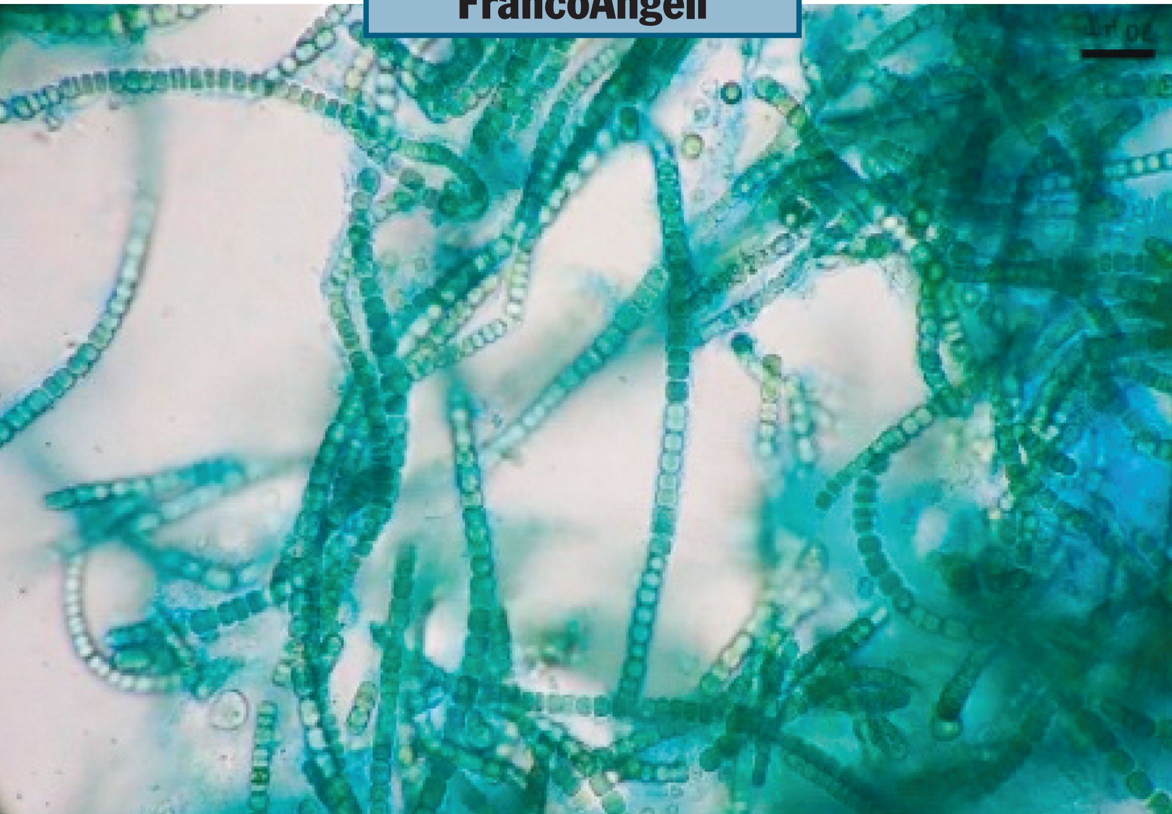
Fiammetta Costa, Attilio Nebuloni
(edited by)

THE JETSONS' KITCHEN

A zero-mile system for waste water recycling and cultivation



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Fiammetta Costa, Attilio Nebuloni
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THE JETSONS' KITCHEN

A ZERO-MILE SYSTEM FOR WASTE WATER RECYCLING AND CULTIVATION

FrancoAngeli

This book has been realized in the frame of a research named "Design for sustainability and ICT: a product system for waste recycling in home environment" funded by Politecnico's Fondo d'Ateneo per la Ricerca di Base 2016 (FARB) del Politecnico di Milano.

The name Jetsons' Kitchen comes from a quotation by Luciana Migliore.

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Appendix

The Jetsons' kitchen. A brief synopsis

Fiammetta Costa[1], *Attilio Nebuloni*[1]

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Zero-mile food production is gaining in popularity worldwide, due not only to greater awareness of the environmental impact of food transport, but also to expanding interest in healthy and sustainable diet trends. Following this trends, growing zero-mile vegetables as part of urban and architectural greening projects generates various benefits in terms of perception and environment. Aesthetic benefits are evident in the composition of vertical partitions and horizontal roofing, while in environmental terms such greening improves air quality and the urban climate with consequent energy savings. In this context, innovative forms of agriculture, which have been termed Zero-Acre Farming (ZFarming), are emerging in cities in addition to the renewed emergence of more traditional community gardens, providing people with space to grow their own food. These new forms of green urban architecture, which are characterized by zero land use or acreage, include rooftop farms and greenhouses, indoor farms, and other building-related solutions. This trend has contextually originated new interest in strategies and processes to promote the valorization of domestic wastewater.

Indeed, ZFarming can exploit wastewater that is already available on-site, since irrigation with reclaimed wastewater, not only reduces the consumption of fresh water, but also the use of fertilizers. Domestic wastewater is typically rich in mineralized nutrients, and peri-urban agriculture has historically benefited from the absorption of these nutrients. On a smaller scale, kitchen wastewater reuse has traditionally been practiced in rural communities.

The research described here sets out to update such practices to make use of the high nutrient content in kitchen wastewater, which is low in pathogens, heavy metals and pharmaceuticals.

Integrating vegetable cultivation in the domestic environment with reusing kitchen wastewater for irrigation is a promising strategy for reducing household freshwater consumption, as it limits the amount of wastewater to be treated by up-cycling nutrients for growing plants, produces healthy plant food and raises environmental awareness among citizens. A first step in this direction is the experimental project to reuse dishwasher effluents described in this book.

Dishwasher effluents were chosen as an initial bench test because of their high nutrient content, low harmful elements and constant wastewater quantity and quality. Further studies are planned to develop such systems at the kitchen, household, and community level. Here, wastewater treatment may consist of a combination of several chemical, physical and biological processes such as aerated lagoons, activated sludge or biofilms in trickling filters. Studies for the development of a domestic biofilter containing a consortium of microalgae and heterotrophic bacteria are also presented.

The book brings together a series of considerations by an interdisciplinary group of researchers from the Politecnico di Milano, Università Statale di Milano and Università di Roma Tor Vergata, ranging from biology to design through sociology and composition. They focus on the potential application of such processes as part of a new system which has been named ZERO MILE.

The first chapter describes some general aspects of the system, from expected results to the biological components needed for its development (Costa *et al.*). It is followed by an in-depth study of the biological filter itself, which will help to establish the design requirements to be adopted in the experimental prototype phase (Migliore *et al.*). On a larger scale, the third chapter focuses on the system's social dimension, investigating users' habits and ecological aspects (Volonté, Grana). The next chapter concerns the development of an experimental prototype at the domestic kitchen scale (Costa *et al.*). The final chapters document potential application scenarios in the building context (with an appendix of case studies and the generative processes used in their design by Nebuloni and Meraviglia) and on a larger scale a discussion of possible extensions to the urban environment (Costa *et al.*).

Benefits of implementing the system at the various project scales include:
1. Domestic or local production of non-contaminated vegetables. On-site production stimulates user participation, supports healthy eating habits, and contributes to a sustainable diet, decreasing the environmental impact of food production.
2. Reduced fertilizer use. Reclaimed wastewater is rich in mineralized nutrients obtained through biofiltration, which boosts plant growth.
3. Lower freshwater consumption and reduction of the amount of wastewater to be treated. The reclaimed wastewater is exploited for plant irrigation instead of using fresh water.
4. Perception of the water cycle and environmental awareness. Active involvement in wastewater recycling may trigger a broader cultural change in consumer attitudes, encouraging a transition from a linear to a regenerative, circular water economy.

The system, which is essentially grounded in the concept of the circular water economy, not only aims to stimulate a change in people's lifestyles and enhance daily living spaces, buildings and urban environment, but may also find potential applications in confined and extreme environments, such as refugee and emergency camps or Antarctic bases and space stations.

Notes

This book presents results research made possible thanks to the contribution of Politecnico di Milano (Fondo di Ricerca di Ateneo and Fondo d'Ateneo per la Ricerca di Base) and Regione Lazio (Programma Torno Subito). The name Jetsons' Kitchen comes from a quotation by Luciana Migliore referring to the futuristic kitchen of the Hanna-Barbera cartoon.

Designing the Future: An Intelligent System for Zero-Mile Food Production by Upcycling Wastewater

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Abstract

The project deals with the environmental problem of water consumption. The aim of this work is to experiment the recycling of dishwasher wastewater through its reuse in growing edible vegetables or ornamental plants; this can also accomplish the valorization of nutrients present in the wastewater. This new process allows to ensure washing functions coupled with vegetables production and to affect users' environmental awareness and habits, following a user-centered system design approach to understand the users and involve them actively in the system development. The presented work is also aimed to experiment a multidisciplinary approach in order to face environmental problems.

Keywords: dishwasher wastewater upcycling, plant growth, User Centered Design

1. Introduction

The concept of sustainable development and especially the component of environmental or ecological sustainability require awareness of the natural resources and the fragility of the environment, the impact of human activities and decisions on it.

One of increasing environmental problem is the consumption of water resources in household appliances. In this context, we propose a technological system to recycle dishwasher wastewater in the cultivation of edible and ornamental plants, to limit domestic water use, reducing the amount of wastewater released in the environment and valorizing nutrients present in wastewater, and to improve the indoor environmental conditions (air quality, temperature and humidity). Furthermore, the system will produce healthy and safe zero-mile food, beneficial to user behaviour and health awareness.

The research relies on an interdisciplinary approach, by combining experimental methodologies and User Centered Design (UCD) techniques (Norman, Draper, 1986): characterization of wastewater, plant growth and functionality analysis, technical design of the remediation plant, product and user inquiry, participatory design for expert and user involvement in the system ideation and development.

2. Material and Methods

2.1. Dishwashing, Analyses of Wastewaters and Study of the Household Treatment System

A household dishwasher (Energy Class A) was used, setting the "eco" program as washing cycle: the amount of wastewater discharged is about 12 L per cycle. As cleaning product, an EU Ecolabel certified dishwasher tablets detergent was selected, while the rinse aid has been excluded.

Two wastewater (W1, W2) and one potable water (C) samples were analyzed for physico-chemical parameters, being pH, BOD5, COD, and ionic composition. Analyses were performed according to Standard Methods (APHA/AWA/WEF, 2012). Wastewater samples were collected under the same dishwasher operating conditions, but different loads in term of food residuals.

2.2. Plant Growth and Plant Descriptor Analyses

40 lettuce plants (*Lactuca sativa* L.), grown in 2.5 L pots with peat-based substrate, were divided into 4 batches: plants irrigated with wastewater (W) or potable water (C), and plants treated with a mineral NPK fertilizer and irrigated with wastewater (W/F) or potable water (C/F). Experiments were carried out indoors under artificial lighting (TLED 26W Growing, Secret Jardin) at photoperiod L:D 16:8 h.

During the vegetative cycle, plants were watered at a rate of about 40 mL/day per plant. After 48 days, the lettuce was harvested, immediately weighed (wet weight), then oven-dried at 105 °C for 72 h and reweighed (dry weight). Furthermore, plant functionality has been evaluated by biochemical descriptors: in vivo determination of leaves chlorophyll content was performed using a CL-01 chlorophyll meter (Hansatech, King's Lynn, UK) and chlorophyll a fluorescence was measured on dark adapted leaves using a portable fluorimeter (Handy PEA, Hansatech, King's Lynn, UK). Nitrate concentration was measured by the salicylsulfuric acid method (Cataldo *et al.*, 1975) and calculated referring to a KNO3 standard calibration curve.

2.3. User Centered Design Approach

The design of the integrated system for zero-mile food production by upcycling wastewater is based on a User Centered Design (UCD) approach. This methodology is developed on a multi-step process, that starts from the analysis of the users' behavior and continues with their involvement in the design practice. The UCD approach has been implemented according to these phases: benchmarking analysis of domestic innovative systems for indoor plant cultivation; secondary data analysis; focus group with consumers and stakeholders.

3. Results

3.1. Wastewater Characteristics and the Water Treatment System

Analytical results show a significant difference in the ionic composition between the two wastewater samples, as well as with the potable water sample. W1 and W2 samples were characterized by a high pH value (W1 = 9.3; W2 = 9.6; C = 6.9) and about 50 and 27 times higher concentrations of sodium (Na+) ion compared to those measured in C sample (34 mg/L). The Na+ increase leads to an increase in salinity (indirectly evaluated by electrical conductivity) and it can be ascribed to both the presence of Na_2CO_3 in the detergent and the ion exchange process which takes place in the water softener inside the dishwasher. Organic composition of W1 and W2 samples is largely derived from food residues and therefore it is highly variable. W2 sample presents a higher organic content in term of both COD (W1 = 730 mg/L; W2 = 2600 mg/L) and BOD_5 (W1 = 210 mg/L; W2 = 1500 mg/L).

3.2. Plant Growth

The production and the quality of lettuce (*Lactuca sativa* L.) irrigated with wastewater or potable water did not show significant differences neither in wet and dry weight (*t*-Student test, n.s.), nor in chlorophyll content ($p<0.05$); the dry weights clearly show that the wastewater irrigation allows even a slightly higher growth than potable water and the use of wastewater (W) determined the highest accumulation of chlorophyll in leaves. Furthermore, leaf functionality was higher in plants irrigated with wastewater, as well as photochemical efficiency of PS II; the measure of the quantum maximum efficiency of PSII (F_v/F_m ratio) changed among different batches, ranging from 0.79 to 0.84: the highest index value was found in W, while it was significantly lower in fertilized batches irrigated with potable water (C/F). Lastly, nitrate content was lower in plants irrigated with wastewater (W ≈ 2900 mg/kg FW; W/F ≈ 2600 mg/kg FW) than with fertilizers, and the highest value was found in C/F (around 4000 mg/kg FW).

3.3. Benchmark, Consumers' Habits and Preferences

Benchmark analysis highlighted that just two companies proposed to connect kitchen's water consumption with plant cultivation by using a really integrated approach, but none of them considered wastewater recycling.

Regarding domestic products for growing indoor plants, the green wall systems show an interesting project's layout in terms of display and settings, responding to the needs of light and water, necessary for plant growth. Technological factors (such as integrated sensors and data processing systems) play an important role in these product systems, since they support the users in the growth and vegetative maintenance of plants.

The consumer's attitude towards diet is characterized nowadays by a kind of food polytheism (CENSIS, 2010): therefore, the identification of a well-defined target for the eco-kitchen and the home cultivation of edible plants is unlikely. Accordingly, interviewees and focus-group participants confessed struggling with enacting sustainable behaviors in everyday life, but showed some concerns regarding the eco-kitchen, particularly related to the functional issues like space involved, costs, compatibility with clean home conditions, rather than with health issues.

4. Discussion

In this study, the reuse of dishwasher wastewater has been successfully obtained by growing lettuce plants: no statistically significant differences were found between wet and dry weights of plants irrigated with control potable water or wastewater. The good plant growth was obtained in spite of the wastewater characteristics, which could affect the feasibility of plant irrigation (salinity) or the stable development of the biological process. In fact, although it is known that plant growth reduced under salt-stress conditions in many vegetable species (ISTAT, 2014), the research findings can be explained by the moderate salt tolerance of lettuce plants (Tunçtürk *et al.*, 2011). Furthermore, as the 'Shelford tolerance law' states, plant growth is optimal within a nutrient concentration range (De Pascale, Barbieri, 1995): the results of dry weight confirmed that the wastewater irrigation ensures even a slightly higher growth than potable water (even when plants were fertilized), thanks to the amount of organic matter and nutrients.

According to the growth data, the physiological descriptors showed that wastewater plants batches were not stressed and had high light use efficiency; moreover, the use of wastewater did not affect the chlorophyll content of lettuce, ensuring a good leaf color, which is an important quality parameter that directly contributes to the visual appearance and consumer's attractiveness (Grattan, Grieve, 1992). Nitrate content is also a relevant index, since high amount of this molecule in the diet can be harmful for human health (Ferrante *et al.*, 2014): in all samples, the levels were maintained below the limit imposed from the current EU regulation (CE n. 1258/2011). Furthermore, due to the use of the eco-labeled detergent, the composition of wastewater does not contain toxic components.

On that basis a conceptual system can be defined and a product developed, considering all different aspects from the functional to the aesthetic ones. In prospect, the integration of the wastewater treatment system in kitchen furniture, in combination with the vertical garden solution, can push a change in the design of indoor growing modules, as well as in user behaviors, while improving the domestic water use efficiency, giving the research a first application outcome.

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Notes

Author Contributions: Fiammetta Costa and Luciana Migliore conceived the project and designed the experiments; Alessandro Amati, Filippo Spanu and Klaudia Krasojevic performed the plant growth experiments; Alessandro Amati, Giacomo Cocetta and Antonio Ferrante performed the plant descriptor measurements; Manuela Antonelli and Michele Di Mauro analyzed the water and wastewater composition; Manuela Antonelli, Fiammetta Costa and Luciana Migliore conceived the wastewater recycle plant; Raffaella Mangiarotti, Paolo Perego, Roberto Sironi, Carlo Emilio Standoli, Giorgio Vignati and Maryam Ziyaee participated in the system design, Paolo Perego collaborated for consumer attitude analysis, Matteo Meraviglia and Attilio Nebuloni developed the outdoor scenarios; all the Authors wrote and revised the paper.

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Developing a microbial consortium for removing nutrients in dishwasher wastewater: towards a biofilter for its up-cycling

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Abstract

Microbial consortia are effective biofilters to treat wastewaters, allowing for resource recovery and water remediation. To re-use and save water in the domestic cycle, we assembled a suspended biofilm, a 'biofilter' to treat dishwasher wastewater. Bacterial monocultures of both photo- and hetero-trophs were assembled in an increasingly complex fashion to test their nutrient stripping capacity. This 'biofilter' is the core of an integrated system devoted to re-using and upcycling of reconditioned wastewater, partly in subsequent dishwasher cycles and partly into a vertical garden for plant food cultivation.

The biofilter has been assembled based on a strain of the photosynthetic, filamentous cyanobacterium *Trichormus variabilis*, selected to produce an oxygen evolving scaffold, and three heterotrophic aerobic bacterial isolates coming from the dishwasher wastewater itself: *Acinetobacter*, *Exiguobacterium* and *Pseudomonas* spp. The consortium has been constructed starting with 16 isolates tested *one-to-one* with *T. variabilis* and then selecting the heterotrophic microbes up to a final *one-to-three* consortium, which included two dominant and a rare component of the wastewater community. This consortium thrives in the wastewater much better than *T. variabilis* alone, efficiently stripping N and P in short time, a pivotal step to the reuse and saving of water in household appliances.

Keywords: biofilter, cyanobacteria, dishwasher wastewater treatment, heterotrophic bacteria, microbial consortia, *Trichormus variabilis*

1. Introduction

Water demand and amount of wastewater produced are continuously increasing worldwide. Hence, wastewater management towards reuse, recycle and resource recovery is a stringent need (WWAP, 2017).

In this context, biological treatment is a key step of wastewater (WW) treatment process. Conventional techniques rely on interconnected, bacteria-based complex and multistep operations (e.g. activated sludge systems) with high costs and energy input. More recently, biological filtering and bioremediation strategies based on the synergistic relationship between photosynthetic and heterotrophic microorganisms, 'microbial consortia', proved to be a more sustainable WW treatment approach both in terms of treatment and cost efficiencies (Posadas *et al.*, 2017).

The consortium partner microalgae/cyanobacteria provide oxygen, through their photosynthetic activity, to the heterotrophic bacteria for chemical oxygen demand reduction, while the bacterial partners, by means of organic matter degradation, release CO_2 and mineral nutrients used by microalgae when exposed to light, resulting in increased pollutant removal efficiency and biofiltration ability (Gonçalves *et al.*, 2017).

Biofilters based on microbial consortia can form biofilms, complex heterogeneous communities occurring either suspended or attached, that proved promising in advanced remediation of municipal wastewater (Posadas *et al.*, 2017). Indeed, cooperative interactions in the biofilms between bacteria and microalgae/cyanobacteria promote the establishment of stable communities in which simultaneous autotrophic and heterotrophic metabolism support nutrient excess, pollutant and pathogen removal from WW.

Microbial interactions in the biofilms, both spatial and functional, are possible thanks to presence of the extracellular polymeric (Extracellular Polymeric Substances, EPS) matrix that embeds biofilm cells mediating their cohesion and exchanges. The matrix gel like network has high retentive properties, serves in the immobilization and accumulation of particulate and noxious compounds - acting as a natural molecular sieve or an ion exchanger of xenobiotics -, entraps particulate matter and exposes exoenzymes for organic matter degradation (Di Pippo *et al.*, 2009; Guzzon *et al.*, 2019).

