrial revolution, especially in the last century, water has become an abused resource. Most of our water bodies have become polluted, and we can no longer safely consume water from most natural water sources. Today's wastewater treatment systems are highly energy-intensive, require massive and extensive infrastructure, and often use chemicals and other less than ideal methods to process wastewater to potable levels. And yet, we drink less than 5% of our daily water use. Not all activities require such high quality water, and different activities produce different types 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. What if we could redesign the system to upcycle and reuse greywater?



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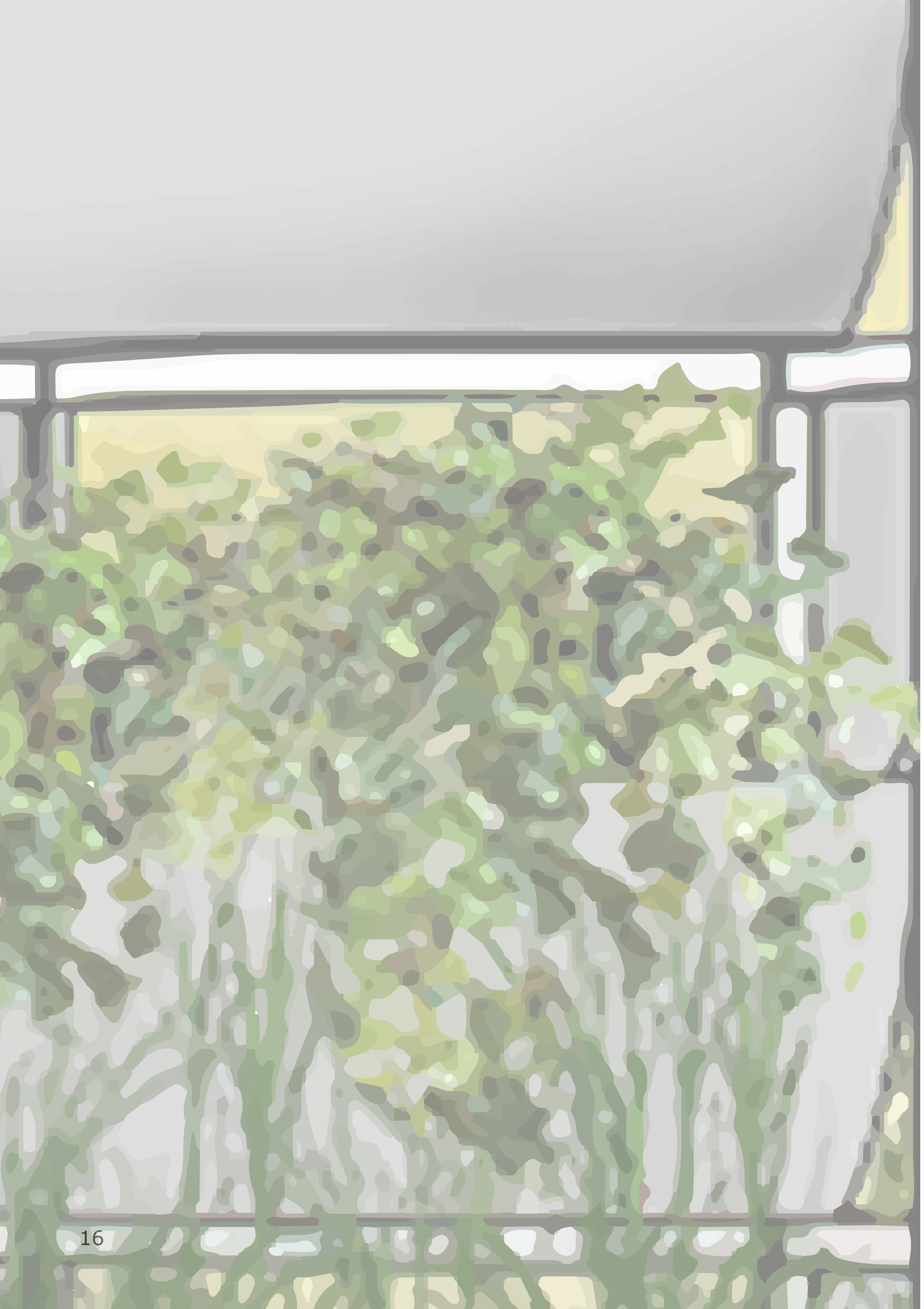
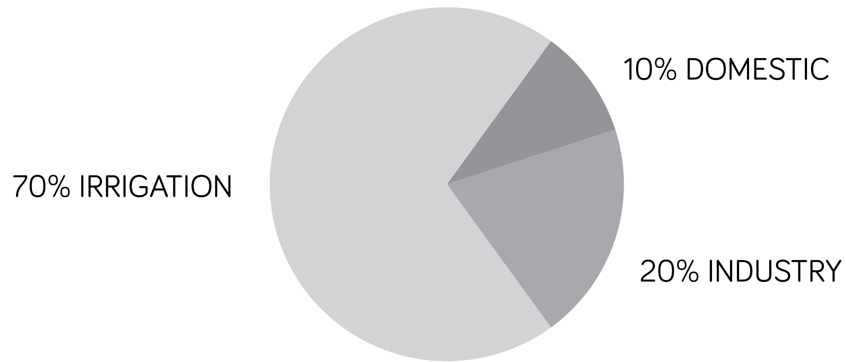
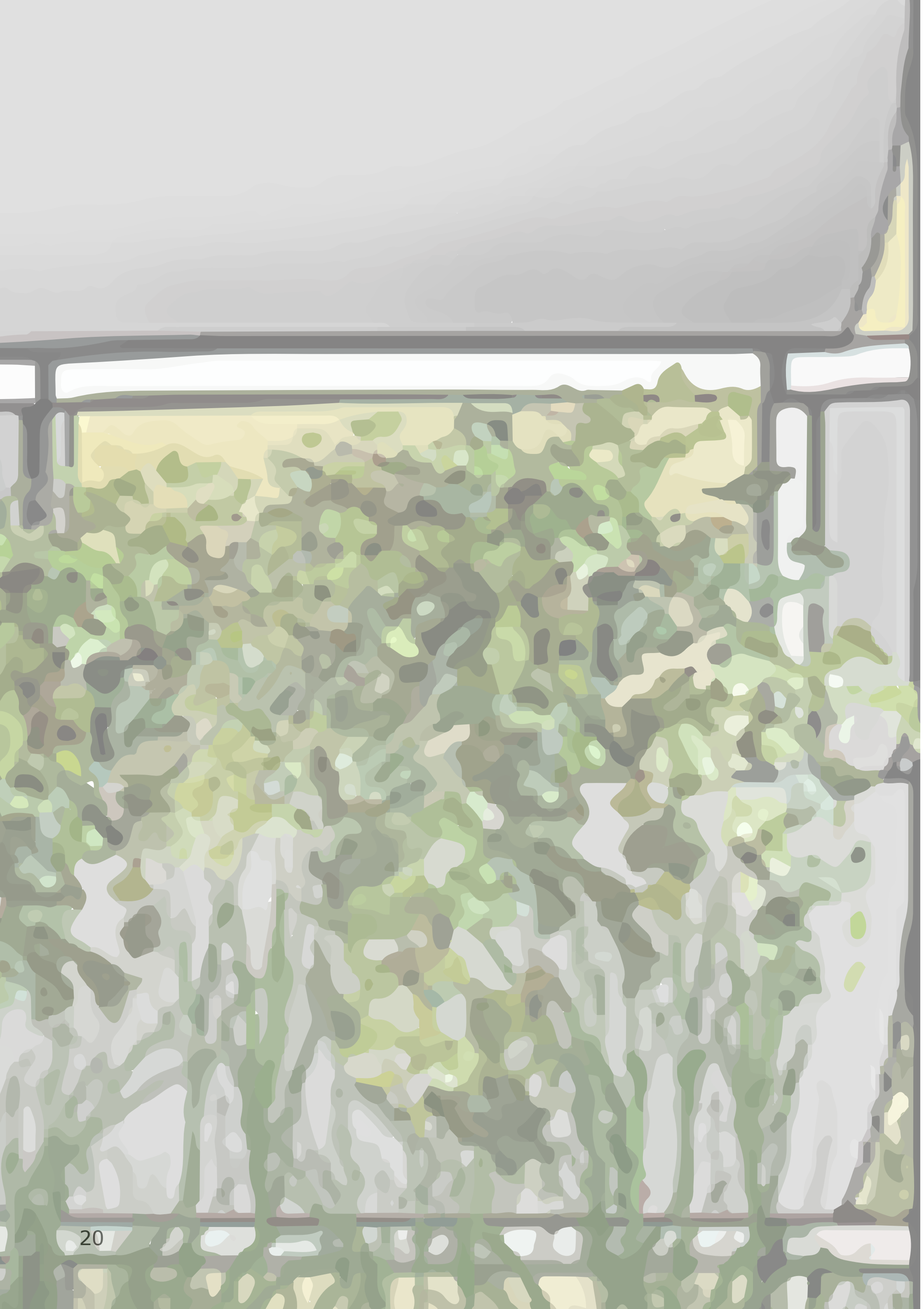