Dishwasher WW (DWW) are often nutrient-rich: urban agriculture could absorb these nutrients and has historically done so. Despite the high nutrient content and the very low presence of pathogens, heavy metals and pharmaceuticals, the reuse of this wastewater is not practiced in modern society, because it is produced by point sources in small amounts. The goal of this work is to build up, in a gradually increasing complexity mode, a microbial consortium based on autochthonous heterotrophic dishwasher bacteria and a photosynthetic EPS network builder. The feasibility of this engineered consortium was checked by studying its structure and function in a lab-scale closed environment system. Consortium members were: (i) the filamentous cyanobacterium, *Trichormus variabilis*, and (ii) selected aerobic bacteria isolated from DWW. This approach allows to test a microbial association highly improbable in nature in a bioremediation challenge to ameliorate DWW.

2. Materials & Methods

2.1. Trichormus variabilis culture

The strain of the heterocytic cyanobacterium *Trichormus variabilis* (Kützing ex Bornet & Flahault) Komárek & Anagnostidis (VRUC168) was isolated from sediment biofilms of a Mediterranean coastal lagoon (Cabras lagoon, Sardinia, Italy). It is maintained as monoalgal culture in the Tor Vergata Rome University Collection (VRUC) in liquid culture medium (Blue Green Medium - Nitrogen, $BG11_0$) at 18 °C and 30 μmol photons m^{-2} s^{-1} irradiance, L:D cycle 12:12 (Di Pippo *et al.*, 2012; Bellini *et al.*, 2018).

Before the experiment, a sample of the stock culture has been acclimated for two weeks at 80 μmol photons m^{-2} s^{-1} irradiance and 25 °C temperature conditions, and then used for the production of the experimental inoculum. *T. variabilis* inoculum was maintained in exponential growth phase (log phase) by adding fresh (semi-continuous) culture medium every 48 hrs.

2.2. Trichormus variabilis growth experiments

Aliquots of the exponentially growing culture used as inoculum were prepared for *T. variabilis* growth experiments by centrifuging 50 ml (2200 *g*, 10 min) and resuspending the pellet in $BG11_0$ to an optical density of 0.5 at 665 nm. Culture growth was tested in DWW as it is (100%) and diluted at 75 and 50 % in culture medium.

Experiments were performed in two settings: (i) ventilated flasks - static cultures, and (ii) aerated (air bubbling) flasks, to facilitate culture mixing and gas exchanges. 3 replicates for each experiment were set and culture growth was measured as *in vivo* chlorophyll *a* absorbance and culture turbidity (OD, Optical Density, at 665 nm and 730 nm, respectively; spectrophotometer ONDA UV-20). Culture chlorophyll *a* concentration was quantified, after extraction in 90% methanol (Wellburn, 1994), along with dry weight, to evaluate cyanobacterium viability and growth at the experimental conditions.

2.3. Identification of the dishwasher wastewater microbial community

The dishwasher wastewater has been collected 16 times from November 2017 to February 2018. From each dishwasher wastewater sample, 10 µl were plated on three solid media: TSA (Tryptic Soy Agar); PSA (Pseudomonas Agar Base); MCA (Mac Conkey Agar). Based on the morphological characteristics of the colonies grown on the media, each different strain was isolated on TSA (24 h at 30 °C) and a sample of each pure culture suspended in 200 µl of sterile dH_2O, gently vortexed and heated at 95 °C for 5 min. Each sample was then centrifuged (10.000 *g*, 5 min) and the supernatant, containing the bacterial DNA, recovered to be identified by SANGER sequencing. To this end, bacterial DNA was amplified by PCR, using COM1 (forward 5'-CAGCAGCCGCGGTAATAC-3'; position 519-536) and COM2 (reverse 5'-CCGTCAATTCCTTTGAGTTT-3'; position 907-926), selective primers for the 16S rRNA gene, identifying the variable region V4 and V5 of ribosomal RNA. 10 µl of the PCR solution contain: 5 µl of EmeraldAmp GT PCR Master Mix 2X, 2 µl of bidistilled water, 1 µl of forward primer COM1 (20 mMol), 1 µl of reverse primer COM2 (20 mMol) and 1 µl of above prepared bacterial DNA (~2 ng/µl). Amplified DNA samples were sent to BioFab Research (Rome, Italy) to be sequenced by SANGER method; results were analysed using RDP Classifier.

2.4. Dishwasher wastewater

A household dishwasher (Energy Class A) was used, setting the "eco" program as washing cycle; as cleaning product, an EU Ecolabel certified dishwasher tablets detergent containing only non-toxic mineral substances and subtilisin was chosen (CAS No.: 9014-01-1; for the composition see Table S1, Supplementary material). The physico-chemical characteristics of the waste are also reported (see Table S2, Supplementary material).

2.5. Co-culture experiments to assemble the final consortium

To produce the engineered microbial consortium, as a first step the bacterial strains isolated from the dishwasher wastewater were challenged with *T. variabilis* in co-culture experiments. In these co-cultures, both the growth of *T. variabilis*, as chlorophyll *a* concentration and *in vivo* absorbance, and co-culture development, as turbidity, were estimated to identify those guaranteeing the best performance.

Each bacterial isolate from the dishwasher wastewater was seeded on a TSA (Tryptic Soy Agar) plate; from each plate a colony was transferred into a 50 ml sterile tube containing 15 ml of TSB (Tryptic Soy Broth). The isolates were incubated overnight under stirring, at 30 °C. Then, the OD was measured at 600 nm and TSB added to reach the OD value of 0.5 in a final volume of 20 ml. The number of bacteria in each suspension was further quantified by plating 10 μl of each bacterial suspension and counting the resulting CFU. The bacterial suspensions were gently vortexed and then centrifuged (6804 *g*, 10 min), the supernatant discarded, and the pellet resuspended in the same amount of $BG11_0$.

The *T. variabilis* suspensions were also prepared, OD 665 nm of 0.5, and used in the co-culture experiments.

The growth of each co-culture was evaluated every 24 hrs, over 12 days (time to reach stationary phase) by recording the absorbance values at the wavelengths of 665 and 730 nm.

2.5.1. Co-culture one-to-one, one-to-two and one-to-three

The development of the engineered consortium, planned to be composed by *T. variabilis* and three bacterial isolates from the dishwasher wastewater, has been built in a step by step process of association. The co-cultivation of the cyanobacterium with each bacterial strain has been the first step of the challenge of *T. variabilis* with 16 bacterial isolates (*one-to-one* consortia). 5 ml bacterial suspension was mixed with 5 ml of *T. variabilis* in $BG11_0$ medium up to a final volume of 30 ml. The growth performance of each *one-to-one* consortium was evaluated by measuring every 48 hrs the absorbance at 665 nm and 730 nm. The second step has been the challenge of *T. variabilis* with two of the selected isolates in *one-to-two* consortia, and the third step has been the challenge of the final *one-to-three* consortium. To maintain the same density ratio among the microbes, in *one-to-two* tests 8.33 ml of *T. variabilis* suspensions were mixed with 4.17 ml of each bacterial suspension; while in *one-to-three* tests 8.33 ml of *T. variabilis* suspensions were mixed with 2.78 ml of each bacterial suspension. The growth performance of each consortium was then evaluated over 35 days, by measuring every 48 hrs the absorbance at 665 nm and 730 nm.

2.6. Growth test of the one-to-three consortium in the dishwasher wastewater

The co-culture of the engineered consortium, consisting of *T. variabilis* and the selected three bacterial strains, was tested at different concentrations of wastewater (100, 75 and 50 % waste, diluted in $BG11_0$ medium), in order to evaluate viability and growth, both by spectrophotometric measurements, in triplicate, at the wavelengths of 665 nm and 730 nm, every 48 hrs and microscopy observation, using a ZEISS Axioskop light microscope at 400 and 1000x magnification.

2.6.1. Nitrogen and phosphorus removal by the one-to-three consortium

The efficiency of the *one-to-three* consortium to modify the concentration of total nitrogen and total phosphorus was assessed in sample of dishwasher wastewater as it is (100%) or 75% diluted in $BG11_0$ after 24 - 48 hrs. The analyses were performed according to the Italian official protocol (APAT IRSA-CNR, 2003). 10 ml samples of 100 or 75 % wastewater were collected immediately before the start of the co-culture experiments and after 24 and 48 hrs treatment, in triplicate. The samples were centrifuged (3400 *g*, 10 min) and the supernatant transferred into new tubes. 2.8 ml of oxidizing solution (50 g $K_2S_2O_8$ - Merck n. 5092, 30 g H_3BO_3, 14 g NaOH in 1 l of deionized water) were added to the samples and autoclaved (120 °C, 30 min) and then left at room temperature.

After oxidation, total nitrogen was quantified spectrophotometrically at 220 nm in 2 ml of each sample. The data were calculated against a calibration curve built with a standard solution of $NaNO_3$ in distilled water at 0-1-5-10 mg/l N, subjected to oxidation as previously described.

After oxidation, to quantify total phosphorus, 0.6 ml of reducing solution (35 g L-ascorbic acid, 0.150 g EDTA-Na_2, 3 ml formic acid in a final volume of 500 ml dH_2O) and 0.6 ml of reagent mixture (0.34 g $KOOC(CHOH)_2COOSb$ ½ H_2O, 8.1 g $(NH_4)_6Mo_7O_{24}$ $4H_2O$, 100 ml H_2SO_4 concentrated, density 1.84, in a final volume of 500 ml dH_2O) were added to each sample, which were then incubated for 15 min. Total phosphorus content was spectrophotometrically measured at 882 nm,. The data were calculated against a calibration curve built with a standard solution of KH_2PO_4 in distilled water at levels of 0-0.25-0.50-1 µg/l P, subjected to oxidation as described.

All the instruments were cleaned for 24 hrs in a specific phosphorus-free detergent, and then rinsed with distilled water.

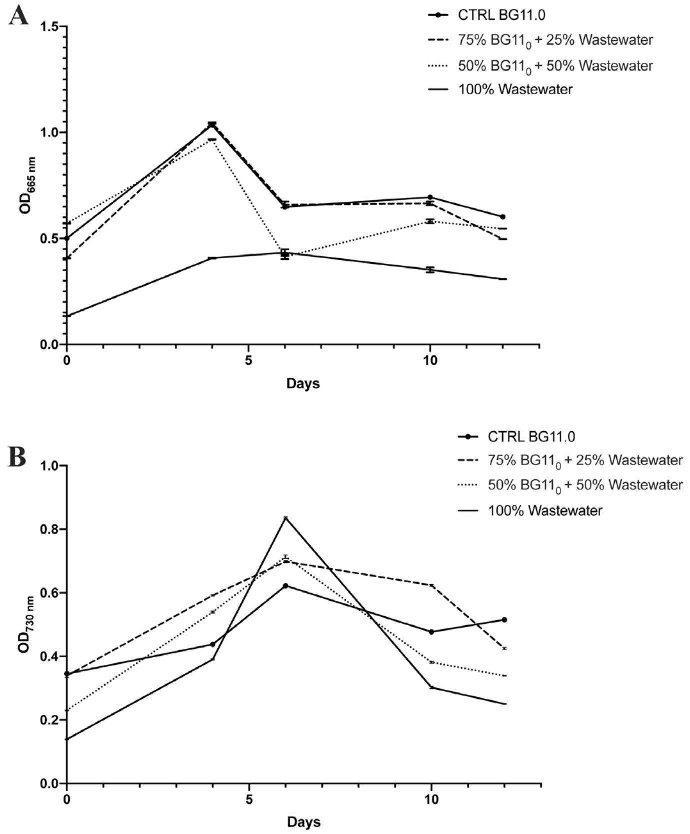
3. Result and Discussion

The synergistic relationship between photosynthetic and heterotrophic microorganisms is a key issue for remediation of wastewaters. In this study *Trichormus variabilis*, a promising oxygen evolving candidate for dishwasher wastewater (DWW) remediation did not survive in the DWW. Thus, we elaborated a process to develop a microbial engineered consortium able to thrive in this DWW and reduce the concentration of nutrients.

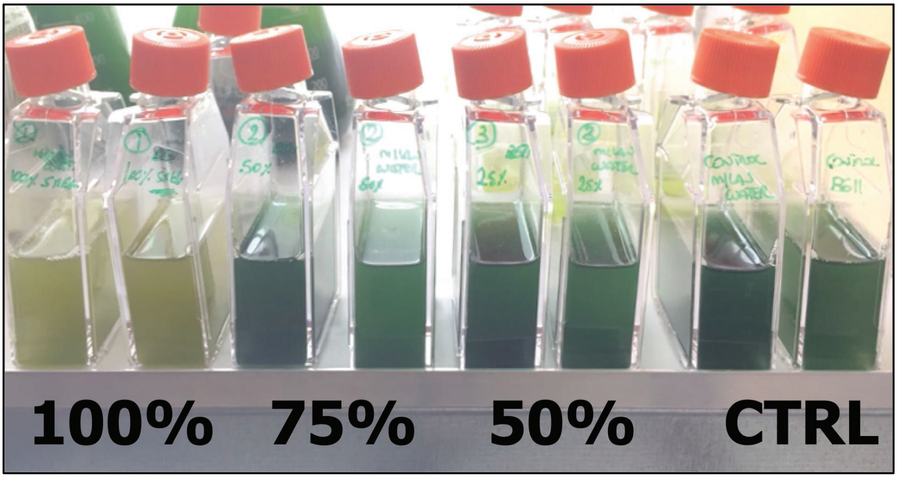
3.1. T. variabilis in DWW

T. variabilis ability to survive and grow in dishwasher wastewater was evaluated recording the absorbance of *in vivo* chlorophyll *a* (OD at 665 nm) and culture turbidity (OD at 730 nm), over 12 days in 100, 75 and 50 % wastewater dilutions.

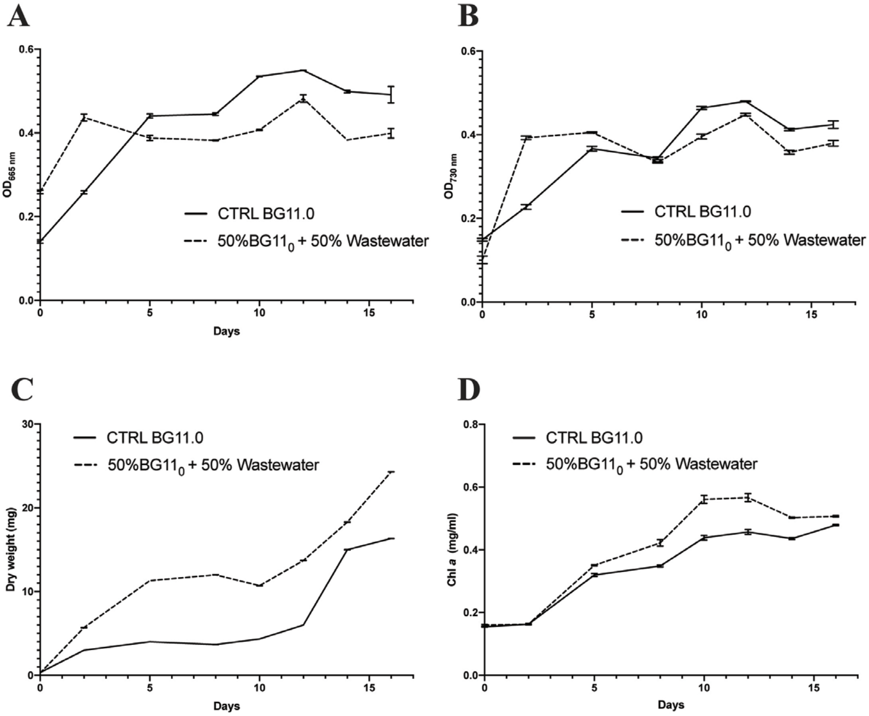
Chlorophyll *a* (Figure 1A) shows that 100% wastewater significantly reduces cyanobacterium growth (ANOVA, $p<0.05$), as confirmed by the loss of pigmentation of the culture (Figure 2). Conversely, *T. variabilis* is able to thrive in 50 and 75 % (ANOVA, $p>0.05$; Figure 1A), indicating its capability of growing under these DWW concentrations. On the other hand, culture turbidity (Figure 1B) increases in all the cultures especially at 100% DWW, with a peak at day 6, probably due to heterotrophic bacteria. No lag phases occurred at all dilutions. Overall, these results suggest that DWW may contain growth-inhibiting compounds/conditions or may lack some essential components which affected *T. variabilis* growth. As a further test, 50% DWW was used for a growth experiment with air insufflation to enable culture mixing and improve abiotic conditions (i.e. illumination and gas exchanges); growth curves clearly evidenced that *T. variabilis* is able to thrive in these conditions although at significantly lower rate than the control (*t*-Sudent test, $p<0.05$). Nevertheless, dry weight, chlorophyll *a* and turbidity values are similar to the control ones (*t*-Student test, $p>0.05$) (Figure 3). This indicates that even a slight modification of DWW composition may allow *T. variabilis* growth.



[Figure 1] T. variabilis culture growth (n=3), static conditions, in DWW at three dilutions 100, 75 and 50%. A: Absorbance values at 665 nm, indicating in vivo chlorophyll a;B: Absorbance values at 730 nm, indicating culture turbidity.



[Figure 2] Image of T. variabilis cultures after 7 days. The loss of pigmentation of the cultures is evident in 100% DWW.



[Figure 3] T. variabilis culture growth, mixing conditions (n=3), evaluated by four descriptors. A: Absorbance values at 665 nm, indicating in vivo chlorophyll a; B: Absorbance values at 730 nm, indicating culture turbidity; C: Dry weight values; D: Chlorophyll a concentration in the extracts.

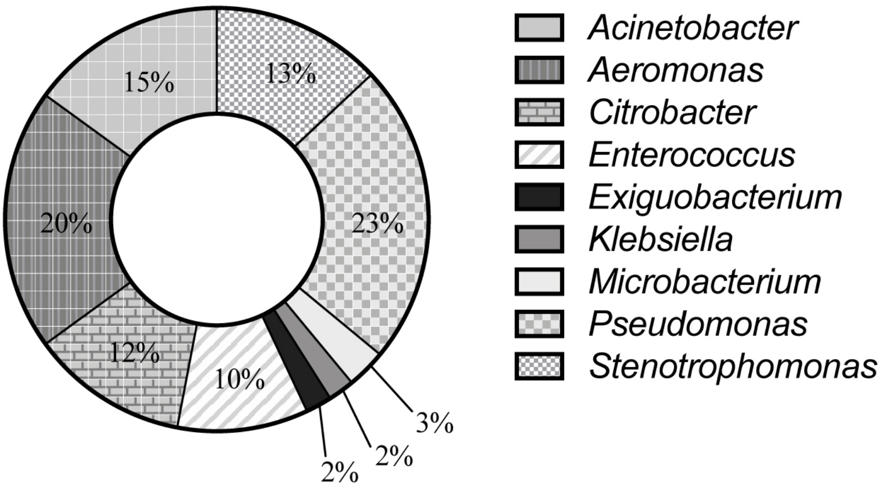
3.2. Isolation of the DWW microbial colonizers

The cultivable aerobic heterotrophic microbial community from 16 wastewater samples grew on three solid media (TSA, PSA and MCA; Table 1); the microbial load ranged from 10^7 cells/ml on PSA and TSA to 10^3 cells/ml on MCA. From these microbial cultures 41 bacterial strains were isolated the basis of their different morphology and taxonomically identified by Sanger sequencing. The main colonizers were Proteobacteria of to the Gamma-Proteobacteria class (34 isolates), followed by Firmicutes of the class Bacilli (6) and Actinobacteria (1). The Proteobacteria are: Aeromonadales (8, all *Aereomonas* genus), Enterobacteriales (6, 5 *Citrobacter* and 1 *Klebsiella*), Pseudomonadales (15, 6 *Acinetobacter* and 9 *Pseudomonas*) and Xantomonadales (5, all *Stenotrophomonas*). The Firmicutes are: Bacillales (1, *Exiguobacterium* genus) and Lactobacillales (5, all *Enterococcus*). The only Actinobacteria belongs to *Microbacterium* genus (Figure 4). As expected, the microbial colonizers of DWW are heterotrophic aerobic generalists, which tolerate the limiting environmental conditions of the DWW. They have been already found in dishwasher biofilms: the *Exiguobacterium* strains, tolerant to wide temperature (-12 to +55 °C), salinity (up to 13 %), and pH (5-11) ranges; the *Acinetobacter* strains, able to thrive in a wide range of temperatures and pH (Vishnivetskaya *et al.*, 2009; White *et al.*, 2013; Raghupathi *et al.*, 2018); *Enterococcus*, common human colonizers have also been found in the home microbiome (Dannemiller *et al.*, 2016), although their presence in extreme conditions is not reported. *Enterococcus* presence in dishwasher biofilms is possible because of the protection provided by extracellular polymeric substances (EPS) conferring tolerance properties (Limoli *et al.*, 2015).