02 ON PRODUCTIVE LANDSCAPES

Agriculture accounts for about two-thirds of global freshwater use. In most cases, greywater is adequate for the irrigation of crops. By combining a readily available greywater supply with existing space, it becomes possible to transform otherwise unproductive landscapes into agriculturally productive ones, addressing the issue of greywater treatment while generating a local food supply.





03 OBJECTIVES

My objectives in designing a system for upcycling greywater were many:

(1) Domestic design

Most water treatment facilities are too large-scale to be practical for domestic purposes. One of the most popular small-scale water treatment options is a multi-stage sand/gravel filter. However, while such a system might prove effective for purifying rainwater, which is essentially free of any chemicals or pathogens, alone it would not be enough to adequately treat greywater.

(2) Ease of integration

A domestic water purifying machine would need to be designed so it could be easily integrated into existing wastewater infrastructure.

(3) Simplicity of filter system

Most water treatment systems today are very complex, requiring knowledge of physics, biology, chemistry, and industrial processes, among other things. However, the most simple wastewater treatment systems available today are also the ones that have been around for the longest time.

Slow sand filters have been around since the 1800s. They require only two key ingredients - sand and gravity - in order to function, both of which are not difficult to come by. As water flows through a slow sand filter, pathogens and other particles are trapped in the sand and removed from the water.

Living machines, or eco-machines, were pioneered by a Dr. John Todd back in the 1980s to address the deterioration of water quality. However, they are based on natural wetlands, also known as nature's kidneys due to their water purification properties. These systems are very effective at breaking down and recycling nutrients, elements, and other contaminants, removing them from the water and converting them into living biomass. Eco-machines range in complexity depending on the size of the machine and the wastewater that needs to be processed - from just a few plant species to an entire ecosystem rich with plants, algae, zooplankton, snails, fish, and many other species.

(4) Flexibility and adaptability

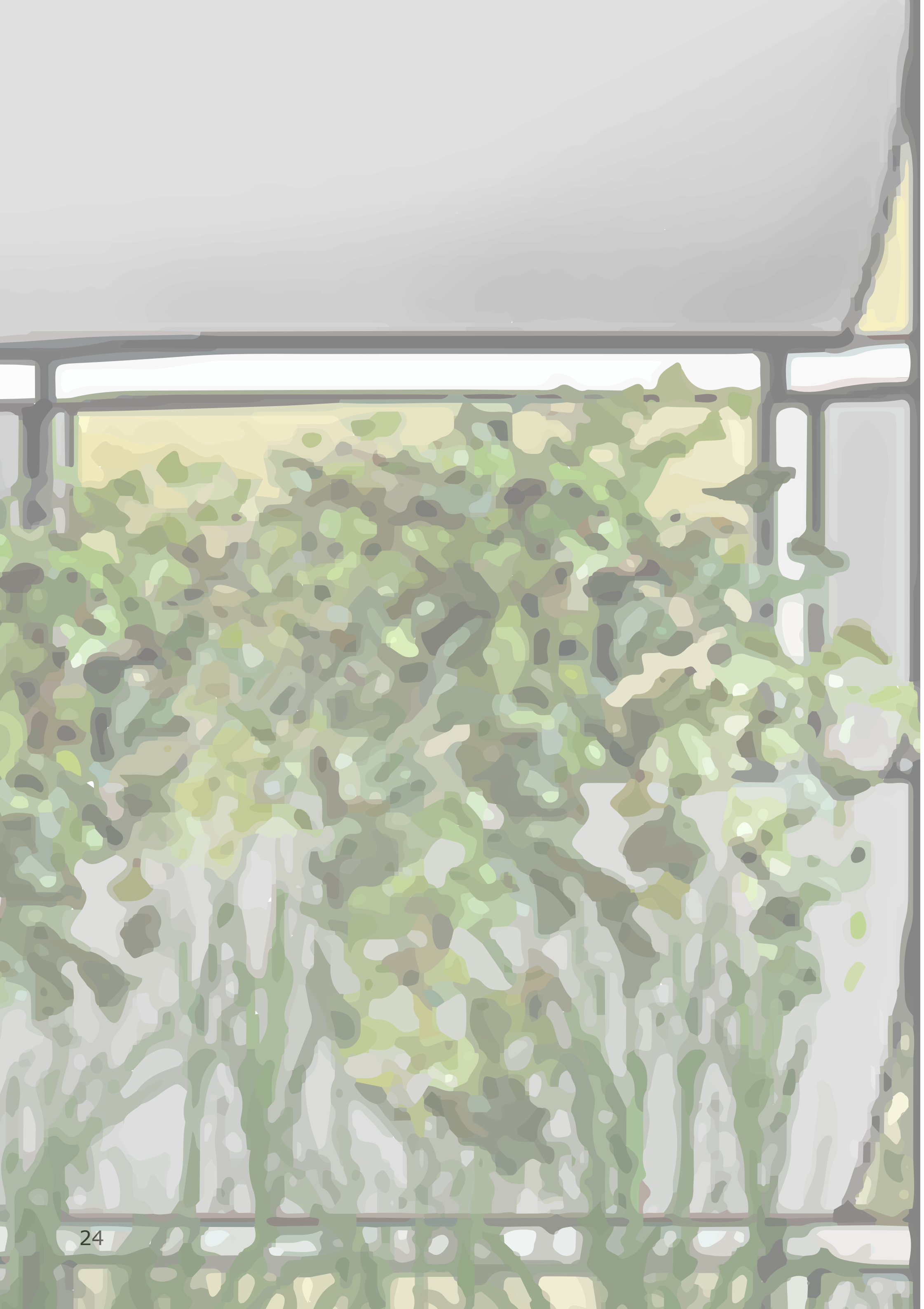
Modular designs allow for flexibility and adaptability within systems. Components can be easily replaced and repaired, and the resulting system is scaleable. In the case of the eco-machines, modular components would allow for the incorporation of a variety of different water purification "cells".