16 isolates were selected to be challenged in co-culture with *T. variabilis*, they are listed in bold in Table 1.

[Table 1] Taxonomical identification of the bacterial isolates. In bold those chosen for the co-culture experiments with T. variabilis

Isolate ID	Taxonomical identification		Isolate ID	Taxonomical identification
3A	***Acinetobacter* [100%]**		**17B**	***Enterococcus* [90%]**
4A	***Acinetobacter* [100%]**		21B	Enterococcus [85%]
15A	Acinetobacter [100%]		22A	Enterococcus [90%]
16A	Acinetobacter [100%]		**1A**	***Exiguobacterium*[100%]**
20B	Acinetobacter [100%]		**11B**	***Klebsiella* [56%]**
21A	Acinetobacter [100%]		15B	Microbacterium [85%]
3B	Aeromonas [100%]		**7A**	***Pseudomonas* [89%]**
6A	***Aeromonas* [100%]**		10A	Pseudomonas [86%]
8A	***Aeromonas* [100%]**		12A	Pseudomonas [83%]
9B	***Aeromonas* [100%]**		13B	Pseudomonas [93%]
10B	***Aeromonas* [100%]**		**14B**	***Pseudomonas* [91%]**
11A	Aeromonas [100%]		**16B**	***Pseudomonas* [90%]**
14A	Aeromonas [100%]		17A	Pseudomonas [93%]
18B	***Aeromonas* [100%]**		18A	Pseudomonas [81%]
5A	***Citrobacter* [45%]**		20A	Pseudomonas [80%]
9A	Citrobacter [45%]		1B	Stenotrophomonas [93%]
12B	***Citrobacter* [63%]**		5B	Stenotrophomonas [100%]
13A	Citrobacter [60%]		6B	Stenotrophomonas [100%]
19A	Citrobacter [58%]		7B	Stenotrophomonas [100%]
1A	***Enterococcus* [96%]**		8B	Stenotrophomonas [100%]
2B	Enterococcus [87%]			



[Figure 4] Taxonomy and frequency of the DWW isolates.

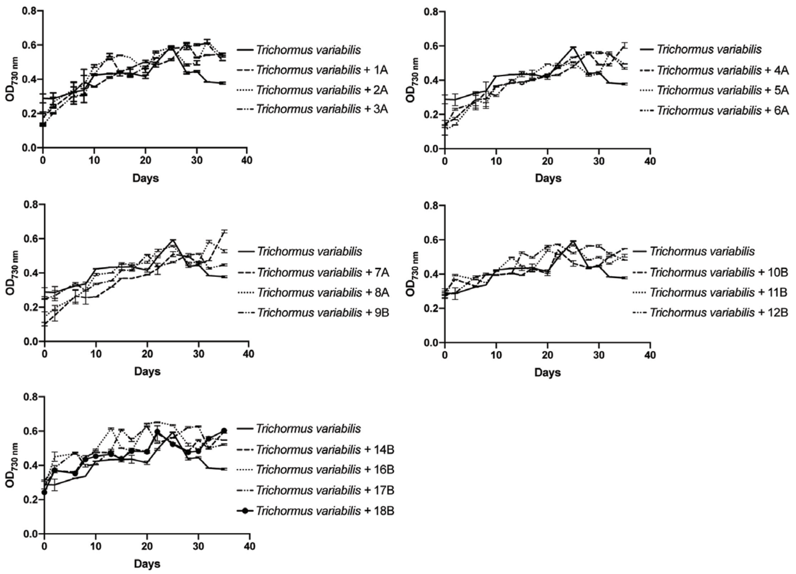
3.3. Co-culture experiments for the engineering of the microbial consortium

The development of the microbial consortium bases on the possibility to produce a functional consortium, including *T. variabilis* and three bacterial isolates from DWW, able to thrive in and clean-up the wastewater. A step by step procedure in co-cultivation has been applied, the first step is to challenge *T. variabilis* with one bacterial isolate in *one-to-one* consortia, followed by progressive integration in *one-to-two* consortia, to end up with a *one-to-three* consortium. These co-cultures were all grown in $BG11_0$.

3.3.1. One-to-one consortia

The first step of co-cultivation involves *T. variabilis* and the 16 bacterial isolates from DWW selected according to their best taxonomic identification by Sanger sequencing. In *one-to-one* challenges, 2 *Acinetobacter*, 5 *Aeromonas*, 2 *Citrobacter*, 2 *Enterococcus*, 1 *Exiguobacterium*, 1 *Klebsiella* and 3 *Pseudomonas* are used (Table 2, bold). Strains of these genera are often used for activated sludge-based WW treatment: *Pseudomonas* degrades carbon by oxidation, *Citrobacter* contributes to floc formation, *Acinetobacter* and *Klebsiella* accumulate phosphorus, removing it from the medium.

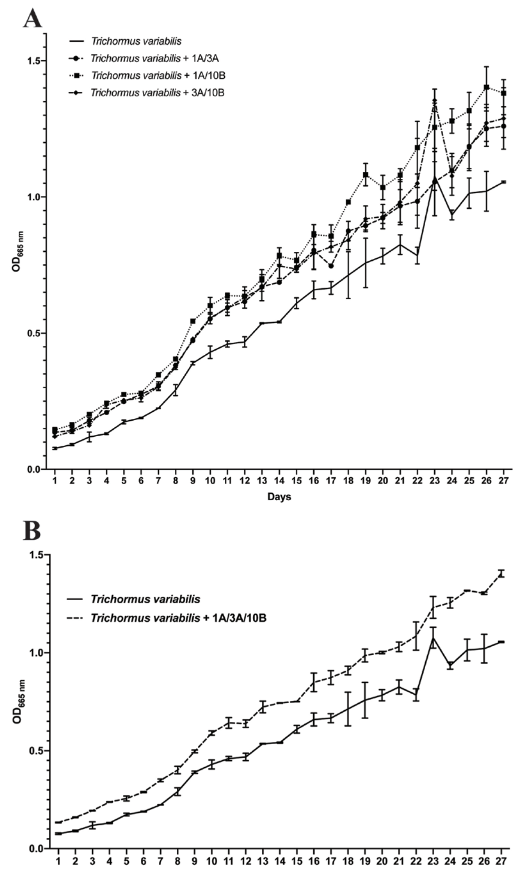
Conversely, *Microbacterium* and *Stenotrophomonas* were excluded because of their potential harm to human health. The taxonomic identification at the genus level does not allow to establish pathogeny or risks for human health, never recorded for home appliances. The co-culture allowed to evaluate the best growth of *T. variabilis* with the aim to select the bacterial isolates to be included in the next steps of the consortium building. *One-to-one* consortium performances are evaluated as *in vivo* chlorophyll *a* (Figure 5) or turbidity (Figure S1, Supplemental material). *T. variabilis* grows well in all the challenges (no significant difference with controls, ANOVA, p>0.05), showing the potential application of all the bacterial isolates.



[Figure 5] One-to-one co-culture (n=3) of T. variabilis and one of the heterotrophic isolates in BG11$_0$. The absorbance values at 665 nm, corresponding to in vivo chlorophyll a signal, of each consortium are reported.

3.3.2. One-to-two and one-to-three consortia

The *one-to-two* co-cultures of *T. variabilis* with couples of heterotrophic isolates from DWW were carried out by selecting the microbes on the basis of their frequency in the DWW and literature data. Since no isolate significantly favoured the growth of *T. variabilis*, the three strains necessary for the construction of the consortium were chosen according to a dominance/rarity criterion: among the isolates from wastewater, two were chosen as the most frequent isolates (probably dominant species among the DWW colonizers) and one because of its rarity, as it was found only in one sample. These three bacterial isolates are respectively: *Acinetobacter* and *Aeromonas* for the dominant component, *Exiguobacterium* for the rare one, according to the isolate IDs in Table 1, the three strains are 3A, 10B and 1A. In biotechnological application, *Acinetobacter* (Liu *et al.*, 2017), and *Exiguobacterium* (Kasana, Pandey, 2018) were used in co-cultivation with cyanobacteria.



[Figure 6] One-to-two (n=3) and one-to-three (n=3) co-cultures of T. variabilis *and the selected isolates (1A:* Exiguobacterium *sp., 3A:* Acinetobacter *sp., 10B:* Aeromonas *sp.) in* $BG11_0$. *A: Absorbance values of each one-to-two consortium. B: Absorbance values of the one-to-thee consortium (both at 665 nm, indicating in vivo chlorophyll a).*

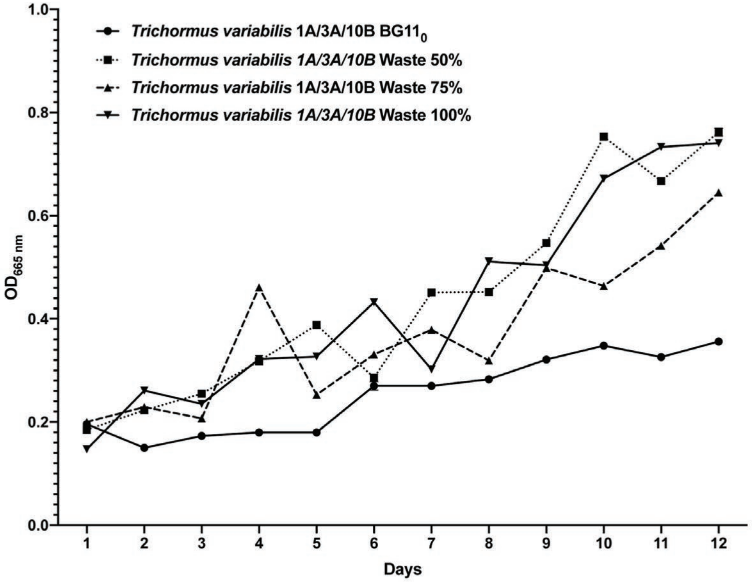
The *one-to-two* consortia grew better than *T. variabilis* alone (control; Figure 6), particularly the *T. variabilis* +1A/10B consortium.

As a final step, the three isolates (1A, 3A and 10B) are challenged in co-culture with *T. variabilis* in the *one-to-three* consortium which showed an enhanced growth of the cyanobacterium prospecting an effective application of this consortium in a DWW biofilter (Figure 6).

3.4. One-to-three consortium in different DWW concentration

To demonstrate the *one-to-three* consortium efficacy it has been grown in DWW as it is (100%) or diluted (75 and 50%) in $BG11_0$ culture medium. The growth curves of the consortium, measured as *in vivo* chlorophyll *a* absorbances, show that DWW promotes *T. variabilis* photosynthetic activity and biomass accumulation at any dilution (Figure 7A). The result demonstrates the cooperative interaction between cyanobacteria and heterotrophic bacteria in the consortium, leading to a stable community where coordinated autotrophic and heterotrophic metabolism supports nutrient removal from DWW. Figure 7B shows a further important emergent property of the consortium, its three-dimensional organization as floating microbial aggregates (a sort of 'green sausages'), not adhering to flask surfaces. These 3D structures are reversible associations that upon strong flask manual shaking disassociate in a homogeneous green suspension, they quickly reconstitute (a couple of hours) when the flask is left to rest. Hence, the 3D structure this microbial consortium must be an advantageous, stable type of association, although *T. variabilis* is known to form compact aggregates attached as biofilms to exposed surfaces (Di Pippo *et al.*, 2012). The development of cyanobacterial-bacterial consortia in WW treatment plants is well known (Congestri *et al.*, 2006; Roeselers *et al.*, 2007; Congestri, 2008; Di Pippo *et al.*, 2014).

A



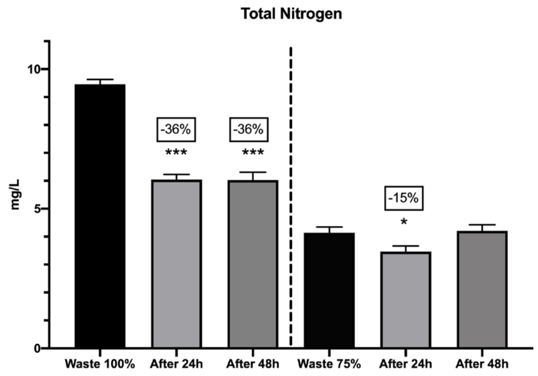
B

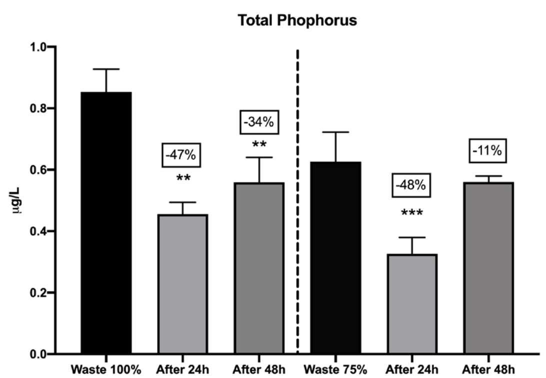
[Figure 7] One-to-three co-culture growth of T. variabilis with isolates in DWW (1A: Exiguobacterium *sp., 3A:* Acinetobacter *sp., 10B:* Aeromonas *sp.). A: Absorbance values at 665, indicating in vivo chlorophyll a (n=3). B: microbial consortia in DWW (0, 100, 75, 50%), at 100% the 3D structures resemble 'green sausages' (n=2).*

3.4.1. DWW nutrient removal by the one-to-three consortium

The efficiency of the microbial consortium in ameliorating DWW as it is, 100% or diluted at 75% in $BG11_0$, has been evaluated as removal of total nitrogen and phosphorus after 24 or 48 hrs (Figure 8). In DWW as it is nitrogen is reduced of 36 % after 24 and 48 hrs, this reduction is significant (ANOVA, $p<0.001$). Conversely, in 75% DWW the reduction was of 15 % after 24 hrs (ANOVA $p<0.05$), no nitrogen variation was found after 48 hrs.

In DWW as it is phosphorus is reduced of 47 and 34 % after 24 and 48 hrs, respectively, both values are significant (ANOVA, $p<0.001$ and $p<0.01$). In 75% DWW the reduction was of 48 and 11 % after 24 and 48 hrs respectively, differences are significant only at 24 hrs (ANOVA, $p<0.01$).





[Figure 8] Nitrogen and phosphorus removal by the one-to-three microbial consortium in DWW (as it is, 100%, or diluted at 75% in $BG11_0$) after 24 and 48 hrs. Asterisks indicate significance levels (= $p<0.05$; **= $p<0.01$; ***= $p<0.001$). In brackets the percent removal.*

4. Conclusions

The engineered microbial consortium made by the filamentous cyanobacterium *Trichormus variabilis*, selected to produce an oxygen evolving scaffold, and the three heterotrophic aerobic isolates from DWW, *Acinetobacter*, *Exiguobacterium* and *Pseudomonas* spp., proved to be able to thrive in raw DWW and reduce its nutrient load. In addition, the engineered microbial consortium self assembles in suspended aggregates and this is particularly promising for its application in DWW processing. This consortium has been planned to be the functional core of a prototype, called Zero Mile System® (Costa *et al.*, 2018), which integrates a dishwasher, a microbial biofilter (the *one-to-three* consortium) and a distribution system for the treated DWW that can be both reused in subsequent dishwashing cycles and upcycled in a vertical garden to produce vegetal food. Zero Mile is conceived to allow the simultaneous reduction of water use and DWW production coupled with the conversion of the organic load into food. It will support the DWW resource recovery and valorisation as envisaged by the circular economy paradigm, intended as a restorative or regenerative system by intention and design (Ellen MacArthur Foundation, 2013).

Zero Mile is dimensioned at individual household size for own plant irrigation, but the further aim is to scale it up to the dimension of a restaurant or a set of households sharing services, such as in a co-housing environment. The ratio behind both applications is that DWW reuse becomes more economically feasible if the point of reuse is close to the point of production.

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Supplementary materials

[Table S1] Safety Data Sheet of "Vivi Verde - Coop" dishwasher tablets: ingredient composition. The dishwasher detergent includes a proteolytic enzyme of bacterial origin. Subtilisin is a biodegradable protein that shows good solubility and poor stability in water. This enzyme reaches the maximum activity in alkaline conditions (optimal pH range: 9-11) and is inactivated during the wash cycle (in the range 55-65 °C; HERA, 2007, Human & Environmental Risk Assessment on ingredients of household cleaning products. Subtilisins (Protease). Available from: https://www.heraproject.com/files/22-F-07_PROTEASE_HERA_Final%20Edition%20(unsecured%20-%20PDFA-1b).pdf.).

SCHEDA DATA DI SICUREZZA (REGOLAMENTO (CE) N° 1907/2006 - REACH) — **Data: 13/07/2016 Page 2/7**
Versione: N° 1 (18/05/2015) — **Revisione: n° 6 (18/05/2015)**
McBride S.p.A. (Bagnatica)

Coop Pastiglie lavastoviglie ecolabel - 16129731 - 3001883

P305 + P351 + P338	IN CASO DI CONTATTO CON GLI OCCHI: sciacquare accuratamente per parecchi minuti. Togliere le eventuali lenti a contatto se è agevole farlo. Continuare a sciacquare.
P332 + P313	In caso di irritazione della pelle: consultare un medico.
P337 + P313	Se l'irritazione degli occhi persiste, concultare un medico.

2.3. Altri pericoli

La miscela non contiene alcune delle "Sostanze estremamente preoccupanti" (SVHC) >= 0,1% pubblicate dall'Agenzia Europea per le Sostanze Chimiche (ECHA) ai sensi dell'articolo 57 del REACH: http://echa.europa.eu/fr/candidate-list-table

La miscela non risponde ai criteri applicabili alle miscele PBT e vPvB, ai sensi dell'allegato XIII del regolamento REACH (CE) n. 1907/2006.

SEZIONE 3: COMPOSIZIONE /INFORMAZIONI SUGLI INGREDIENTI

3.2. Miscele

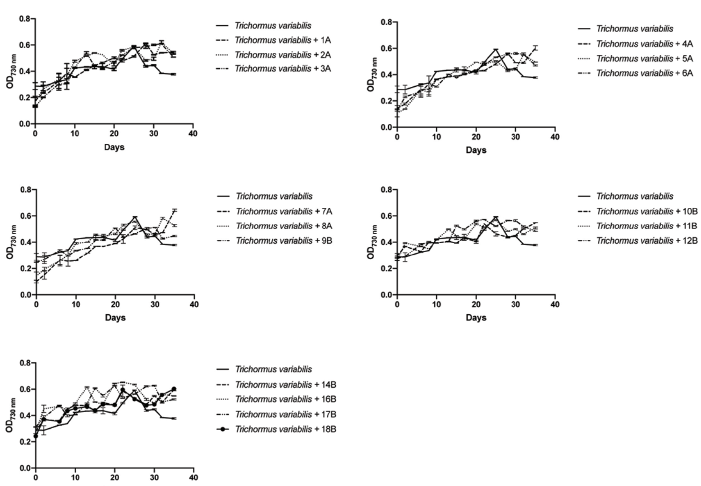
Composizione:

Identificazione	(CE) 1272/2008	67/548/CEE	Nota	%
INDEX: 011-005-00-2 CAS: 497-19-8 EC: 207-838-8 REACH: 01-2119485498-19- SODIO CARBONATO	GHS07 Wng Eye Irrit. 2, H319	Xi Xi;R36		25<=x%<50
INDEX: 1001124 CAS: 15630-89-4 EC: 239-707-6 REACH: 01-2119457268-30 DISODIUM CARBONATE, COMPOUND WITH HYDROGEN PEROXIDE (2:3) (SODIUM CARBONATE PEROXIDE)	GHS07, GHS05, GHS03 Dgr Ox. Sol. 3, H272 Acute Tox. 4, H302 Eye Dam. 1, H318	Xn,O Xn;R22 Xi;R41 O;R8		10<=x%<25
INDEX: 1002122 CAS: 1344-09-8 EC: 215-687-4 REACH: 01-2119448725-31 SILICIC ACID, SODIUM SALT (2.6 MR 3.2)	GHS07 Wng Skin Irrit. 2, H315 Eye Irrit. 2, H319 STOT SE 3, H335	Xi Xi;R36/37/38		10<=x%<25
INDEX: I77_92_9 CAS: 77-92-9 EC: 201-069-1 REACH: 01-2119457026-42- CITRIC ACID	GHS07 Wng Eye Irrit. 2, H319	Xi Xi;R36		2.5<=x%<10
INDEX: 647-012-00-8 CAS: 9014-01-1 EC: 232-752-2 REACH: 01-2119480434-38- SUBTILISINA	GHS08, GHS05, GHS07 Dgr STOT SE 3, H335 Skin Irrit. 2, H315 Eye Dam. 1, H318 Resp. Sens. 1, H334	Xn Xn;R42 Xi;R37/38-R41		0<=x%<2.5

*[Table S2] Main physico-chemical parameters of wastewater (WW) and control water, CW, samples (analyses on 3 l of WW and CW, the tap water used for the washing cycles). Standard Italian and European methods were used. Legend: WW1/WW2 = wastewater samples; CW = control (drinking) water sample. *Data from: https://www.milanoblu.com/la-tua-acqua/lacqua-di-milano/ access date: September 2019*

Parameter	Unit	CW*	WW1	WW2	Analytical method
pH	-	6,9	9.3	9.6	APAT-IRSA 2060, 2003
Conductivity	µS/cm 20 °C	585	6600	3300	APAT-IRSA 2030, 2003
Potassium	mg/l	2	4.3	7.9	UNI EN ISO 17294-1 2007 e 17294-2 2005
Sodium	mg/l	34	1608	901	UNI EN ISO 17294-1 2007 e 17294-2 2005
Calcium	mg/l	109	140	59	UNI EN ISO 17294-1 2007 e 17294-2 2005
Magnesium	mg/l	18	33	13	UNI EN ISO 17294-1 2007 e 17294-2 2005
Iron	mg/l	0.012	0.054	0.094	UNI EN ISO 17294-1 2007 e 17294-2 2005
Manganese	µg/l	2,1	6,1	14	UNI EN ISO 17294-1 2007 e 17294-2 2005
Alkalinity	mg $CaCO_3$/l	235	613	941	SM 2320B, 2012
Nitrate	mg/l	31	29	9,8	APAT IRSA CNR 4020 Man 29/2003
Sulphate	mg/l	61	72	79	APAT IRSA CNR 4020 Man 29/2003
Phosphate	mg P/l		< 0.05	< 0.05	MU 201, 2006
Total phosphorus	mg P/l		0.255	1.6	MU 201, 2006
Total COD	mg O_2/l		730	2600	MU 201, 2006
Soluble COD	mg O_2/l		665	1550	MU 201, 2006
Total Nitrogen	mg N/l		5.8	17	MU 201, 2006
Anionic Surfactants	mg MBAS/l		0.99	5.4	MU 201, 2006
Non-Anionic Surfactants	mg TAS/l		98	173	MU 201, 2006
BOD_5	mg O_2/l		210	1500	DIIAR/POP. 99. 421 Agg.1
Total Suspended Solids (TSS)	mg/l		72	700	APAT IRSA 2090B, 2003

[Figure S1] One-to-one co-culture in BG11$_0$ of T. variabilis *and one of the heterotrophic bacteria isolated by dishwasher wastewater. The absorbance values of each consortium are reported (in spectrophotometry at 730 nm, corresponding to the turbidity of each culture)*



What people think: Attitudes towards recycling, recycling for food use, and a prototype eco-dishwasher

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Abstract

The development of a new technology for dishwashing not only follows technical constraints and opportunities dictated by the materials and the way designers are able to assemble and operate them, but also depends on the constraints and opportunities that different social groups see connected with a certain way of washing dishes. This chapter reports the results of an inquiry into attitudes and choices of relevant social groups about sustainable consumption and kitchen behavior, and addresses reactions and opinions of interviewees in front of a prototype of eco-dishwasher.

Keywords: science and technology studies, sustainable consumption, kitchen behavior

1. The general framework: technology and society

Technological innovation is embedded from the outset (i.e. from scientific research) in a societal context that contributes – often unwittingly – to determining how technology develops and towards what goals it strives (Flichy, 1995). Awareness of this phenomenon has matured over the last few decades thanks to the work of Science and Technology Studies (STS), which has highlighted that no substantial gap separates technology and society (Bijker *et al*., 1986). Engineering has developed and been successful over the past two centuries by leveraging what Kenneth Keniston called the 'engineering algorithm': a set of basic principles governing engineering regardless of the technical problem it tackles each time. The engineering algorithm is based on an assumption that closely resembles the Popperian principle of demarcation. Specifically, the problems that human beings have to face both individually and collectively can be divided into two separate realms, namely technical problems, which to be solved require physical or mathematical knowledge as well as adequate technologies to be developed, and everything else. This second realm includes, among other things, social problems, value issues and philosophical or religious matters. Very briefly, the engineering algorithm states that, in order to effectively address the first type of problem, technologists must be completely disinterested with regard to the second type of problem. Engineers develop technologies, and the better they are at isolating technical problems from social and cultural variables, the more successful they will be. The task of evaluating the social impact and ethical implications of technologies will fall to others afterwards.

Yet the assumption that technological innovation can develop along purely rational lines while societal impacts, political choices and peculiar consumer behaviour are an afterthought, is deceptive. STS has shown that the working of a device is not an intrinsic property of the artifact, accounting for its success, nor is it an intrinsic property of sound design. Rather, it should be considered a result of the artifact's success. Its working should be the explanandum, not the explanans (Bijker, 1995: 14). A device 'works' when it fulfils the expectations of a relevant social group. This approach can obviously be extended to electrical appliances for domestic environments (Shove, Southerton, 2000), including dishwashers. Not only does the development of a new dishwashing technology need to comply with the technical constraints and opportunities dictated by the materials and the way we are able to assemble and operate them, but it also depends on the constraints and opportunities that different social groups see connected with a certain way of washing dishes. For this reason, it was envisaged from the outset that the research process to develop an eco-dishwasher would include an inquiry into attitudes and behaviours of relevant social groups toward general issues, such as water waste, recycling, domestic cultivation of edible plants and food styles, and the specific issue of a prototype eco-dishwasher.

2. Approach and Methodology

Thus, the design and prototype development of the eco-dishwasher included a research phase, which took an exploratory, qualitative approach to investigating people's attitudes to recycling and in particular to a potential domestic and industrial washing waste recycling system, as well as to the developed prototype itself. We addressed both potential types of end user: domestic users and other stakeholders, such as users of industrial kitchens of the type found in places such as schools and restaurants. The data was collected in Milan in 2019. We have adopted a multi-method approach (Seawright, 2016), sometimes also called mixed-method approach, combining qualitative and quantitative methodologies. Our methodology included a secondary analysis of quantitative data, a focus group and interviews with consumers and stakeholders, and a short survey. The secondary analysis of the data available in the literature was used to prepare the focus group and a double interview[1], accompanied by a questionnaire[2] on the use of the dishwasher and eating habits administered at intermediate project dissemination events. The focus group and the double interview made use of visual tools (photographs of a domestic kitchen, an industrial kitchen, and the prototype ecodishwasher), which were used as stimuli for discussion. We have chosen to explore public attitudes towards food sustainability, focusing in particular on attitudes towards daily reuse and recycling behaviours, and the recycling of dishwashing wastewater, with a specific focus on the strengths and weaknesses of the eco-dishwasher design.

[1] The seven participants in the focus group (out of 9 invited) represented families of different types, did not know each other and had never heard of the eco-dishwasher project. They referred to their own experience of home cooking. The double interview was administered to food service workers, who referred to their own experience with industrial kitchens.

[2] Given the sample selection criteria and the small number of questionnaires, the sample has no statistical validity. Nevertheless, our results provide some indications regarding kitchen-related habits of the people who took part in the project dissemination events.

3. Attitudes towards sustainable consumption

All interviewees showed high sensitivity to environmental protection. Many eco-friendly behaviours, such as recycling, reuse of objects and food, and saving water and electricity, have already become established habits for many consumers. However, radical approaches are not common. The interviewees reported that frequently virtuous behaviours are objectively or subjectively unfeasible and difficult to put into effect. They immediately pointed to water as a key issue.

Members of the focus group concerned with the domestic kitchen, when asked to visually identify the elements that recall existing recycling or reuse behaviours and those that could be implemented, offered various indications with respect both to what they were already doing and areas in which they could do more.

When asked about behaviour that they had already adopted, all respondents answered that recycling was an established habit, albeit with some problems. Equally widespread behaviours included reusing objects and food, and taking care to avoid wasting water and electricity. Figure 1, which reproduces a domestic kitchen, was used to conduct the focus group. The dots indicate parts of the kitchen that are related to what is already being done, and were explained by participants as follows:

- Electric light: energy-efficient/LED bulbs.
- Water (tap): frugal use of running water; reusing cooking water, or using it to clean food or wash dishes.
- Recycling.
- Oven: cooking several dishes at the same time.
- Refrigerator: energy saving appliances; reusing food leftovers.
- Dishwasher: using eco-washing programs; using full loads.
- Boiler: energy-saving appliances.
- Table: using paper napkins; recycling; reusing napkins.
- Compartment: conservation of objects with a view to reuse.

Participants pointed out potential conflicts between saving different resources. For example, washing in the dishwasher instead of by hand saves water but not electricity (and vice versa). Green dishwasher programs, which consume less water and electricity, require powerful, non-ecological detergents. With regard to margins for improvement, participants identified various areas in which behaviour could be more sustainable: specifically, food management, more efficient use of household appliances (electric oven, microwave oven, refrigerator,

[Figure 1] The domestic kitchen. Visual stimulus used for the focus group.

boiler and dishwasher) and electric light, recycling, careful use of water and gas, disposal of furniture and use of recycled materials.

Despite showing interest in reducing their environmental impact, participants were not always aware of actions that they might actually take to do so. Information is a significant issue in its various aspects, ranging from the use of acoustic and visual signalling devices to the question of trust in information sources. Participants deemed the following problems significant:

- The acoustic signal to indicate that an appliance has completed its cycle is useful for optimising times, but also irritating.
- Doubts are widespread regarding information that can be collected on both household appliances (for example regarding energy class) and consumer products (for example regarding so-called green detergents). There is a need for reliable information.
- There is a lack of information on manufacturers' choices in terms of sustainable materials and products.
- There is a lack of information on actual consumption at any given moment of daily use ("The kitchen does not provide any information on what you are consuming").
- Finally, another major theme concerns the relationship and contradictions between individual and collective behaviour. Individuals who personally believe in the need to adopt sustainable behaviour run into the systemic obstacle of collective neglect. Nevertheless, this does not negate their personal commitment.

To sum up, it more detailed, more accessible information on consumption levels would allow users to make informed choices and manage their behaviour better, for example by basing choices on indications of the water and electricity consumption demands of different dishwasher programs. Participants also highlighted the ambivalent relationship between sustainable behaviour and its economic cost. Sometimes sustainable choices save users money (lower consumption means lower electricity bills). Other times they cost more (for example green detergents or energy-efficient household appliances). In short, the main obstacles to sustainable behaviour are represented by scarce or incomplete information (external and internal), lax attitudes towards compliance with rules, laziness, habits, and lack of space. Also in the case of the industrial kitchen (Figure 2) many components are related to established sustainable behaviours (dots in the figure) and potential points for improvement (rectangles in the figure).

[Figure 2] The industrial kitchen. Visual stimulus used for the focus group.

Induction hobs are already used in kitchens, as well as high energy-class appliances, low-consumption ighting and innovative building materials; waste food and oil are disposed of separately, and low impact product packaging is preferred. According to the interviewees, there is ample room for further improvement in areas such as wastewater recycling, water cooling, reducing gas emissions, heat recovery from lighting and appliances, and composting. With respect to the domestic cooking focus group, an additional element highlighted by the interviewees is attention to building materials, indicating a concern for sustainability which extends beyond how kitchens are used and takes in their design. Overall, in the domestic environment, families see individual behaviour and controlling consumption as the main ways of reducing environmental impact, while technological innovation, such as information management and home automation, being harder to fathom and more the realm of experts, takes second place. However, the desire to make improvements in this area runs up against a lack of information about possible solutions. Information is therefore a key factor that may also reduce uncertainties related to conflicting behaviours, such as the trade-off between making consumption savings in one resource while simultaneously increasing the consumption of another. In the field of industrial kitchens, in contrast, the contribution that technology can make to reducing environmental impact was more evident among participants, and concerned areas such as wastewater recycling, heat recovery from lighting and appliances, composting, and water cooling.

4. Strengths and weaknesses of the prototype eco-dishwasher

The immediate reactions of the "domestic" focus group upon being presented with the prototype, which is a radically innovative, completely original device, ranged from amazement to puzzlement: why such an innovation? On the other hand, the users of industrial kitchens appeared more curious and open to innovation. However, once the prototype's features and how it operates had been better explained to and understood by the domestic focus group, various strengths and weaknesses were highlighted by participants. The problem of space required for installation of the eco-dishwasher was the first weak point highlighted by participants, who pointed both to the additional equipment needed and the shelving for the plants. They focused on the fact that it would take up space normally dedicated to other uses which they considered priority. Another critical aspect was the purchase cost, along with the ongoing commitment to maintaining both the machinery and the plants (that is, purchasing and replacing plants and concerns over untended, messy plants due to a lack of gardening skills, especially when the dishwasher is not used for a while).

Concerns were expressed about unpleasant odours from the treatment tank (a maintenance-related aspect) as well as insects being attracted by the plants. Only one participant mentioned the issue of child safety in relation to the climbing wall, while another mentioned potential problems of compatibility with pets.

Finally, the participants raised the question of the electricity consumed by the water pump and lighting, which could potentially overload the electrical system. Among the pros, the group discussion showed that the symbolic message channelled by the device ("it's cool"), that is, its visibility and – perhaps above all – its "talkability" is in itself an innovative aspect. Its novelty value prompts discussion and provides an opportunity to affirm one's commitment to sustainability. In this, the eco-dishwasher differs from other kinds of sustainable devices and behaviour, such as recycling, which are less visible. Some participants speculated that its strong visual impact could potentially foster a spirit of emulation in others. Some participants highlighted the importance of water recycling regardless of the proposed innovation. In this regard, two attitudes emerged: some seemed inclined to adopt sustainable behaviour despite the challenges involved, whereas others, while appreciating the device's sustainable nature, considered themselves unlikely to adopt it if it involved additional effort, such as reusing boiling or rinsing water to prewash the dishes. Many participants appreciated the possibility of growing aromatic herbs in the kitchen: although several already grow them on their balcony, having them even closer to hand was seen as a positive aspect.

In terms of aesthetics, the prototype drew mixed reactions. Needless to say, these were strictly based on the image presented (Figure 3) and mainly concerned the relatively large size of the wall and the as-yet unfinished appearance of the containers. On the other hand, participants with a more "visionary" outlook said that it recalled the walls of innovative buildings such as the Milan Bosco Verticale skyscraper and certain pavilions at Expo Milano 2015. As regards cost and propensity to buy, assuming that the aforementioned critical issues are tackled, price range is a major factor.

Some participants considered the price premium of 50% over an average dishwasher (i.e. €900 over €600) excessive, while others would be prepared to pay as much as twice the price in return for greater sustainability and if justified by the quality of the device. Moreover, the convenience of having an indoor vegetable garden and a positive attitude towards potential results were mentioned as reasons that would help break down the barrier of the additional cost.

[Figure 3] Prototype eco-dishwasher. Visual stimulus used for the focus group.

An analogy was drawn with electric cars, which also command a price premium which sustainability-conscious consumers are willing to pay, with the additional advantage for some that such a choice displays their commitment to sustainability. The trade-off between environmental and economic sustainability remained uncertain. The main unknown quantities were additional maintenance requirements and ease of use. However, some participants overcame the uncertainty by taking an ideological stance: they would purchase the machine to purify the water, regardless of the cost.

Interestingly, no doubts were expressed about the quality of the edible plants watered with this system. When asked if they would be confident about eating plants watered using wastewater, participants unanimously answered yes, as long as they had enough information or a guarantee issued by a reliable body or manufacturer. They thus fell back on trust. In any case, the topic did not arouse much interest and was immediately set aside to return to a discussion of technical features, purchase and maintenance costs, and dimensions, particularly the minimum dimensions of the shelving for the system to be economic and ecological at the same time. Any limitations with regard to the variety of plants that can actually be grown with wastewater were seen as an obstacle to acceptance of the system, while flexibility in terms of location, such as the living room as opposed to the kitchen, was considered a facilitating factor.

The food service professionals interviewed, who are familiar with industrial kitchens, immediately showed particular interest in the new system, expressing curiosity and requesting further information. They discussed the possibility of using the prototype at an industrial level and the type of detergents to be used in the dishwasher, given that organic detergents cannot be used in places open to the public for hygiene reasons, and are not geared to large-scale production.

The strengths that emerged during the discussion were similar to those highlighted by the domestic focus group. In addition, the interviewees observed that, for both domestic and industrial use, the safety of edible plants grown without fertilisers and pesticides and protected from urban pollution represented significant added value. With regard to the aesthetic aspect, their opinion was favourable. They pointed out that aesthetics depend on the plants to be used, as edible plants, once used, are no longer decorative for a certain period. The idea of growing edible and ornamental plants was also proposed.

The opinion was also expressed that this system might be of educational value, regardless of the amount of water reused, if located in collective settings such as schools, rest homes and the like[3]. Plants are already grown in some of these places to raise environmental awareness or for other educational purposes; this device might be used to focus on the importance of reducing the consumption of natural resources. With respect to the theme of saving and reusing water, however, it was pointed out that in such collective settings a similar prototype should be designed for the whole kitchen since, for example in restaurants, more water is wasted directly from taps than by use of the dishwasher. A point which emerged in the interview in accordance with the focus group was the symbolic meaning of the system, which is also linked to aesthetic considerations. One restaurant owner and manager believed that the product, thanks to its visual impact, could pay dividends in terms of businesses' environmental credentials.

Questionnaire responses generally indicated a positive attitude to the innovation in question, and confirmed the critical aspects mentioned by participants to the non-standard data-collection actions (Table 1).

5. Conclusion

Attitudes towards domestic cultivation of edible plants are characterised nowadays by a kind of food polytheism (CENSIS, 2010). Food orthodoxy is being replaced by openness to different and even contradictory behaviours: many people consume fast food or junk food whilst having an increasing interest in quality and organic food.

Accordingly, interviewees and focus-group participants, who generally showed a clear interest in sustainability issues, admitted to struggling to put sustainable behaviour into practice in their everyday lives and displayed a critical attitude with regard to a number of

[Table 1] Main obstacles to the use of the eco-dishwasher

In your opinion, what are the main obstacles to using the proposed system? (max two answers)	N. answers	% of answers	% of respondents
Space required	16	33	62
Ease of use	12	25	46
Price	10	21	38
Food use of cultivated plants	4	8	15
Habits	3	6	12
Environmental hygiene	2	4	8
Confidence in the quality of the food product	1	2	4
Total	**48**	**100**	

[3] Some comments in the questionnaires also suggested adapting the system to be used in apartment buildings.

significant variables, such as the availability of clear information and wariness with regard to hidden costs. This observation is consistent with the fact that most concerns regarding the eco-dishwasher were related to functional issues such as space, cost and domestic cleanliness, as opposed to health issues. Hence, the task of identifying a clear target for the ecodishwasher project is not straightforward. Nevertheless, certain characteristics of the target consumer may be assumed: sensitivity to sustainability issues, an upper middle class economic status, and an ideologically driven (i.e. value related) approach to consumption. Of course, an in-depth analysis and a marketing survey would be required to investigate this aspect once the project is finalized.

The eco-dishwasher meets a demand which has not yet been clearly manifested, although participants appeared to be sensitive to and relatively proactive with respect to environmentally friendly behaviour. In general, they had no qualms about the idea of using dishwasher wastewater to grow food plants. The system in itself generated significant interest; however, technical aspects and flexibility in terms of how much space it occupies, what plants can be used and ease of maintenance would significantly influence any decision to adopt it or not. Such decision would therefore be based on a strong ideological inclination to make environmentally sustainable choices, thus overcoming any perceived negative aspects relating to practical considerations or costs. The symbolic meaning is considered an important motivation to choose this system: unlike other eco-friendly devices, the eco-dishwasher is talkable and aesthetically pleasing. It may also be of educational value if installed in collective environments such as schools and rest homes. Another extremely important variable relates to complete, accessible information about technical features, quality of the edible plants, maintenance, and consumption. With regard to the potential application of such a system in industrial kitchens, which appears promising at least in principle, an ad hoc design approach would be required in order to take into account the specific features of the setting as well as the activities that take place therein. In this field, new opportunities for development of such technology seem to open up.

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Design for sustainability and ICT: a household prototype for wastewater recycling

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Abstract

ICT can play a role in environment preservation, to face degradation of the ecosystem, and innovation, to satisfy emerging needs. This research focuses on experimental application of interaction design methodologies and digital technologies to foster the transition towards sustainability in the framework of a wider interdisciplinary research about the development of a system for recycling water at home to grow edible plants.