(5) Ease of maintenance

Another difficulty with water purification systems involves their maintenance. Filters and membranes need to be replaced, pumps and machines need to be cleaned and disinfected, water quality needs to be checked constantly. A domestic water purification system would ideally demand no more maintenance than is regularly required around the home.

(6) Aesthetic

Water purification systems are generally designed only for functionality. A machine meant for the home would ideally also have aesthetic appeal in addition to its functional purpose.



04 BIOHYDRO UPCYCLER

Enter the BioHydro Upcycler. This biophysical water purification machine relies on simple technologies to upcycle greywater for reuse. Compact and adaptable, it is designed to be integrated into a domestic setting, unlike most biophysical water treatment systems, which operate at larger industrial scales. One such machine has the capacity to purify, at minimum, the daily greywater output of a single person. The physical and biological mechanisms within the machine break down and consume the pathogens, nitrates, phosphates, organic compounds, as well as other elements, purifying the greywater to a level suitable for irrigation purposes. Such a decentralized approach to water management demands minimal infrastructure and would help to alleviate the load on urban water treatment systems, while creating increasingly self-sufficient and resilient cities and communities with local food supplies.

The BioHydro Upcycler is comprised of three water purification channels:

(1) Bio Sand Filter

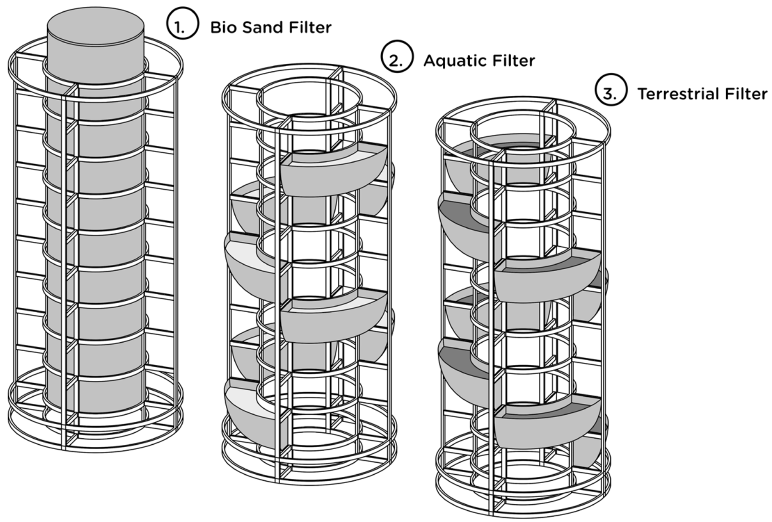
The bio sand column is where most of the pathogens and organic matter are removed.. A biofilm layer called the schmutzdecke forms in the top 2 cm of the sand. It is in this layer that pathogens and organics are trapped and consumed by microorganisms in the schmutzdecke. Any pathogens that make it past the biofilm quickly die from a lack of nutrients and oxygen - the deeper the sand column, the more effective this process.

(2) Aquatic Filter

Natural wetlands - the kidneys of our Earth - contain a multitude of plant species that are highly effective at removing nutrients, especially nitrogen and phosphorus, as well as metals, and even toxins from the environment. Constructed wetlands attempt to emulate these natural systems, usually with high degrees of success. Since the BHU is intended for smaller-scale operation, the water-purifying macrophytes need to be chosen to fit the scale of the machine, as there are many varieties (such as bulrush and reeds) that grow a matter of meters and would not fit by size.