An iterative design process, articulated in prototyping-evaluating-improving cycles, has been implemented, with the involvement of different stakeholders, to develop the interaction system applied to manage wastewater and information flows needed to control water decontamination, plant irrigation and lighting. The paper reports the main features of the system and the main outcomes of the user studies.

Keywords: Interaction Design, Internet of Things, User Centred Design, Environmental design

1. Introduction

The paper presents a research project aimed to experiment the application of interaction design methodologies and digital technologies to foster the transition toward sustainability. To this purpose, we developed an interactive prototype based on a domestic water recycling system drawn up with life science experts. The system consists of a dishwasher integrated with an indoor planting device, where the wastewater is treated to make it available for the cultivation of vegetables or for the reuse in following washing cycles (Costa *et al.*, 2018).

The potential of ICT is exploited in an ecosystem approach, overcoming the current application, often reduced to the restyling of old-fashioned products. In fact, a new user centred interactive product typology is designed to create a living space fulfilling the requests of a society focused on environmental needs and quality of life.

This new product will stimulate the development of healthier eating behaviours in users. In fact, the in situ production of edible plants will increase their contribution to the diet, reducing simultaneously the environmental impact due to the transport of food, produced and marketed in a standard way (Bhamra, Lilley, Tang, 2008). In addition to aesthetic perception and indoor air purification, broader sustainability is achieved in a circular economy meaning, since what is left from an application (washing water) will become a resource for another (irrigation).

2. Research Background

The theoretical background of the presented research is manifold comprehending natural science, socio-cultural matters and technological issues.

Zero-mile food production is gaining popularity worldwide. Beside healthy eating habits trends, this renewed interest is due also to the environmental benefits it can provide. These benefits include increased urban and architectural greening, reduction of food transport, and recycling of nutrient in wastewater. Innovative forms of green urban architecture include rooftop gardens, rooftop greenhouses, indoor farms, and other building-related forms, defined as “ZFarming” (Walk, Dierich, 2014). Domestic wastewater streams are often nutrient-rich, and urban agriculture could absorb these nutrients and has historically done so. However, the reuse of kitchen wastewater is no more practiced in modern society despite the high nutrient content and the low presence of pathogens, heavy metals and pharmaceuticals. The integration of domestic edible plants production in homes with the exploiting of kitchen wastewater for irrigation represents a promising strategy to reduce water consumption in households, to decrease the amount of wastewater to discharge, to produce healthy plant food and to enhances the environmental awareness of citizens.

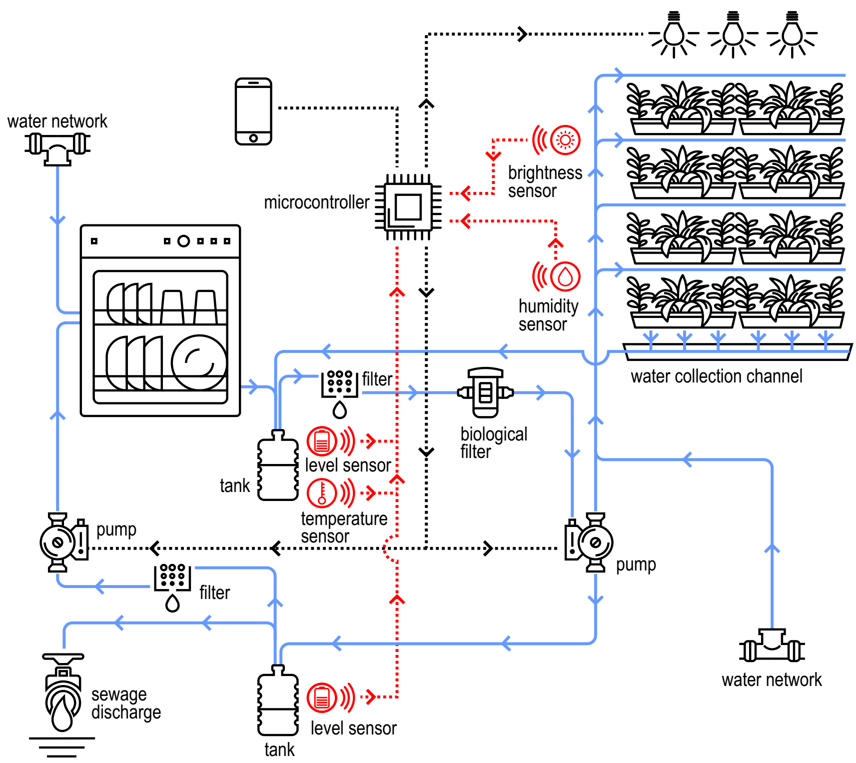
Regarding socio-technical aspects, the success of the system relies on customer acceptance. As Norman states, technological innovation is simple; on the contrary, social, cultural and organizational changes are difficult. To this end, household appliances must turn into "info-appliances" to support users controlling energy and water consumption (Norman, 1999). According to User Center Design guidelines, involving the end-user in all phases of the design process, from the requirement analysis to final evaluation, is needed to achieve a high level of usability efficiency and pleasantness.

Following an Interaction Design approach, the development of innovative product/services requires user studies since the very first phases of the design process (Benyon, 2013), so to orient the design toward a solution capable to produce value and satisfaction. The investigation of the context is even more important in the creation of solutions for the domestic environment, since most people see home as a personal territory, a place of intimacy, wellbeing, safety, and expression of self (Pillan, Colombo, 2017). Authors such as Claire Rowland (Rowland *et al.*, 2015), introduce four different ways to look at a context: operational, behavioral, ecological, and socio-cultural. The *operational context* refers to the characteristics of the physical world where the product/service will be located (thermal factors, presence of wet/dust, spatial arrangements, ...).

The behavioral context includes time and space factors related to the interactions of users with the product itself and its surroundings. The sociocultural factors are related to the motivations, expectations, value, psychological and relational needs of users. Finally, the ecological context concerns the products ecosystem and involves the organization model between stakeholders related to the solution, also including the economical and transactional factors. For this reason, the research presented in this paper includes several activities aimed at investigating attitudes, needs, expectations and constraints of users, with respect to planting at home, re-use water and to the availability of adopt such a system.

3. System Description

The system represented in Figure 1 consists of a dishwasher integrated with an indoor planting device, to recycle wastewater from dishwasher for two parallel purposes: (i) making available the organic nutrients present in wastewater for the cultivation of vegetables in home environment; (ii) reusing the recycled water for following washing cycles. Wastewater is treated by a biological filtration, taking advantage of bioremediation techniques: selected algae and microorganisms mineralize nutrients from the wastewater, enriching the filtered effluent, 'fertilizing' water and, therefore, supporting zero-mile plant cultivation. IoT technologies are applied to support the interactions between user, functions and surrounding environment. An experimental in balance prototype as shown in Figure 2 was built considering: (1) the mean Italian dishwasher uses around 4 times a week; (2) the amount of wastewater discharged, approximately 12 lt. per washing cycle; (3) the daily water consumption per plant, around 40 ml for salad.



[Figure 1] System (diagram by Marco Aureggi)


[Figure 2] Prototype

4. Research Method

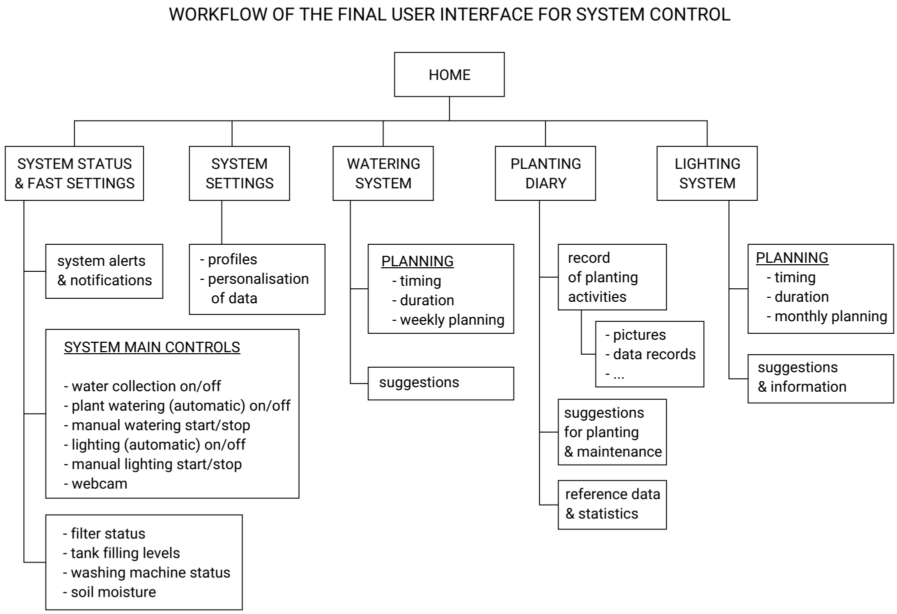
The methodological process consisted in 6 main steps.

At the beginning, we conducted benchmarking through an internet-based research using key-words (such as: green wall, growing plants appliance, cultivation system indoor, green kitchen) and performed field-research during Eurocucina, Milan Design Week 2018.

A mixed methodology, including secondary analysis of quantitative data and focus groups with consumers and stakeholders, has been applied to understand consumer habits regarding water recycling, home cultivation and eating preferences.

On the base of the results of the previous steps and the biological experimentation, that was conducted in parallel, we organised a co-design workshop to generate the system concept.

The final user interface was developed according to the workflow represented in Fig. 3. An experimental prototype was then built to test plants growth and interaction modalities through an iterative process, articulated in prototyping-evaluation-modification cycles, with the collaboration among different professionals and the involvement of expert users. The collaborative development of the interaction system is in progress thanks to the use of software and prototyping platforms such as MIT App Inventor and Arduino. User trials are planned to test the prototype's interface usability.



[Figure 3] Workflow of the final user interface for system control

5. User Needs

People representative of possible final users have been involved up to now through a questionnaire, a focus group and interviews to investigate attitudes and opinions about the *system*. The research involved people, of different age and personal disposition toward environment issues, none of which had a preliminary knowledge of the concept. The focus-group (7 people), reported the motivation of users toward a better use of water and a diffused awareness of the advantages of using domestic appliances selecting the ecological program. The core phase of the focus-group was based on the presentation of the concept with the support of some images reporting the scheme of the system and the experimental apparatus. The impact of the presentation was positive, and it created a fertile conversation between the participants about potential and critical factors of the concept. We schematically condense the outcomes in terms of critical, positive features and other relevant issues.

To begin with criticalities, the discussion evidenced space constraints (dimensions, encumbrance and positioning); maintenance and hygiene (management of leaves and organic wastes, insects, smells); safety regarding breakdown of the electric or water system and risks related to behaviors (as an instance, kids climbing on the plant-shelf); consumptions and economic impact (initial costs, consumption of electricity for lighting and for feeding the watering system). The list of positive factors includes elements of gratification related to the adoption of behaviors giving a convenient contribution to environmental issues; the pleasure of gardening at home; availability of pot herbs; the flexibility of the system with respect to different uses of recycled water; the opportunity to distribute the components of the system (e.g. locating the planting shelter out of the kitchen); the symbolic impact of hosting the system at home. The focus-group revealed also a trusty attitude of users toward recycled water: while the research team is paying much attention on the possible impacts on health and is dedicating several research activities to the monitoring of the quality of the veggies, users showed a positive attitude with respect to the safety of the process and positive expectations about the impacts of plant facilities in domestic environments. Users consider positively the requirement of using only eco-friendly detergents. Target interviews with professionals were dedicated to the discussion of technical and maintenance requirements of the system and to its potentials with respect to other contexts, such as restaurants and canteens.

The conversation with users pointed out also the importance of a suitable communication apt to better explain the potentials and the ‘reasons why’ of the system: while the attitudes of the people involved in the survey showed interest and curiosity, it is also evident that innovation as such is not considered as a value in its own, and it is important to accompany the development of the new domestic solution with a broad conversation about its potentials and criticalities. This result is of general importance and it is coherent with a general principle of Interaction Design, i.e. that innovation requires social engagement to discuss the impacts and verify consensus (Erwin, 2013).

6. Conclusion and Future Developments

The experimental development of the integrated system reported in this paper was conducted following a research method based on a design driven creation of a scenario and concept that were shared with the project partners since the very first phases of the concept generation, through the design/experiment cycles, so to enable co-design and progressive improvements based on independent contributions of researchers from different disciplines and collection of hints from potential users. The research is still going on and the next steps will focus on the iterative prototyping and refinements of the digital interfaces for control, on the investigation of the quality of the final organic products and on the technical characteristics of the system.

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Urban agriculture and water recycling

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Abstract

The paper is devoted to present the collective application of the ZERO MILE system, already studied at individual/family scale. The System deals with the reuse of dishwasher wastewater in vegetable cultivation, producing several benefits. The first benefit is the reduction of the amount of fresh water consumed (by filtering and re-using wastewater), and the amount of wastewater discharged. The System is based on a biofilter containing an ad hoc engineered consortium of selected microorganisms, which attack and consume the organic material present in the dishwasher wastewater (food residues), mineralizing it. The reclaimed wastewater is used in plant production and in the following dishwasher cycles. The second benefit is the home-made production of veggies, which allows the users to grow the wanted veggies and to freshly consume them, along with the gratification of 'grow your own'. The home-made production of not contaminated edible plants contributes to a sustainable diet, stimulates healthy eating behaviors, and contemporary reduces the environmental impact due to food production, transport and marketing by standard procedures. A third benefit deals with a cultural change on the acquisition of a different perception about the real value of wastewater, and on the passage from an abstract recycling concept to a real one. These changes may trigger a further positive feed-back in consumer life style, pushing citizens to move from a linear economy to a regenerative circular one, as a general rule.

The methodological approach applied to drive the integration of the system at collective scale, i.e. in service and built environment, is based on the participation of the relevant stakeholders in the co-design of the applications. The aim is to develop future socio-technical scenarios at architectural and urban level and to create a community of interest towards the project, rising awareness about its environmental and social benefits.

Keywords: Social Innovation, Environmental Design, Circular Economy, Design for the Common Good, Bioremediation

1. Introduction

Worldwide growing of water demand and shortage of water resources, point out the crucial role of managing potable water even in domestic cycles (Zygmunt, Walker, 2008). In this context wastewater is gaining attention as a reliable alternative source of water, shifting the paradigm of wastewater management from treatment and disposal to reuse, recycle and resource recovery (WWAP, 2017).

Wastewater can be a cost-efficient and sustainable source of energy and nutrients and its reuse becomes more economically feasible if the point of reuse is close to the point of production. For this reason, the destination of reclaimed domestic water to urban agriculture, taking advantage of its nutrients content, is an interesting strategy to gain value from it (McClintock, 2010). This strategy also contribute to face the problem of water consumption in agriculture, which is estimated to be 70% of the withdrawal from renewable and accessible freshwater. Hence, treatment, reclamation and reuse of municipal wastewater for crop irrigation is recognized as a valid solution to tackle water scarcity (Kunz *et al.*, 2016). To date, biological treatment is a key step of the wastewater treatment (WWT) process. Most techniques rely on interconnected bacteria-based complex and multistep operations with high costs and energy input. A more sustainable WWT approach is the use of the synergistic relationship between photosynthetic and heterotrophic microorganisms: microalgae-bacteria consortia can be cost-effective and efficient (Posadas *et al.*, 2017).

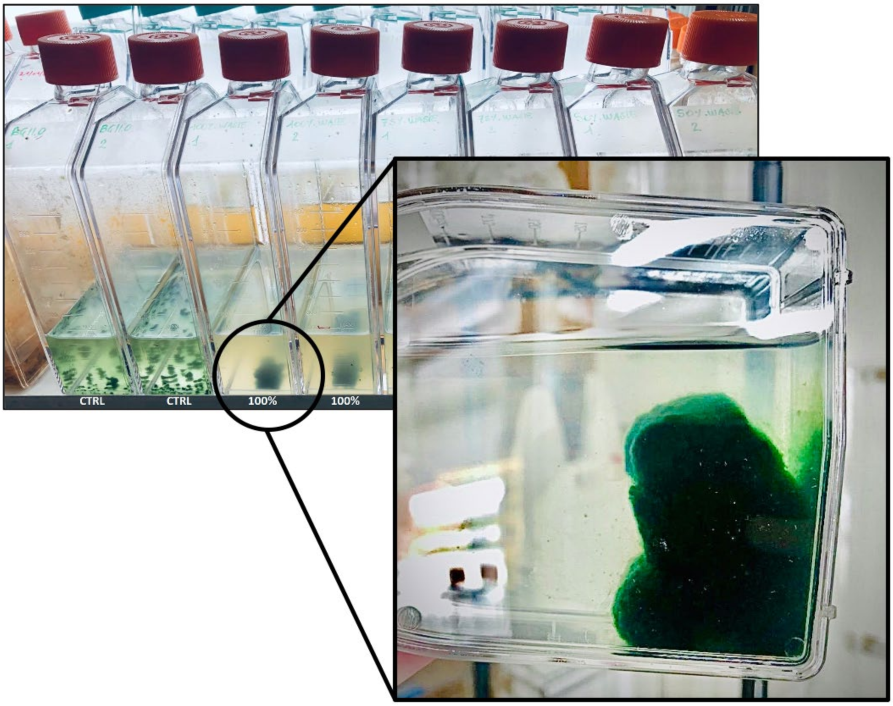
Although the water reuse practices in traditional agriculture are investigated at a greater extent, the exploitation of wastewater produced by households, both individually and by groups of people, is a relatively untapped research topic. In the meantime, urban gardening is gaining popularity. Beside healthy eating habits, this trend is also relevant for the environmental benefits it can provide, including city greening, reduction of food transport and recycling of nutrients in wastewater. Innovative forms of green urban architecture applied in so far are rooftop gardens, rooftop greenhouses, indoor farms, and other building-related forms, defined as "ZFarming" (Walk, Dierich, 2014).

The ZERO MILE system collective applications analysed in this paper are based on a prototype system (Fig. 1) called ZERO MILE, that authors are developing in an interdisciplinary team for the upcycling of the dishwasher effluent (Costa *et al.*, 2018). To this end, a new concept of biofilter is introduced, based on an ad hoc designed, closed and safe tool, operating continuously, able to produce reclaimed water that is then reused for food production and to run further dishwasher cycles (Congestri *et al.*, 2019 a, b). The new concept of biofilter represents the node of the integrated dishwasher/vertical garden system prototype, that simultaneously allows the reduction of wastewater produced, its recycling and its conversion in domestic plant biomass, thus supporting the transition of wastewater in resource, the recovery and valorisation of by-products, as envisaged by the circular economy approach.

[Figure 1] Experimental ZERO MILE prototype

The use of controlled microorganisms in the biofilter (Fig. 2), directly isolated from the dishwasher wastes, makes the biofilter virtually safe. Moreover, it will permit lower acclimation periods, higher degradation rates and higher volumetric influent load when the biofilter will be engineered for the up-grade to full-scale, enhancing a more compact design. To the best of our knowledge, this is the first attempt to upcycle the dishwasher wastewater and represents itself a step forward in kitchen wastewater recycling.

The integration of edible plants production in the domestic environment with the exploitation of kitchen wastewater for irrigation represents a promising strategy to reduce water consumption in households, to reduce the amount of wastewater to be discharged, to produce healthy plant food and to enhance the environmental awareness of citizens. Furthermore, this vegetable household production brings about energy and space saving also by cutting the costs of food transportation and reducing the agriculture land use.



[Figure 2] Biofilter microorganism tests

2. Zero Mile upscaling in the built space

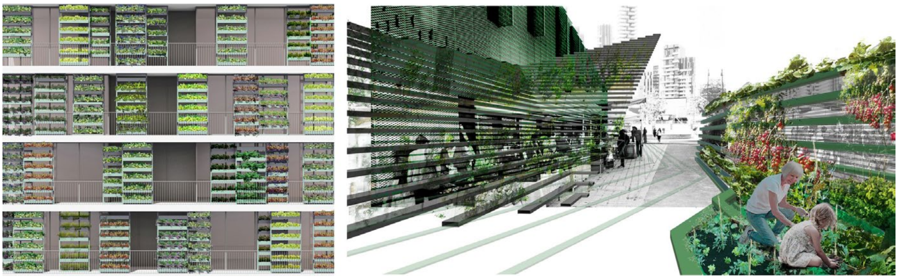
The integration of the wastewater treatment system in built space context is a goal that can push a change in the user behaviors while improving the domestic water use efficiency. Therefore, design solutions have to address a path of progressive integration, starting from independent and simply superimposed solutions, to hybrid forms for morphology and construction components (Blasi, Padovano, 2003). Three main types of applications are possible:

- Independent application: a simple support of technology. This application does not replace traditional building components. Simple, fast and economical solution, suitable for full or partial redevelopment processes.
- Application by overlapping: characterized by standard technological elements. Building envelope acts as a simple support achieving a "superstructure" effect, a kind of second "skin" which often contributes to increase the environmental and/or energy performance already achieved by the constructive component. Simple, fast and economical application, indicated in the retrofitting process.
- Application by integration: unique components able to replace some of building's elements functions. Whole is not easily divisible in its basic elements. It is applied in new interventions or in case of replacement of significant portions of an existing building.