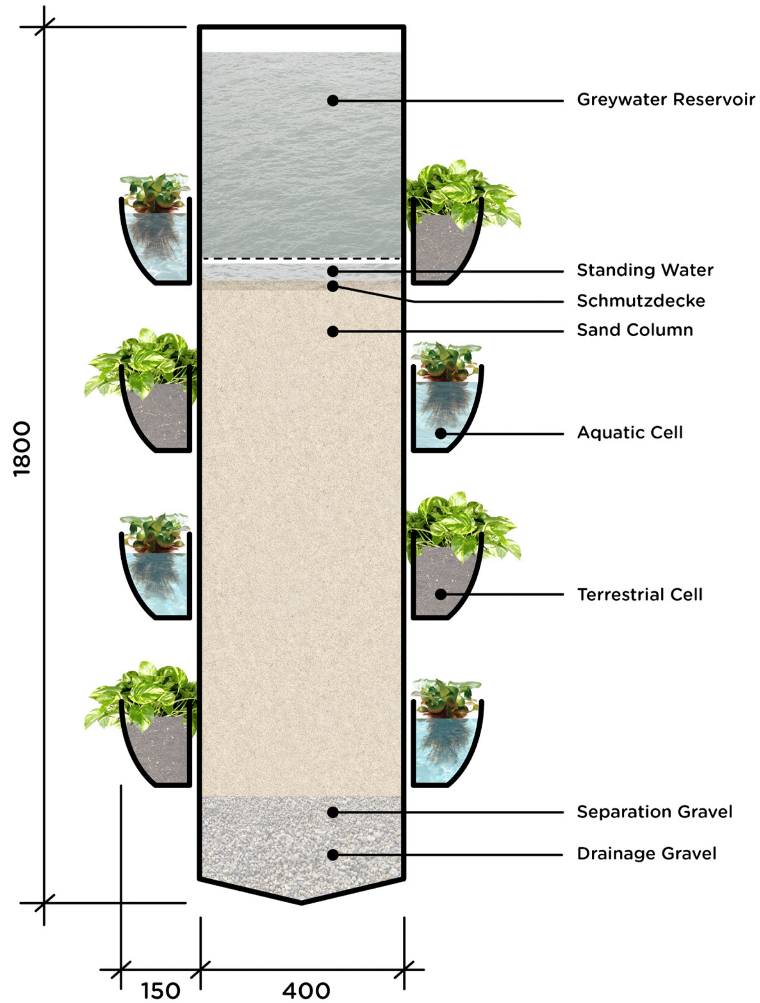
(3) Terrestrial Filter

Last, but not least, the terrestrial filter contains a series of soil-based potted plants. The microorganisms in the soil are different than their aquatic counterparts and offer an additional dimension to the water purification process. Terrestrial plants can also exhibit higher tolerance to weather and temperature changes.



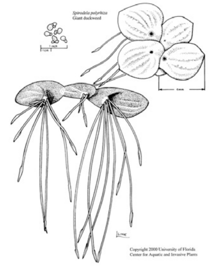
Together, these three water purification channels work synergistically to purify greywater to a level that would not be possible with each filter alone. This is important for several reasons. First and foremost, pathogens can form a serious threat to human health, and even though they are present in greywater in small quantities, their removal is necessary in order that they do not come into contact with the edible plants that we intend to irrigate with this greywater. Secondly, depending on the greywater source, concentrations of certain chemicals might be too high for garden plants to tolerate, so by removing some of these elements beforehand and normalizing both their concentrations and the pH of the water, the greywater will not result in acute or chronic degradation of irrigated plants and soils. For example, the first wash from laundry machines typically has a pH of 10.5, while soils normally tolerate a maximum pH from 8-9. Ideally, the application of the BHU would be preceded by a shift to more environmentally friendly and less chemically intensive soaps and detergents, a step that should make common sense even in our everyday consideration of water use.

Another aspect of the BHU design is that the individual aquatic and terrestrial cells are modular and can be configured to more effectively match the greywater influent. Terrestrial and aquatic cells can also be interchanged - say, if more macrophytes are required to remove metals and toxins from the greywater supply.



The use of an aquatic filter requires a careful consideration of macrophyte species. There are three types of macrophytes: submerged, emergent, and floating. Typically, many macrophytes employed for water purification purposes in both natural and constructed wetlands are fairly tall - some, like bulrush and reed, can grow to a height of 4 metres. Naturally, this size does not fit the compact and domestic nature of the BHU machine. As such, smaller plants need to be chosen. Water hyacinth is one of the most effective known phytoremediating plants and can be found in virtually all constructed wetlands; duckweed is another. Each plant varies in its ability to uptake certain nutrients and chemicals. Heavy metals, for example, would become trapped in the growing biomass of the plant itself. Otherwise, with floating macrophytes, the bacteria and other beneficial microorganisms that develop on the roots of the plants purify the water as it flows past them. For this reason, water undergoes more effective purification if it is allowed to remain in contact with the plants for longer.