Possible application outcomes at the different scales of the project were investigated in the first stage of the research (Nebuloni, Buratti, Meraviglia, 2019), when the requirements for the implementation have been defined as follow: (i) modularity of the system; (ii) differentiation between system infrastructure and frame; (iii) flexibility of cultivation; (iv) ease access to the system for maintenance and movement; (v) system implementation. With the aim to address integrated design solutions for technology and construction, two main output scenarios were defined:

- at architectural design scale, modular green shading systems integrated with small vegetable gardens for domestic use – a kind of architectural green brise-soleil, acting as both technological element of façade and system to support a small domestic urban cultivation (Fig. 3.A);
- at the widest scale of the open space, a green shelf structure system linked to small/medium sized commercial activities and

aggregative spaces, promoting an idea of not-profit cultivation; this structure may drive the recovery of marginal urban area, promote socialization and space regeneration (Fig. 3.B).



[Figure 3] A - Architectural scale scenario (left), B - Urban scale scenario (right)

These scenarios are a kind of meta-design solutions, open to changes by what still needs to emerge in research, but able to fix some key aspects for the system's implementation, both at indoor and outdoor environments. Therefore, they are design suggestions and starting point to address a multi-scale approach (product, technology and space application) that will guide the next design's steps.

Technological application will be the fil rouge throughout all examples in this design step, also focusing on relation that leads from the building to the open space, and again from the open space to the building, so shaping a unique "circularity" of the recovery system. Therefore, two are the main scientific fields to integrate: first of all the field of energy and the related technological plant cultivation system, then the landscape design.

3. Co-design workshop

The methodological approach applied to drive the integration of the system at collective scale, i.e. in service and built environment, is based on the participation of the relevant stakeholders in the co-design of the applications. The aim is to develop future socio-technical scenarios at architectural and urban level and to create a community of interest towards the project, rising awareness about its environmental and social benefits.

The workshop has been organized at Politecnico di Milano in the laboratory where the prototype is installed to give a practical demonstration to the participants. Specialists has been invited to complete the teams' competences involving environmental engineering, architectural technology, agronomics, service and industrial design, energy saving. It engaged 14 people and lasted three hours, organized in introduction (description of the functional system and a short presentation of the results of the experiments already performed); participants' presentation and plenary discussion; group building on two topics; group discussion and ideas generation; final reciprocal presentation of each group's results.

The plenary discussion lead to the identification of two application context: the restaurant context, considering also indoor cultivation, and housing context with outdoor cultivation.

In the restaurant context the use of vegetables is collective, but the dishwasher wastewater is produced punctually in a much greater amount than in our previous experiments. The collecting system is conceptually similar to the prototype one, but large tanks will be needed for storage and treatment and the available reclaimed water will make it possible to irrigate wide indoor and outdoor surfaces. In such context, hygiene regulation for water storage has to be taken into account as well as guidelines for irrigation water parameters.

The wastewater production by the restaurant kitchen alone has also the advantage to facilitate the system control, for example regarding the choice and use of environmentally certified detergents. This wastewater has relatively constant characteristics that have to be analysed in order to adjust the existing treatment system. On the other hand, the cultivated vegetables have to undergo specific regulations to be used as ingredients in the preparation of the restaurants' dishes.

Indoor cultivation is very attractive from the interior design point of view, considering both indoor air purification and aesthetic perception, but it raises several questions that have to be carefully analyzed regarding energy use for illumination and plants health monitoring. A possibility emerged in the group discussion is to limit indoor cultivation to ornamental plants, in analogy with our everyday experience concerning apartments' plants, and produce vegetables in the court, on the façade or on the roof. Furthermore, in both indoor and outdoor cultivation, unused spaces can be exploited to maximize the sustainability of the system.

Another important point to be addressed is the community of stakeholders needed for the implementation in the restaurant context: from the installer of the hydraulic plant, to customer and citizens as students, educators, informal groups and associations.

The application at restaurant scale seems suitable to stimulate a cultural change, as the acquisition of a different way of thinking about the real value of wastewater, may move people from an abstract recycling concept to a real one, with the development of new everyday behaviour. To this purpose precise information on plants characteristics and the possibility to assess the actual quality of reclaimed wastewater are needed to support consumers overcoming mental barrier to eat vegetables cultivated with wastewater trusting in the reclamation process. It also may drive to the creation of a creative community able to push public authorities towards the development of policies to support locally-deployed water reuse production projects.

At wider outdoor scale, water recovery system shifts research's focus from a single home to a settlement with a target of 180-200 people (equal to about 90-100 housing units), that is the minimum useful mass for eco-systemic interventions at building and open space scale. System's application can therefore extend to all outdoor space, with a significant impact both in irrigation supply and in domestic water treatment. Therefore, this application scale is set to an "intermediate" level of the open space - between building and landscape - anticipating hybrid design solutions focused on circular economy. Two main feedbacks emerge:

- starting from individual apartment, water returns to the building after a treatment process which allows its reuse in a parallel and non-potable supply circuit - hybrid solutions are also possible using the water thermal energy for the housing heating;
- buildings and water system create an eco-systemic services environment, where the wastewater management is measured as Total Economic Value. It's also possible using wastewater to irrigate plants needing great quantity of water (e.g. willow, poplar, birch), to feed local small biomass power plants, reaching more environmental targets (wastewater reuse, energy saving, landscape recovery).

Focusing on design requirements, the wastewater system application in the housing context needs to study some key aspects.

Firstly, gradual shift from the kitchen (where wastewater is produced) to its application into eco-systemic design strategies, through the use of one or more water tanks. The reason is the necessity to check the water quality (the wastewater management at user level cannot be simply transferred to a larger scale of application) and the variability of the outdoor water consumption (seasonality, atmospheric events).

A second aspect concerns the relationship between the wastewater system and the rainwater collection. This aspect refers to the evaluation of wastewater and land use legislation, as possible constraints to the development process. Examples are the various local hygiene regulations that establish guidelines for collection and wastewater management, rainwater management, underground water, etc. Institutional stakeholder involvement (e.g. water management companies, regulatory authorities) is therefore strategic starting from the first research steps.

A further aspect is quantitative and shifts research interests to environmental certifications both at building and urban/landscape levels. Moreover, system's certification is a lever in awareness raising, as well as for possible economic grants for latest environmental technologies and systems as already happened for photovoltaic technology. As the above aspect, also in technology development the stakeholders' involvement is a key aspect.

Last key aspect is the relationship between indoor and outdoor outputs, understood not as autonomous systems, but overlapping and in synergy with each other. At urban scale level this gradual design approach increases users's awareness through co-participation. On the basis of the similar photo voltaic energy account, a "water account", allowing a wider scale of system development, is also possible.

4. Conclusion

Both alternatives, restaurant and housing applications, accommodate the phenomenon of green consumerism and in particular the growing interest in zero-mile organic food products, whereas the self-production of vegetables.

The use of vegetal elements in architecture inevitably acts on languages and on art of building technologies. It does not indeed mean a simple application of a coating to an already existing wall, but the construction of a wall in which the plant component is an integral part and compositional matter, able to interact with other materials to create a specific language.

Through a careful study of plant species for food and non-food use, it is possible to improve the hygrothermal quality of indoor environments and the airiness. External plant walls and roofs offer advantages such as the absorption of CO_2, UV rays and pollutants, heat and sound insulation, significantly limiting energy.

The possibility to integrate the prototype system in the housing context seems very interesting from the conceptual point of view, but it highlights several criticalities. Mainly: the number of stakeholders involved; the high cost and times of experimentation, realization and maintenance; the multiplicity of variables (wastewater sources, climatic conditions, space availability and suitability, users' preferences…); the structural and hydraulic system's requirements. On the other hand, the development of the prototype system in the restaurant context appears more feasible in the short time, because of the smaller scale, the concentrated and more controlled wastewater production (from both a quantitave and qualitative point of view) and last but least, the interest of one of the participants to host indoor and outdoor applications. In both cases wastewater characteristics, hygienic regulation, and vegetables dietary quality has to be carefully monitored.

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Zero kilometre plants production. An integrated design application

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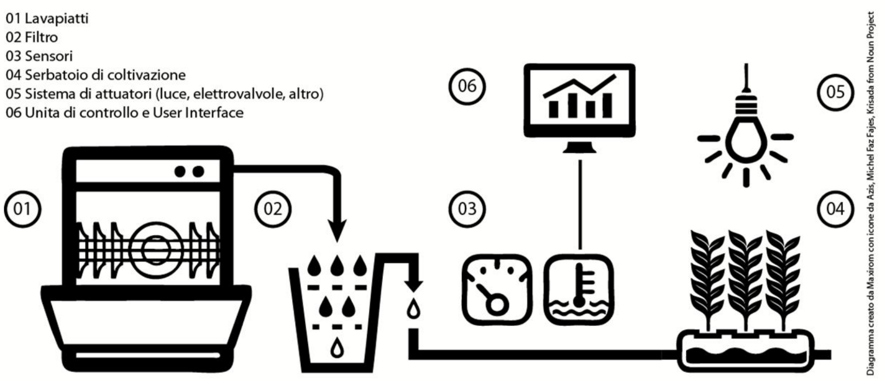
Abstract

Interest in urban agriculture as well as the various forms of zero kilometre production for domestic use, necessarily passes through the redefinition of the parallel system of building components, both regarding technological and innovation level of the built space, towards their progressive integration: from independent solutions or simply superimposed on the building, towards increasingly hybrid forms, as expression of an increasingly integrated collaboration between architecture, agriculture and design. The result is the progressive replacement of traditional products with elements and components directly integrated in construction by composition and technology. The paper presents the first results of the design research whose objective is to experiment the possible applications to the contexts of the built space, to the different scales of the project, of a product system for the recycling of washing waste in a domestic environment for the production of plants. edible products underway at the Design Department of the Milan Polytechnic.

Keywords: sustainable gardening, wastewater recovery, green integrated solutions

1. Introduction

Environmental or ecological sustainability requires awareness of the natural resources. The impact of human activities and decisions on it is therefore of first interest in sustainability research deals with living spaces (architecture and construction activities). In this context an increasing research area of interest is focusing the consumption of water resources in household appliances, particularly all technological systems and/or solutions able to recycle dishwasher wastewater for the cultivation of edible and ornamental plants. However, there is still a significant gap concerning the possible application of these innovative technologies to the built space context. Therefore, the integration of the wastewater treatment system in kitchen furniture, with green or gardening architectural solutions as first application outcome of the research itself, can push a change in indoor growing modules design, as well as in user behaviours, while improving the domestic water use efficiency (Figure 1).



[Figure 1] Functional diagram

An in progress interdisciplinary research on WasteWater Food Converter (WWFC) by Department of Design of Politecnico di Milano, aims to study a product system for recycling wastewater in a domestic environment for the production of edible plants through an autonomous cycle, whose preliminary phases were[1]: characterization of wastewater, plant growth and functionality analysis, technical design of the remediation plant, product and user inquiry, participatory

[1] For more information see Aureggi, Carboniero, Costa, Perego, Pillan, Vignati "Design for sustainability and ICT: a household prototype for wastewater re cycling", also published among the acts of The LeNS World Distributed Conference – Designing Sustainability for All.

design for expert and user involvement in the system ideation and development, followed by the development of a functional prototype designed for indoor installation, equipped with a series of sensors and actuators for the control and regulation of the entire system, as well as a low emission system with low environmental impact (Figure 2).

The paper presents the first results of this system possible application at the built space context, and at the different scales of the project.

[Figure 2] Prototype

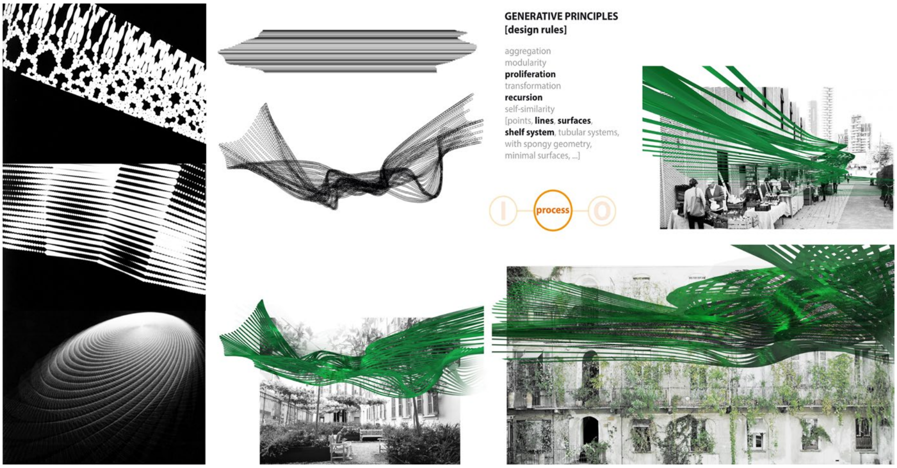
2. Towards an integration of the system

Foreword to the project research was the collection and critical analysis of case studies on issues of vertical green, urban and indoor gardening, in the search for dependency relationships between application technologies and built space, useful in defining the related application strategies to apply into follow design phase. Two were the references adopted particularly: the development that over the years has taken place in the context of research on photovoltaic components, on the one hand, and the design experimentation of green solutions for roofing systems and façades, on the other. Over years, their design solutions have experimented a path of progressive integration, from independent solutions and simply superimposed on the building, to increasingly hybrid forms for morphology and construction components, addressing basically three main types of applications, as summarized in the following Table 1 (Blasi, Padovano, 2003; Blasi, Padovano, Nebuloni, 2007).

[Table 1] Towards an integration of systems - main application types

INDEPENDENT APPLICATION	APPLICATION BY OVERLAPPING	APPLICATION BY INTEGRATION
It does not act as a building envelope and the building presents itself as a simple support of technology (morphology that does not determine the arrangement of the components of the application).	It is characterized by standard technological elements that differ only for the type of support used. The envelope acts as a simple support (technology components anchored to the construction with a parallel and not far structure).	Hybrid nature of the constructive system that arises between architecture, nature, open space and because of a different interpretation of the organization of space in morphological, technological and thematic terms.
The application does not replace traditional building components (both the construction and the technology maintain their autonomy, functional and spatial) and its location with respect to the building partitioning system is closely related to the type of vegetation or technology.	"Superstructure" effect: technological elements that do not substitute envelope parts or sub-systems, but are limited to their overlap (second "skin" strictly dependent, which often contributes to increase the environmental and/or energy performance already achieved by the constructive component).	Technological-constructive components studied ad hoc and able to replace, incorporating, some or all the functions related to the elements of the partitions and the built space. The complex ensemble that results from it is not so easily divisible in its constitutive elements.
Simple, fast and economical solution, suitable for full or partial redevelopment processes.	Simple, fast and economical application, indicated in the retrofitting process.	It is applied in new interventions or in case of replacement of significant portions of an existing building.

The three emerged application strategies were the basis for defining the design hypotheses in which the WWFC system can be applied to the different scales of the project, with integrated solutions both in furniture design and in façade construction components, thus determining a functional and technological reinterpretation. To this goal, meta-design principles and generative rules have been explained, which in the form of spatial suggestions, have allowed to direct the design research as integration between architecture, agriculture and design dimensions (Figure 3). The integration of the wastewater treatment system in kitchen furniture, first, and with the vertical gardening solutions, second, make it suitable for end consumer, giving the research a first application outcome, further developed into design scenarios, where the system can also implemented with additional water recycling sources.



[Figure 3] Generative principles and outdoor scenarios (Font: Authors)

3. Scenarios

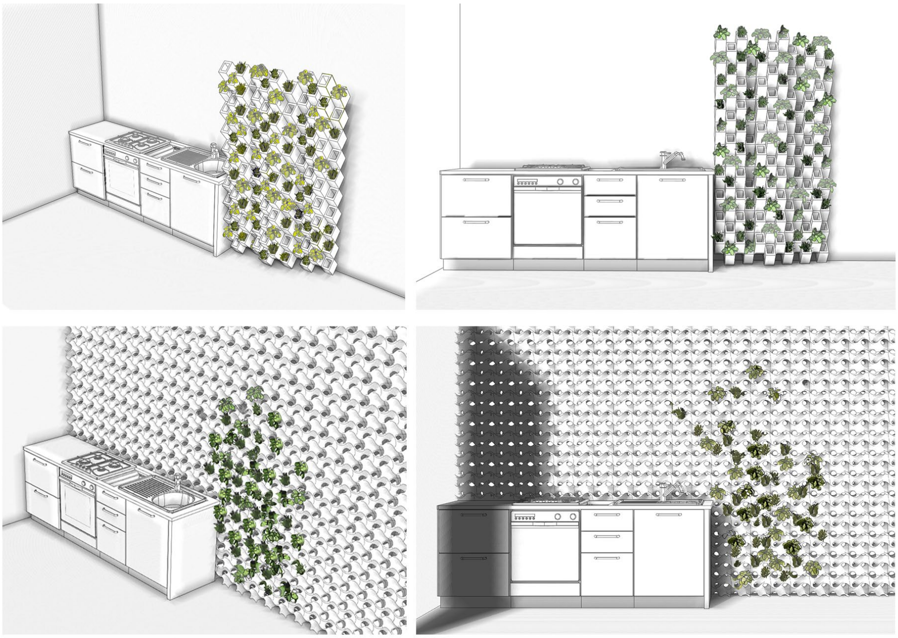
The industrial and profit-making logic that supported the modern food production system it considers food as a commodity to be produced and sold with the maximum cost-benefit ratio. This process creates situations of natural and energy resources unsustainable exploitation, incompatible with the continued world population growth. The debate has progressively expanded over recent years, involving not only researchers and politicians, but the entire population. The consequence is the emergence of a market promoted by conscious consumers, who buy not only for hedonic purposes, but with the awareness that buying and selling process also has a social and ecological impact. The focus is no longer just the price, but also to healthiness of the purchased food, to influence it has on its own health, to attention for sustainability of the production process in social and environmental impact terms.

From the results of the experimental research (Costa *et al.*, 2018) a significant amount of useful surface to accommodate the various species of edible plants was emerged. Specifically: 80 lettuce plants equal to a consumption of 3.5 liters of water/day of waste recovered and filtered, equal to a surface of about 3 square meters, which make it possible to use the average waste production of an Italian family.

With the aim to direct the project development towards integrated solutions for technology and construction, the project requirements for the implementation of this phase have been defined as follow:

- modularity of the system, from the single base unit (in the study prototype represented by simple polystyrene vases of 60x20x18 cm, containing three plants each, mounted on a vertical metal frame) to their aggregation in functional sets;
- differentiation between structure/frame, with the related systems for irrigation and wiring of the sensors, and the modules for the support of vegetation;
- flexibility of cultivation, providing both the possibility of cultivating more edible species, each with a specific consumption of water, and the possibility of integrating the system with ornamental types;
- easy access, maintenance and movement of the elements (single and aggregated);
- implementation of the urban scale system in the redefinition of themes and functions, also focusing on issues of socialization and the redevelopment of living spaces.

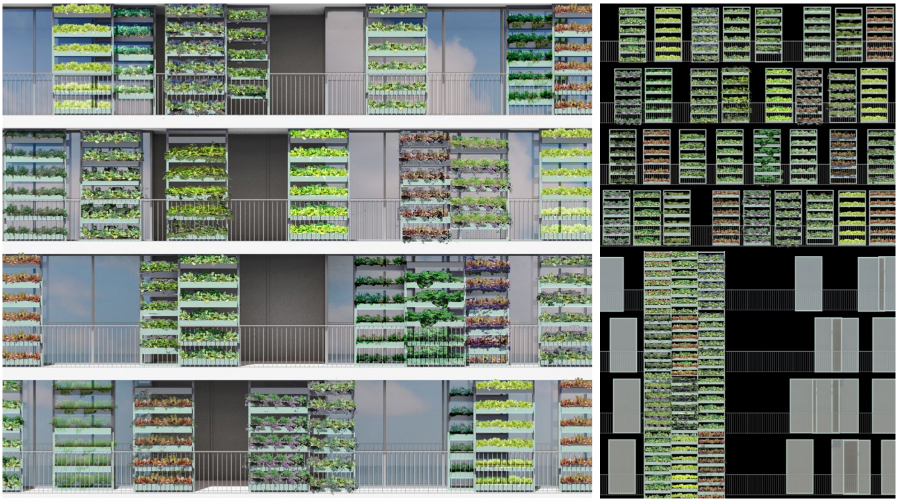
Those listed are general features of the system which may have different repercussions depending on the implementation scale. In designing a system for domestic use it is necessary to consider food consumption practice as an action of meaning attribution, which contributes to build costumer's personal identity (Blay-Palmer, 2010). There's therefore an attention that opens up new trends in domestic environment, in particular for kitchen area (Figure 4). Despite sensitivity of potential consumers it's necessary the new system is independent and functional as possible. Contrary to outdoor vegetable garden, where time dedicated to cultivation is perceived as a hobby, in a domestic interior the system must subtract the user as little time as possible.