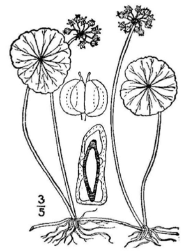
Sedge grass



Duckweed

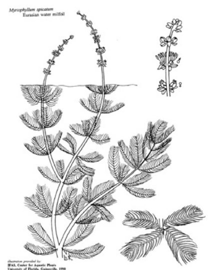
Broadlead arrowhead

Water hyacinth

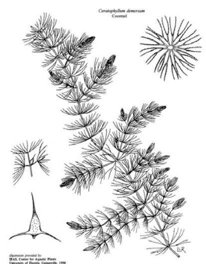


Pennywort

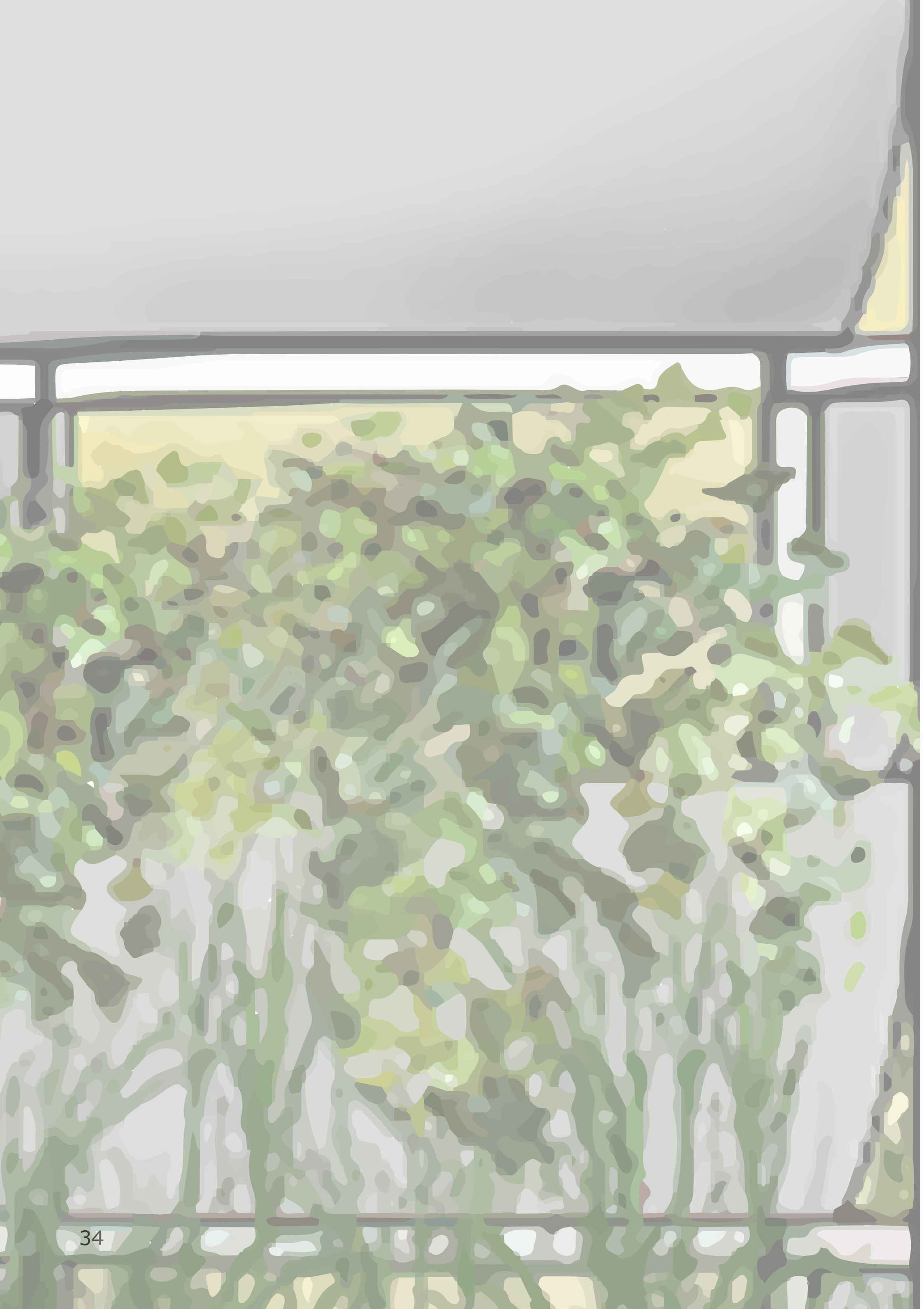
Frogbit



Eurasian watermilfoil



Coontail

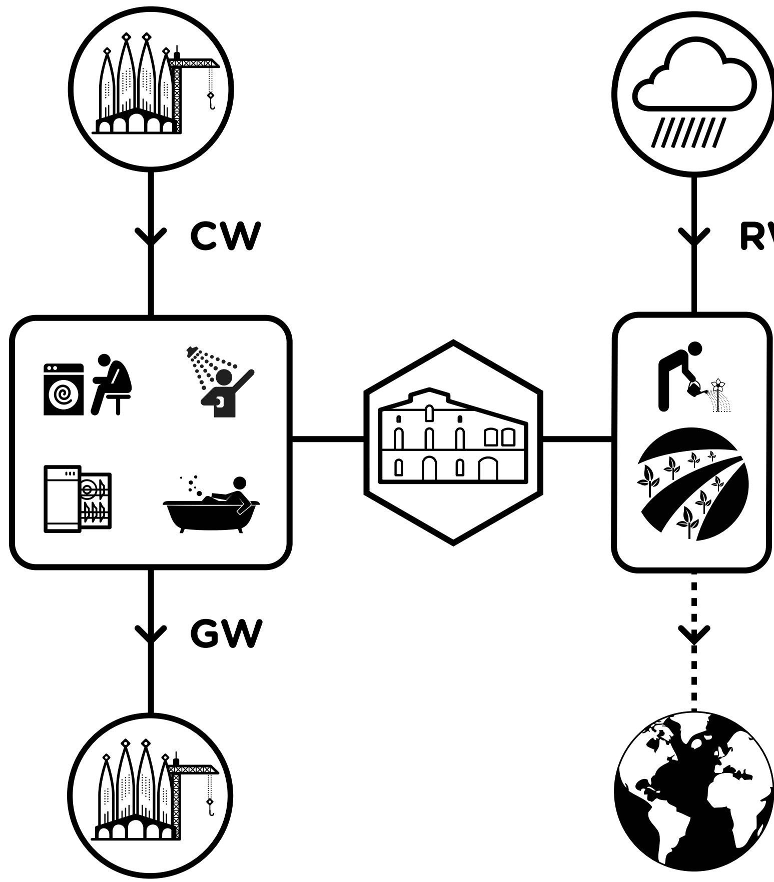


05 VALLDAURA

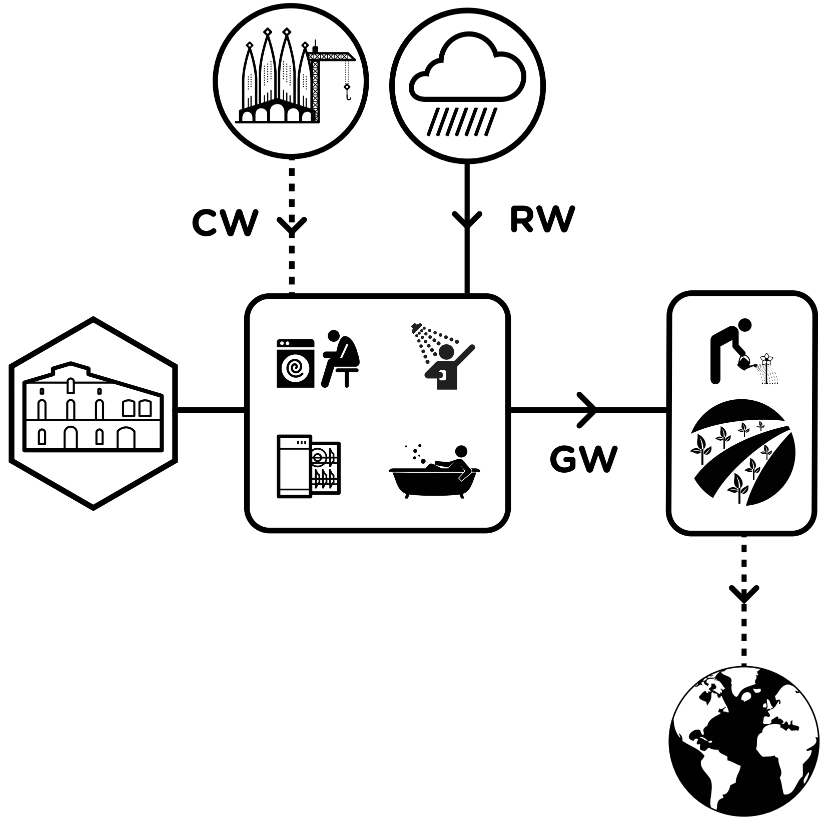
In Valldaura, water is a precious commodity. Since it is a location without service, water must be trucked in from the city of Barcelona, and consequently wastewater in sewage form must be trucked out. Meanwhile, the rain collected from the site is used solely for irrigation purposes. However, since rainwater is practically clean and much easier to purify to potable levels, it would make more sense to do so and then use the resulting greywater to irrigate the surrounding landscape.