[Figure 4] Indoor scenario (Font: Authors)

Electronic devices will monitor growth protocols by regulating luminance, entrusted to particular LED lights (specifically modulated to optimize and accelerate different species life cycle), the temperature and the humidity required, no matter of the real conditions, at any latitude. The vegetables so cultivated do not undergo contamination with chemical substances or potentially polluting soils, allowing the consumption of fresh products that maintain their organoleptic properties unaltered (Eigenbrod, Gruda, 2015). Form is designed to integrate green in kitchen environment, satisfying the needs of different vegetal species through modularity, in adaptable and reconfigurable morphologies for limited spaces (Buratti, 2017).

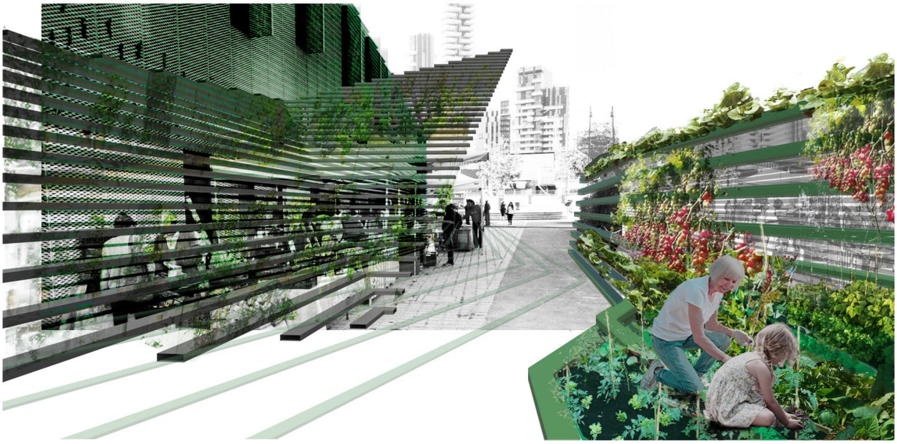
On an architectural scale, integration is instead shaped by the rethinking of a traditional module of vertical obscuration of the façade, to integrate the cultivation system of edible and/or decorative plants: a sort of brise-soleil, at the same time a technological element of façade and cultivation. The panels, modular elements equipped with a frame integrated with the irrigation system and a series of vases housing the plants, maintain the kinematic nature of the shading systems and can therefore run on tracks integrated into the façade, characterizing a dynamism appearance (Nebuloni, 2017), both for the movement of the frames and for the growth cycle of the plants. By exploiting the surface of the panels, this solution allows you to create a small vegetable garden or vertical garden for domestic use and directly connected to it, flexible, implementable (from a few panels to an entire facade solution) and easily compatible with other spaces of the building, even in contexts where it is not possible to realize more traditional urban gardening solutions (Figure 5).



[Figure 5] Architectural scale scenario (Font: Authors)

At the widest scale of the open space, the project finally configures a shelf structure, supporting and housing vases for cultivation, conceived as an element in adherence to small / medium sized commercial activities and aggregative spaces, where to promote an idea of cultivated area not profitable, but open and shared, from which, with a parallel to what was promoted in the naturalistic field, it's name: "vegetable garden to lose"[2]. In addition to encouraging the recovery of more marginal urban spaces and environments, the recall effect of this solution, thanks to the commercial part's lever in the recovery of wastewater produced by the established activities and in the more general promotion, cure and basic maintenance of the system, would help to promote socialization and caring of urban space (Figure 6).

[2] Solution implemented in places where the fauna is damaged or in danger, providing the animals with help in the form of food. This form of protection also acts as a lure for other species of animals, in particular small invertebrates, which in a virtuous circle sometimes attract other species. Among the plants the strawberry, in particular, is very sought after and being a perennial plant it is possible to find it in the vegetable garden all year round.



[Figure 6] Urban scale scenario (Font: Authors)

4. Discussion

WWFC technology in future could change both building and space factors of green decoration to producing more resilience indoor and outdoor products, also taking into account the legitimate needs of users with regard to the satisfaction of both the food quality aspects and the aesthetics of the system as a whole.

The scenarios are therefore not to be read as products to themselves, as suggestions inserted within a broader experimental research and whose goal is to anticipate the results of hypothesizing, in addition to the size of the product, the possible forms of application of the technology itself to the built context. In this sense, they are configured as meta-projects, solutions open to change deriving from what still needs to emerge from experimental research, able to fix some key aspects for the implementation of the system's application strategies, both indoors and outdoors.

The design requirements of these scales, in particular, as well as the feasibility and application contexts, and their relationship with the functional aspects of the technology for the recovery and filtration of wastewater, are in fact still configured as critical nodes from solve in the search.

A multi-scale approach that considers a contemporary action to the dimensions of the product, as technology, and space, as application output, will then guide the next steps of experimentation.

In addition to the prototyping of the various solutions, development of the design research aims to study a further scenario on territorial scale, as an extension of the principles and requirements defined in introduction, thus moving from a timely dimension that binds the product of the WWFC technology to the building components of domestic space, to a more widespread and networked one, characterized by intermediate dimension between space of the neighborhood and that of interactive connections.

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Appendix

Integration of the "eco-domestic" systems in the urban and architectural context

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Introduction

This part of the research focuses on the possible integration of the "eco-domestic" system/service in the wider context of living spaces and in specific relation to the scales of architectural and urban design.

To this end, we will study the possibility of extending the idea behind the research from the context of "production technological systems" for internal use (already on the market), to that of "technological process systems" and for their possible application to build spaces, whether they are mediation and/or urban. It is therefore expected that this research will provide useful ideas for the development of an innovative approach to urban cultivation and vegetation, as a prerequisite for their integrated application in the design of living spaces. The "eco-domestic service" is an environmental design project whose goal is to create sustainable product-service systems. From a technical point of view, the project develops the concept of a new type of product integrated into the home which allows, in the recycling of waste water collected in the kitchen environment, a sustainable application for the on-site production of vegetables for domestic use. This technology is based on a multi-level system that starts with the process of recovery and cleaning of wastewater and ends with the irrigation of plants for domestic use. The device, in the testing phase, consists of a dishwasher, a collection tank, a renaturalized water filtering and distribution system, sensors for active behavior management, a cultivation tank, a system of actuators (lighting) and a user interface.

The interest of research in such a technology appears to be of particular importance if associated with the emergence of a greater interaction of living with the natural and vegetational component in view of self-production, especially in urban and metropolitan contexts. Modularity and flexibility are the aspects of technology that characterize its application in such contexts (architectural and urban levels), opening the field of experimentation from the domestic environment of the kitchen space to the wider dimension of the neighbourhood open space. To this end, attention will be paid to the relationship between construction and some main components capable of orienting a different articulation of the organization of space: water, lighting, vegetation, technological sensors, control devices and cultivation system.

The use of eco-vegetational systems and components is therefore an interesting opportunity to experiment alternative and innovative forms of sustainable technologies, capable of implementing a reinterpretation of traditional building envelope systems, which in promoting forms of interaction between the different living spaces and the natural environment, give shape to new compositional matrices of the architectural space.

BETWEEN ARCHITECTURE AND TECHNOLOGY
main application types

independent application
a. horizontal layer/roof:
Green roof, Los Angeles - Synthe
Pocket habitat, London - ARUP
b. vertical layer/green facade:
ex Ducati, Rimini - MCA
I'm lost in Paris, Paris – R&Sie

application by overlay
a. horizontal layer/roof:
Academy of Sciences, San Francisco - RPBW
b. vertical layer/grren facade:
Quai Branly Museum, Paris – J. Nouvel, P. Blanc

application by integration
a. merging context / construction components:
Delf Library, Delft – Mecanoo
ACROS International Hall, Fukuoka – Emilio Ambasz
Cantine Antinori, Firenze –Archea associati
Novartis Campus, Basilea – foreign office architects
b. technological clusters:
Brise soleil - Usa Pavilion EXPO 2015, Biber Architects
Acoustic barriers
c. thematic clusters:
Urban farming
Urban gardening

GENERATIVE PRINCIPLES

aggregation
modularity
proliferation
transformation
recursion
self-similarity
[points, lines, surfaces,
shelf system, tubular systems,
with spongy geometry,
minimal surfaces ...

TOWARDS A SYSTEMS INTEGRATION

from principles to design

Methodology

This phase of research proposes a reinterpretation of the eco-domestic system, from system-product to system-process technology, in order to experiment, in the transfer of knowledge gained in contexts similar to the world of architecture, possible solutions integrated into the building systems. The aim of the design research is therefore to experiment the possible forms of such integration in terms of innovation of spaces and tools of the design itself.

There are two main instrumental references in this study: the development that has taken place over the years in the context of research on photovoltaic components, on the one hand, and the design experimentation of green solutions for roofing and façade systems, on the other. In both solutions, whose environmental matrix frames their research, the aspects of technology have experienced a similar path of progressive integration, from independent solutions simply supported or superimposed on the construction, to integrated forms which, in replacing traditional building components, have built a family of new hybrid products. On the basis of these experiences of development and progressive integration between the technological aspects and the construction components of the building envelope (an element of mediation between various spatial dimensions that define architecture, first of all the relationship between internal and external space), the research aims to bring out, through significant case studies, characteristics, areas and technological aspects common in three main types of applications: (1) independent; (2) superimposed; (3) integrated-hybrid.

Applications

1. Independent application

This type of application does not perform the function of a building envelope. The building acts as a simple support for technology and its morphology does not a priori determine the layout of the components of the application: its location with respect to the partition system (horizontal and/or vertical) is closely related to the type of cultivation/vegetation to be applied. The application, therefore, does not replace building components traditionally used in construction. This category is the one that most differs from the concept of integration and presents itself as the simplest, quickest, and cheapest intervention technique, especially suitable for building renovation processes (whether integral or partial).

Case studies:

a. horizontal layer/roof:
 a1. Green roof, Los Angeles - Synthe
 a2. Pocket habitat, Londra - ARUP
b. vertical layer/green facade:
 b1. Former Ducati Complex, Rimini - MCA
 b2. I’m lost in Paris, Parigi – R&Sie

1_a1

1_a2

1_b1

1_b2

2. Application by overlay

This type of application is characterized by a series of standard technological elements, which differ only in the type of support used. The surface of the case acts as a support, since and unlike the autonomous systems of the first application, the components of the technology of which it is composed are anchored to it by means of a special structure parallel to the surface and not far from it.

The technological performances deriving from this application on the construction can sometimes be “redundant”, as they do not replace existing elements or sub-systems of the envelope, but are limited to their overlapping, thus covering surfaces already provided with specific performances. For this reason, in some cases this solution may contribute to increase certain environmental and/or energy performance, already partially fulfilled of the construction component itself. In other words, the "support" (horizontal or vertical - roof or wall), should have a superstructure capable of meeting the needs of support and growth of vegetation.

The resulting green surfaces are therefore to be understood as a kind of second "skin" that covers the construction and is strictly dependent on it. As for the previous application, also in the case of the overlapping solution, the intervention technique is quite simple, quick, and cheap. The addition of technology and functionality to an existing system, which thus extends its useful life, makes this solution particularly suitable for retrofitting building redevelopment processes.

Case studies:

a. horizontal layer/roof:
    a1. Academy of Sciences, San Francisco - RPBW
b. vertical layer/green facade:
    b1. Quai Branly Museum, Parigi – J. Nouvel, P. Blanc


2_a1


2_b1

3. Application by integration

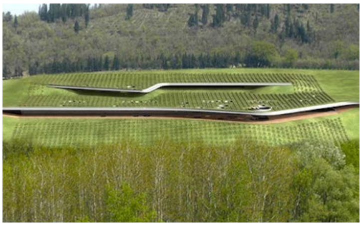
This third form of application is characterized by the hybrid nature of its construction system. In this case we are not talking about standard elements superimposed on a reference base already equipped with specific performances, but of technological-constructive components specifically designed for use in architecture and able to replace, incorporating, some or all the functions referable to the elements of the partitions and the built space. It is therefore possible in this case part of hybrid construction components between architecture and nature, whose flexible nature allows an opening of the building to the wide dimension of the urban open space (infra-green-scapes).

Compared to the previous solutions, in the case of integration the system finds application in new works or in the case of replacement of significant portions of an existing building. More than a simple "green" construction, the results is a real hybrid infrastructure between architecture and vegetation, whose overall solution cannot be divided into its constituent elements. The identification of the characteristics, areas, and technological aspects of this form of application can also be referred to some different categories:

- between architectural system and spatial context:
    a. merging context/construction components:
        a1. Delf Library, Delft – Mecanoo
        a2. ACROS International Hall, Fukuoka – Emilio Ambasz
        a3. Cantine Antinori, Firenze –Archea associati
        a4. Novartis Campus, Basilea – foreign office architects

3_a1

3_a2



3_a3

3_a4

- with respect to applied technology, where integrated solutions capable of implementing the basic system are found, on the one hand, with other functions associated with it, on the other in consideration of the design interpretation of themes and functions of the organization of the urban-architectural space:
    b. technological clusters:
        b1. Brise soleil - Usa Pavilion EXPO 2015, Biber Architects
        b2. Acoustic barriers
    c. thematic clusters:
        c1. Urban farming
        c2. Urban gardening


3_b1


3_b2


3_c1

3_c2

Between architecture and technology

Through the critical reading of the vegetational experimentations on the building systems for roofs and facades, the application of the eco-domestic product system opens up to the wider dimension of the built space, finding in the following project addresses the main references of architectural research: (i) the (progressive) replacement of traditional products with elements and components integrated by composition and technology directly in the construction; (ii) the emergence of thematic matrices that, in adopting new approaches to urban cultivation, determine the revitalization of marginal and/or disused spaces and structures; (iii) the development of a family of new "in-between" spaces, as places of interaction and socialization that open the building to the context, while redefining characters and themes of living.

This results in the possible design strategies for the next phase of research: design scenarios from domestic to urban neighbourhood space, made by authors of this article. The objective of this intervention, extended to the dimension of the architectural-urban space, is to build suggestions towards which to direct not only the application, but also the experimentation of the eco-domestic system, in the form of integrated collaboration between architecture, vegetation, design and services.

a1. SYNTHe _ An Urban Rooftop Garden Prototype, Los Angeles
Design: Alexis Rochas, SCI_Arc Design-Build Community Programs

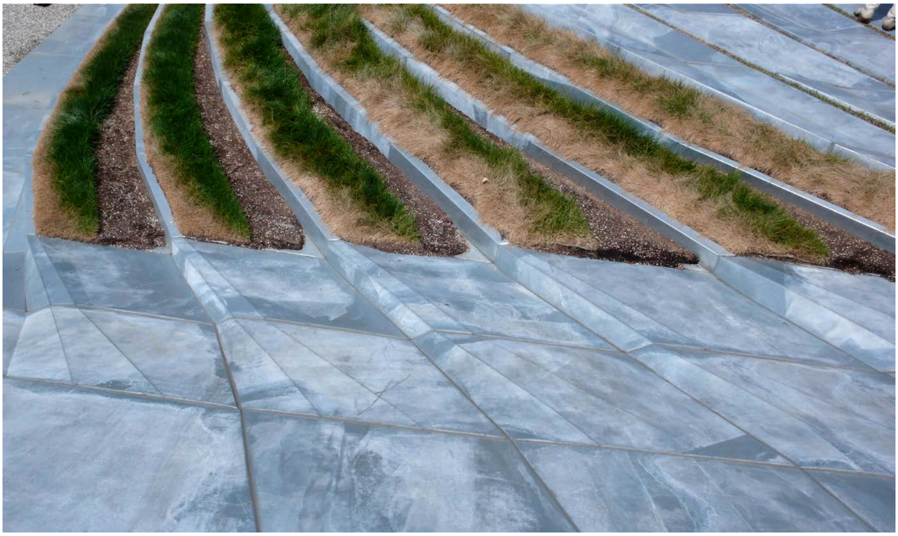
The intervention is located on the roof of a building in central Los Angeles and investigates the development of adaptable green structures.

The Rooftop Garden is a suspended corrugated metal roof, which forms a series of green canals, or cultivation lines, to produce edible vegetables, mainly intended for the restaurant located on the ground floor of the building.

Each culture channel contains less dense than natural soil and an automatic drip irrigation system.

The rows are arranged to receive maximum sun exposure and use the entire available useful surface. On a physical and formal level, the result is a soft artificial ground for the production of organic food and a public meeting space, which at the same time increases the thermal insulation of the roof, the air quality and the management of excess rainwater.

The intervention is made up of an adaptable prefabrication system, consisting of three main elements: a metal frame superstructure placed on the existing concrete structure, a sub-structure specialized in recycled plywood and a coating in galvanized metal sheet to support the vegetal soil.



a2. POCKET HABITAT

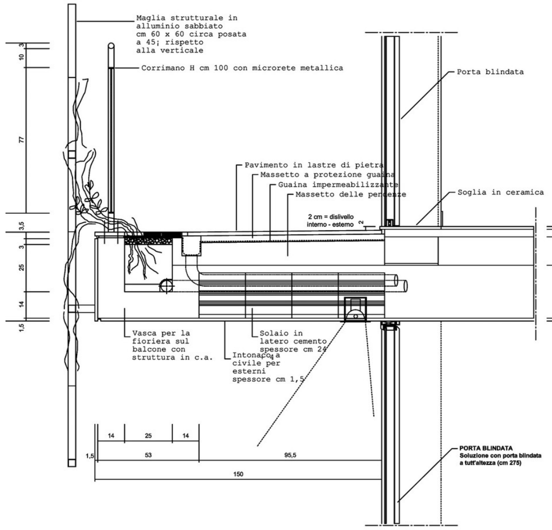
Design: ARUP

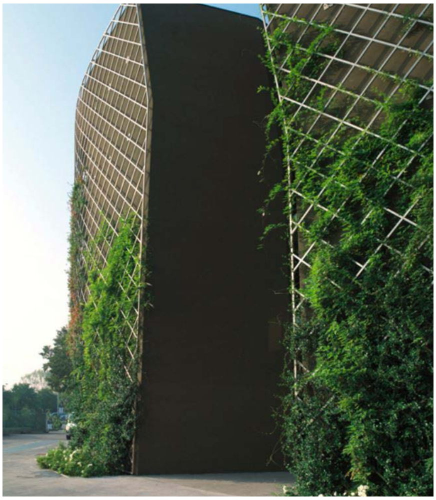
Pocket Habitat, the project developed by ARUP, is a modular system for the construction of a green roof, made with totally recyclable materials. Each bag is made of recovered fabric, which in addition to allowing a natural drainage of rainwater, ensures easy installation and maintenance, reducing time and costs of construction. The soil is a mix of pre-mixed crops and studied in order to obtain a biodiversity that includes both cultivated species and a plurality of insects and invertebrates, such as bees, butterflies and spiders, which find nourishment and shelter in these environments.

This system is particularly suitable in the redevelopment of roofs of existing buildings or in the construction of temporary event facilities. The modularity and low weight of each bag (about 20 kg), which can be moved by hand, allow easy maintenance, both system and of the construction on which it is placed. The project has been designed and developed for the existing building of the London-based company British Land, but its versatility makes it particularly suitable for a variety of spaces, both private and public, from roofs to balconies, from the redevelopment of degraded areas to urban furniture. The system meets BREEAM sustainability criteria for its rainwater drainage and collection capacity, sound insulation and improved urban air quality.

b1. Former Ducati Complex, Rimini
Design: Mario Cucinella Architects, 2007

The project for the former Ducati building conceived by Mario Cucinella in Rimini hosts a new commercial and service programme. The building has a double facade system connected by a structural balcony: the first is a traditional, glazed façade with sliding doors and windows, the second one, external, consisting of a real "vegetable skin". This second envelope is made with a 60 x 60 cm stainless steel mesh grid, fixed to the structure of the balconies leading to the offices and on which climbing plants grow (Gelsomino Rincosperma). The result is a sort of vertical garden, a compact and naturalistic urban front with high thermal cooling and environmental control properties.