Crops usually demand a consistent and steady supply of water. Since household water use provides consistent output on a daily basis, greywater would provide such a reliable supply. This is also a logical arrangement when considering that greywater should not be stored for longer than 24 hours, otherwise it runs the risk of multiplying in pathogens and turning into blackwater. Rainwater, on the other hand, can be stored without worry for extended peridos of time. Since rainfall can be unpredictable, large quantities of rainwater can arrive all at once, then be filtered and stored for even daily distribution in the household, resulting in a regulated greywater supply for landscape irrigation.

The current water situation in Valldaura is based on a centralized water distribution system. It exhibits little to no self-sufficiency or resilience. Water is brought from the city, used in the household, and then the resulting wastewater is transported back into the city for cleaning. Meanwhile, rainwater is collected and used for watering the gardens, but can only be used once since it then returns to the soil and returns to the water cycle. As such, both water supplies are only applied once before they are either contaminated or lost to nature. This results in a very low efficiency water use model.



The new scheme would provide a high level of resilience with little to no reliance on an urban water supply, except in the case when there is not enough rainwater collected to supply the residents of Valldaura house. Rainwater could be used and then upcycled and reused as greywater for irrigation before it is lost to nature. Not only does this kill two birds with one stone, so to speak, but it results in a system where contaminated water is purified locally and with minimal effort by the BHU, and when the upcycled greywater is eventually released straight into the ground, it is already clean enough that nature can do the rest. This contrasts sharply with contaminated waters and leachates from industrial processes which must be collected and stored indefinitely, often due to unavailable treatment methods, because they are too highly concentrated and toxic for immediate release into the environment.



The is how the BHU machines might look when implemented in the context of Valldaura. Indoor positioning is also an option, as would be the case for apartments and housing without outdoor space in an urban context. Ideally, the machines would be positioned at a location lower in elevation than the household water supply in order that gravity can do most of the work, eliminating the need for extravagant pump systems. In fact, laundry machines already come with a built-in pump which could be harnessed to push the greywater through the purification system.

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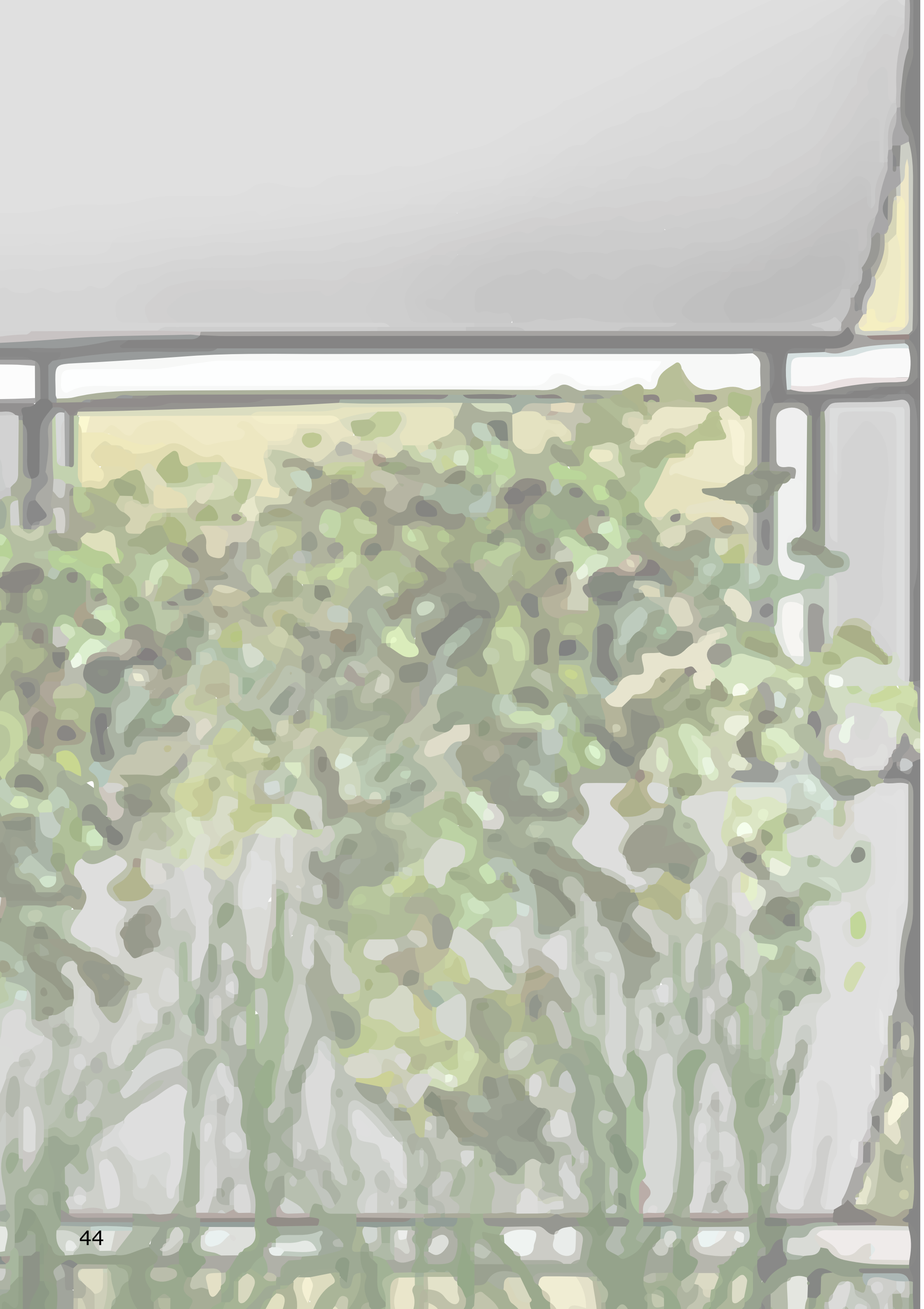


06 TERRITORIAL SCALING

One such machine has the capacity to purify, at minimum, the daily greywater output of a single person, or 50 to 70 L. This is enough to irrigate a 10 m^2 garden plot per day, which is enough area to provide at least half of the annual vegetable needs of one person. If implemented in an area with more readily available green space and greywater supply - single family homes, for example - the agricultural output would have the capacity to create self-sufficient microcommunities with a reliable local food supply.

Such a proposal could manifest itself in 3 main scenarios:

(1) High density urban context

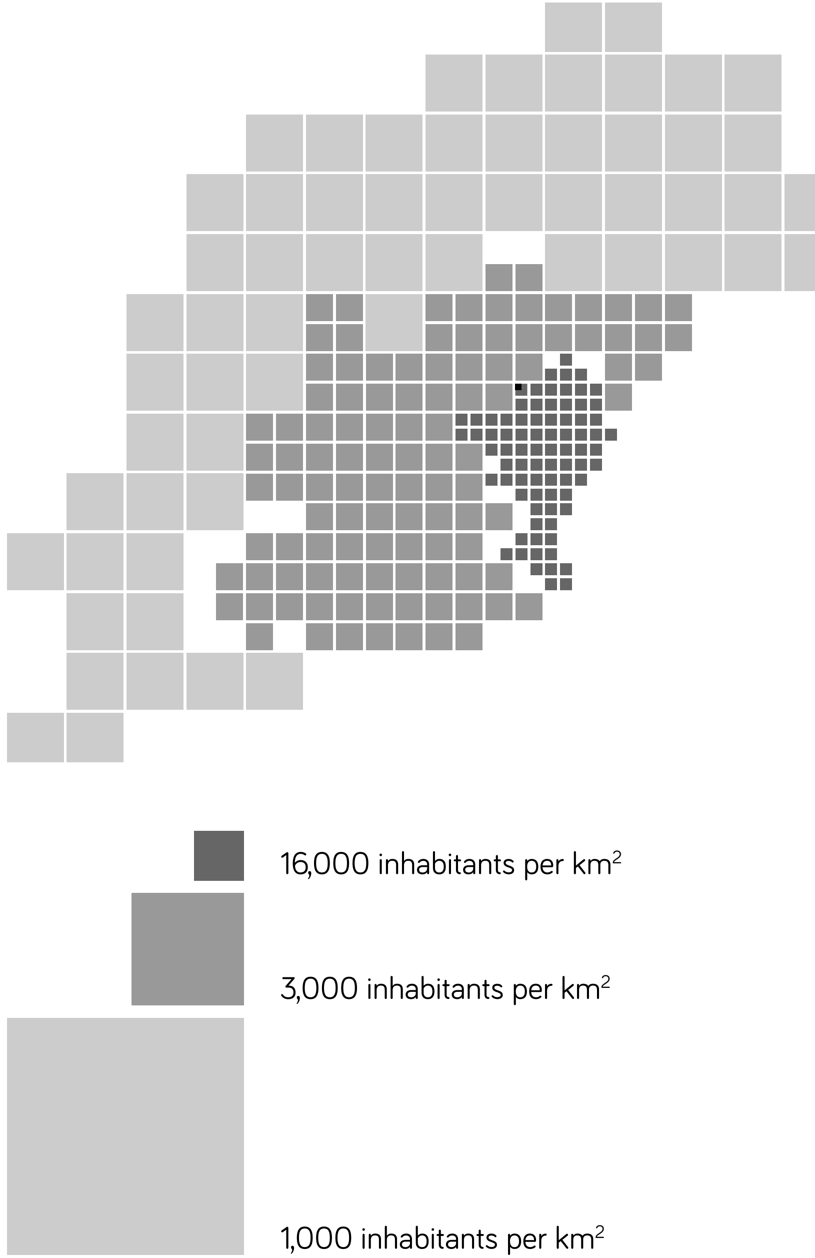
Due to the relatively high capital costs of the BHU (1,000s) and the relatively low direct returns (100s), as well as the limited amount of available growing space per person, the BHU system might not prove economical or effective enough integrated in such a context.

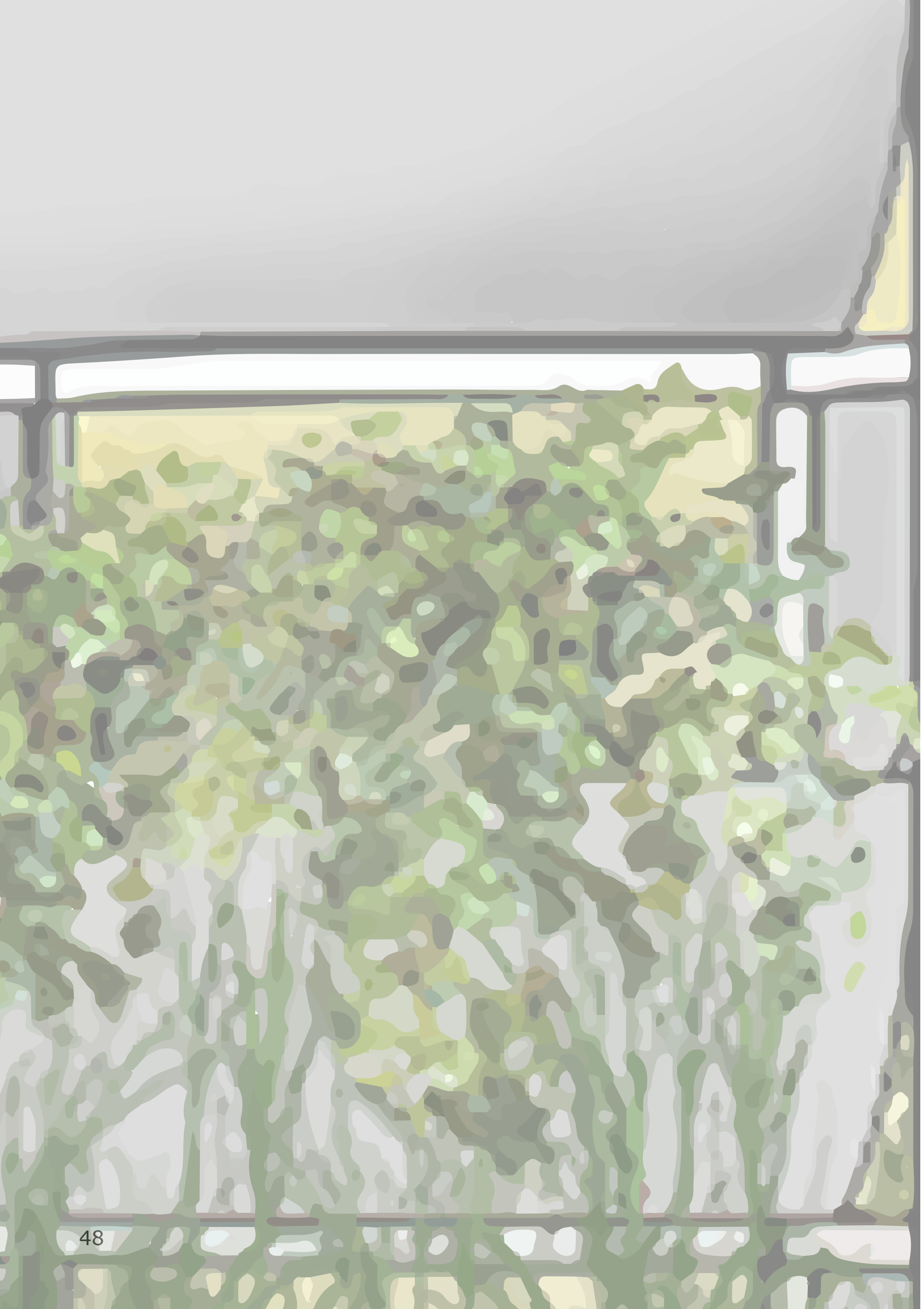
(2) Medium density suburban context

This is a more promising scenario and still dense enough to ensure that there is an adequate supply of greywater. Since there is more space per person to grow food, both direct returns (water cost savings) and indirect returns (food cost savings) would be higher.

(3) Low density rural context

Essentially farmland, such a context would likely not generate enough greywater to cover the available land areas. However, this context could exhibit higher self-sufficiency since there is an opportunity for households to satisfy most of their water needs from rainwater and groundwater.





07 CONCLUSIONS

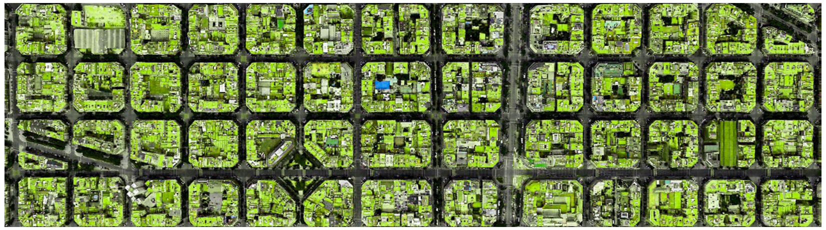
In conclusion, while the BHU system might not be the most salient water purification option in economic terms, there are still many advantages and benefits to this kind of approach to greywater management:

(1) It saves water and reduces the demand for fresh, high-quality water - both in terms of its use, which can increase water supplies by about, and also through decreased distribution loss, since water is lost through leakage - usually upwards of 10% and as high as 30%!

(2) Treating greywater on-site decreases both the need for and the load on infrastructure since there is a smaller volume of wastewater that needs to be transported to processed in a central treatment location.

(3) Greywater is rich in nitrogen and phosphorus, as well as other elements, making it a valuable nutrient source for landscaping and agriculture irrigation, and even more so in arid climates with pressures on water supply.

(4) Greywater reuse systems reduce pressures on the environment, not only by lessening surface and groundwater pollution from sewers and septic systems, but also by reincorporating nutrients from the waste stream into agricultural soils and crops in a manageable and distributed manner.



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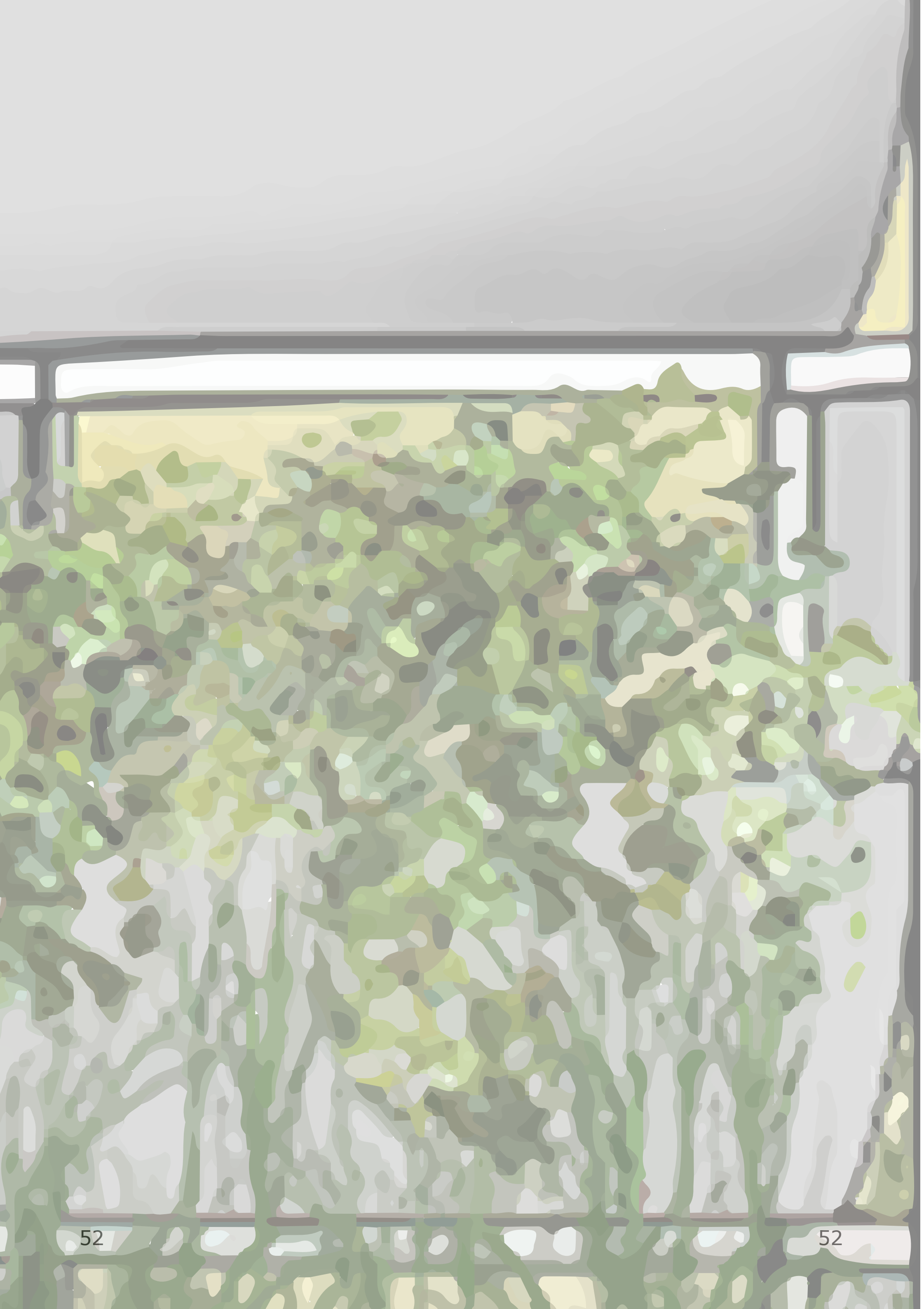

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