Maglia strutturale in alluminio sabbiato cm 60 x 60 circa posata a 45; rispetto alla verticale
Corrimano H cm 100 con microrete metallica
Porta blindata
Pavimento in lastre di pietra
Massetto a protezione guaina
Guaina impermeabilizzante
Massetto delle pendenze
Soglia in ceramica
2 cm = dislivello interno - esterno
Vasca per la fioriera sul balcone con struttura in c.a.
Solaio in latero cemento spessore cm 24
Intonaco a civile per esterni spessore cm 1,5
H. cm 275
PORTA BLINDATA
Soluzione con porta blindata a tutt'altezza (cm 275)

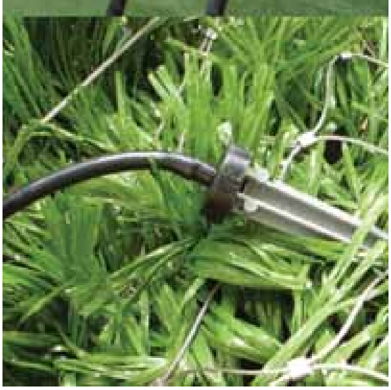


b2. I'm lost in Paris
Design: R&Sie(n), 2008

The project proposes the development of a private laboratory based on the idea of a hidden duck's nest, which takes the form of a complex green cladding system, whose facades are made up of 1,200 hydroponic ferns, fed by 300 extra-light blown glass beaks, in which the bacterial culture is found.

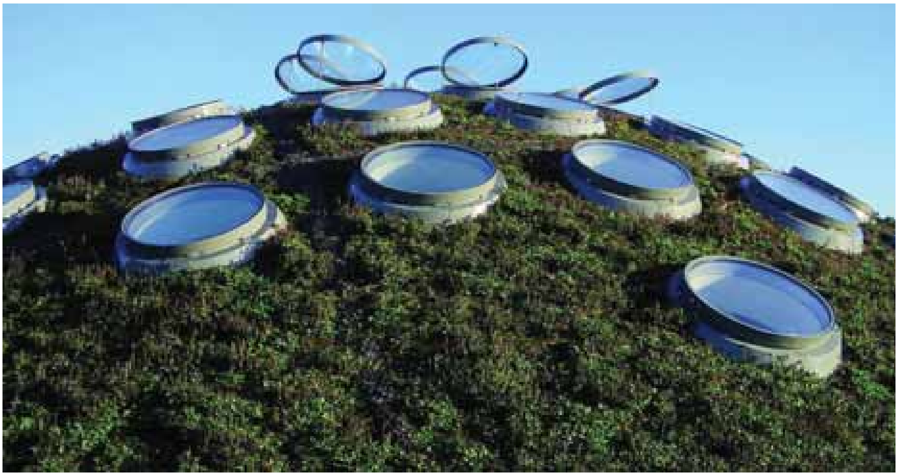
The intervention involves the recovery of rainwater used to feed an individual mechanical drip irrigation system, which includes a nutritional addition and proportional control.

The structural system for climbing creepers is independent of that of the existing facades, to which it simply clings with anchors and spacers that allow easy maintenance.



2. Application by overlay
a. Horizontal layer/roof

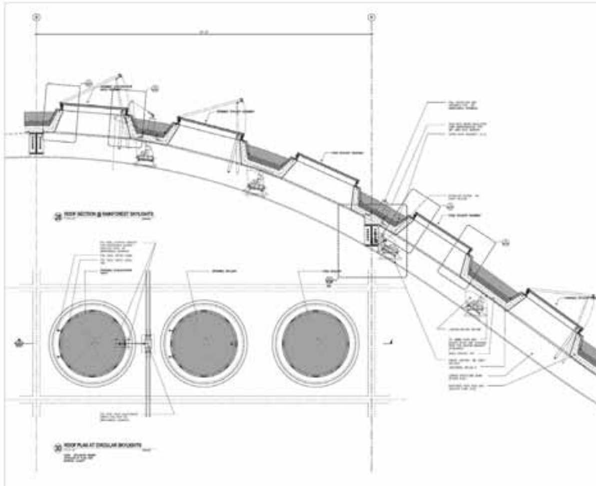
a1. California Academy of Sciences, San Francisco
Design: Renzo Piano Building Workshop, 2008

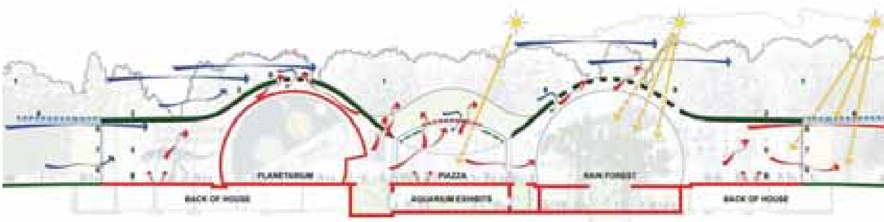


The building houses under a single large roof a plurality of functions, such as a natural history museum, aquarium, and planetarium. Each of these activities has a dedicated space that matches the design of the roof.

In terms of general layout, the building follows the morphology of the park on which it stands, extruding from the ground at a height of ten metres. Although not inhabitable, the roof is the image of the building: covered by over one and a half million autochthonous species grafted in biodegradable containers, its shape is flat at the ends and wavy at the centre, thus creating domes that host the main functions of the building (the two main domes contain the planetarium and the tropical forest). Its openings are controlled by the building's intelligent management system to regulate lighting and ventilation.

The soil covering the roof allows to obtain excellent results of thermal inertia, significantly contributing to the reduction of the energy input for cooling the spaces. The choice of materials, the contribution of technologies, the use of passive systems for environmental control, the integration of natural ventilation systems and rainwater recovery, have allowed the building to obtain LEED platinum certification.




PLANETARIUM
PIAZZA
RAIN FOREST
BACK OF HOUSE
AQUARIUM EXHIBITS
BACK OF HOUSE

2. Application by overlay
b. Vertical layer/green facade

b1. Musée du quai Branly Greenwall
Design: Jean Nouvel - Greenwall: Patrick Blanc, 2005

The museum designed by Jean Nouvel, is known for the large green wall that covers the facade facing the Seine. The major intervention was carried out by the botanical artist Patrick Blanc and it is a vegetal wall of 800 square meters with about 15.000 plants of 150 different species, coming from different parts of the world. The main ones are: Elastostema umbellatum, Pilea petiolaris and Ixeris stonlonifera from Korea and Japan, Berberis darwinii and linearifolia from Chile, Phygelius capensis from South Africa.

The plants are grafted to the wall thanks to a thin foil that combines PVC with felt and grow thanks to the controlled irrigation placed inside.

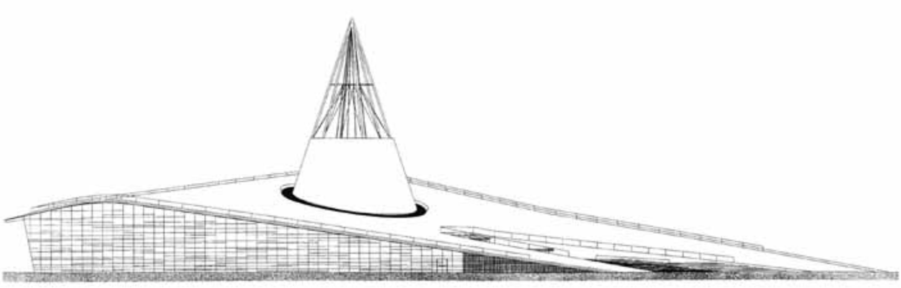
Blanc’s intervention is not intended to replace elements of the building, but to overlap it, creating an image of architecture that, thanks to the plants themselves and the pruning interventions, give the facade an ever-changing green image.

3. *Application by integration*
a. Merging context/construction components

a1. Library, University of Technology, Delft
Design: Mecanoo architects, 1993/1998

Grass carpets with trees and flowers where students and professors can meet informally are the basis of Mecanoo's idea for the library of the University of Technology in Delft, where the lawn, as it rises, shapes the roof of the building, which thus loses its specification and designs a new multipurpose space open to the city.

With the simplicity of this gesture, architecture and context merge into a whole that does not clearly distinguish a priori the boundaries between the areas of the building and those of the green space next to it, both in terms of construction and function, but integrates them by determining a system of overlapping urban/landscape/architectural layers, rather than a real building.



a2. Prefectural International Hall, Fukuoka
Design: Emilio Ambasz, 1994

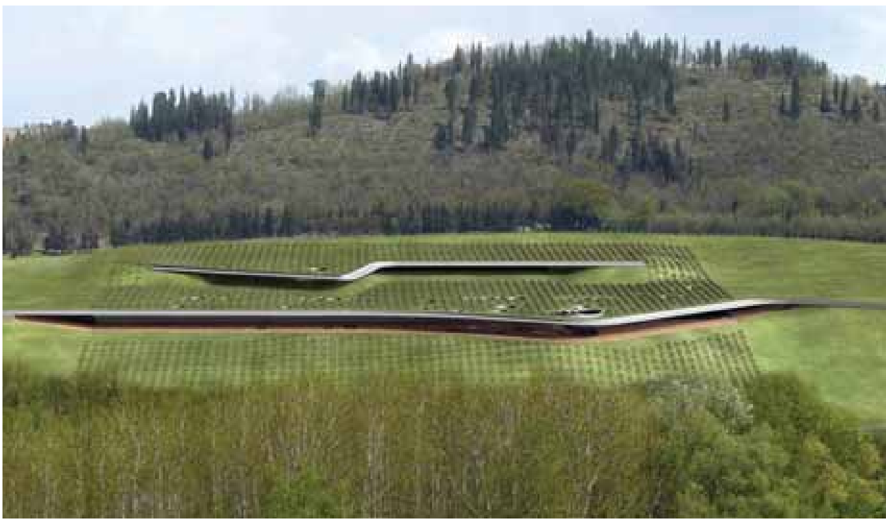
The ACROS Fukuoka Prefectural International Hall (Asian CrossRoad Over the Sea) develops a spatial solution capable of combining a building for cultural and institutional functions with a public space open to greenery.

The North facade of the building has the shape of a traditional office building, inside which there are a concert hall, conference rooms, a cultural centre, government offices and an art gallery, with a general layout characterized by a full-height space that distributes the various rooms.

The South side, on the contrary, proposes a new spatial morphology that hybridizes the building and the urban green space of the city into a large mediating site, extending the park into a series of terraced gardens that climb along the entire height of the building to the large rooftop belvedere.

In terms of the general organization of the space, the integration of the physical components between the urban context and the construction, which takes place by replacing traditional elements of the construction with new spatial systems, configures a sort of large open-air amphitheatre for the whole city.

a3. Cantine Antinori, Bargino, Firenze
Design: Archea associati, 2004-2013



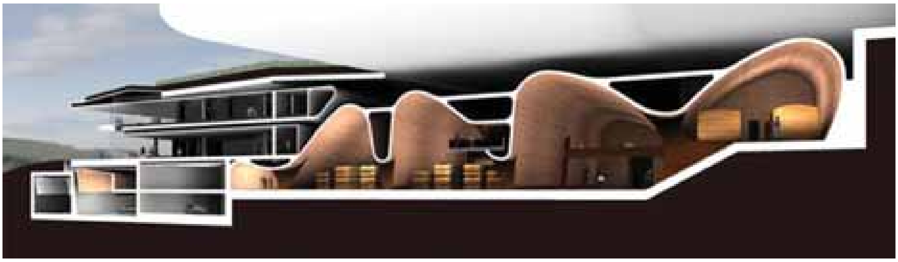
The area on which Cantine Antinori stands, located between Florence and Siena, is part of the Chianti wine and hillside context.

The enhancement of the landscape and the surrounding area was therefore a fundamental premise of the architectural intervention, whose programme immediately promoted a total fusion with the context, with which, in terms of the general organisation of the space, it is morphologically integrated.

The result is a wine-growing complex dissolved into a roof capable of defining, in the resumption of the contour lines, a new vineyard country plan and designed by two horizontal cuts that respond to the lighting and ventilation ratios between inside and outside.

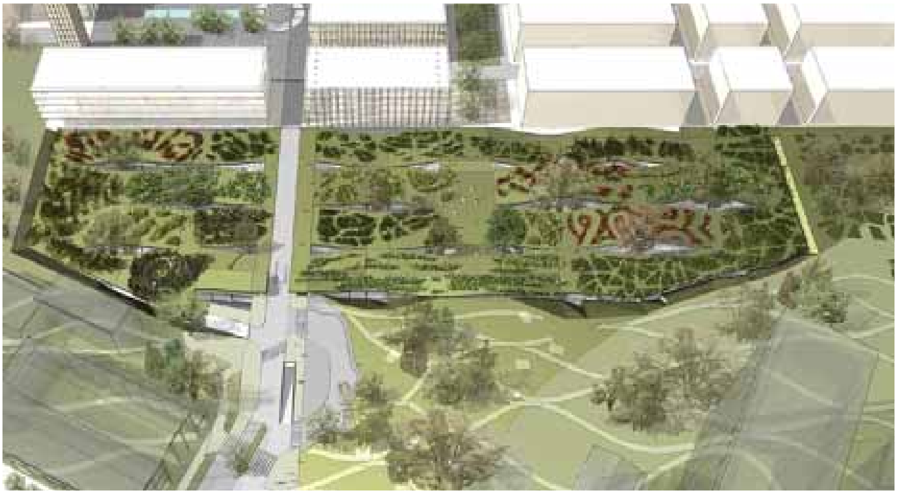
The functional program plays on this ambiguity of the resulting soil architecture and proposes a mix of activities that combines the winery's own industrial and administrative uses with those of an auditorium, museum, library, as well as various rooms for wine tasting and sales.

The facade of the building is the same hill of the place and the soil does not appear as a simple coating system superimposed on a consolidated construction but represents its true foundational essence.



a4. Novartis Campus - car park, Basilea

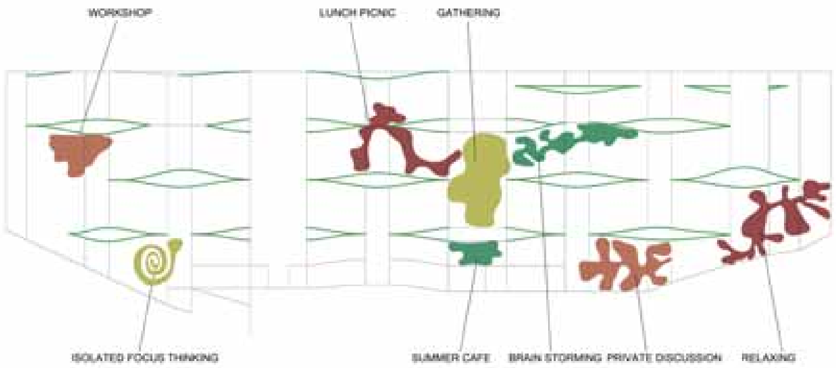
Design: f-o-a architects, 2003

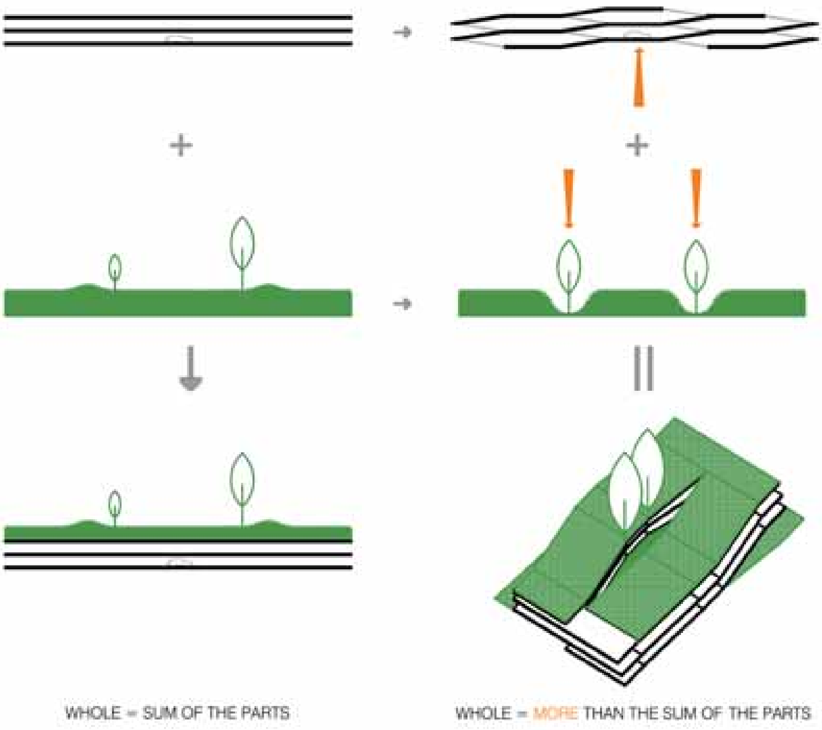


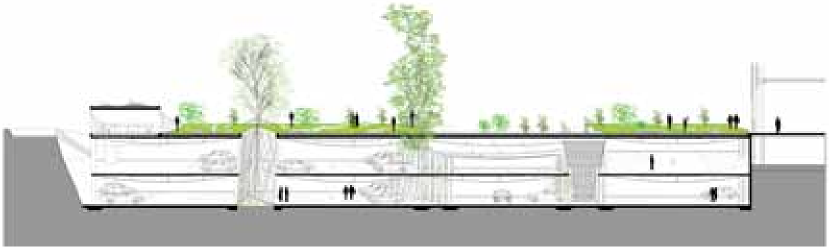
F-o-a's design proposal for the access to the campus of the scientific company Novartis of Basel, merges the areas of the park with those of the parking lot to generate a unique system, where natural and artificial are mixed into each other, in new forms of space enhancement.

The project is also an opportunity to explore and capture the potential of emerging artificial ecologies, as well as in Novartis' biotechnological research and development processes, in the design of the future work environment.

In the project's objectives, the intention was therefore to create a new "dense" spatial ensemble, where the various functional programs could enhance each other; at the same time, the intention was to build a sort of landscape continuity between the interior of the campus and the surrounding public green area. The relationship parameters between the systems are both geometrical, with the alveolar structure that presents itself simultaneously in plan and section due to the geometric characteristics of the parking area, and functional: both entities produce waste that, in a feedback cycle, feeds the systems themselves (the cars in the parking produce carbon dioxide that returns in the form of oxygen once absorbed by the plants, in turn used in combustion engine processes).


WORKSHOP
LUNCH PICNIC
GATHERING
ISOLATED FOCUS THINKING
SUMMER CAFE
BRAIN STORMING
PRIVATE DISCUSSION
RELAXING


WHOLE = SUM OF THE PARTS
WHOLE = MORE THAN THE SUM OF THE PARTS



3. Application by integration
b. Integration by technological clusters

b1. Brise soleil - Usa Pavilion EXPO 2015
Design: Biber Architects, 2015

The vertical wall system of the USA pavilion at Expo 2015 in Milan was born from the reinterpretation of the concept of brise-soleil, with the aim of creating a vertical garden for the controlled growth of vegetables typical of the American context, over forty varieties of plants, vegetables, cereals and herbs.

The system arises from the composition of a series of modular panels, motorized to always face the sun and integrated by a series of systems for hydroponic cultivation and water recovery, which move a traditional vegetable garden of ninety degrees on the construction, integrating it into the building and thus replacing a traditional compositional element for the control of solar radiation, with a new hybrid technological component between architecture and nature.

b2. Acoustic barriers

Acoustic barriers made with green systems are exemplary of the applications for integration. The choice to opt for such vegetated solutions instead of prefabricated technological walls, is due both to aesthetic reasons, in order not to realize extraneous elements to the landscape, and functional-environmental ones (containment, drainage, soil permeability, retention of pollutants, etc.). The vegetated embankment structures used in such contexts are mainly two types:

_natural embankments: they take advantage of the natural slope and generally use the aggregates coming from the excavation activities of the infrastructures, on which hydro-sown vegetal soil is placed. The planting of native shrubs takes place mainly on slopes with the function of increasing roughness for the purposes of sound absorption.

_compressed embankments: are autonomous structures filled with inert material and then vegetated to allow an effective soundproofing action. They can reach a height of 5 m and an occupation of 2-3 m. The supporting reinforcements of earthy bodies can be made of wood, steel, or concrete. The types of construction are very diversified; they all require drip irrigation systems and the maintenance of the plant system is linked both to the soil substrate and to the choice of species to be planted (autochthonous and pioneer shrub species are to be preferred).

c1 + c2. Urban farming and Urban gardening

Urban farming: soa architects - La Tour Vivante, Rennes, 2005 - competition / Une ferme sur les toits, Romainville, 2012 - spatial feasibility study / Mini-Ferme, prospectives sur l'agriculture urbaine, Paris, 2006/2012 - design research

Urban gardening: Work ac - Public Farm One, MoMA PS1 Young Architects Program, New York, 2008

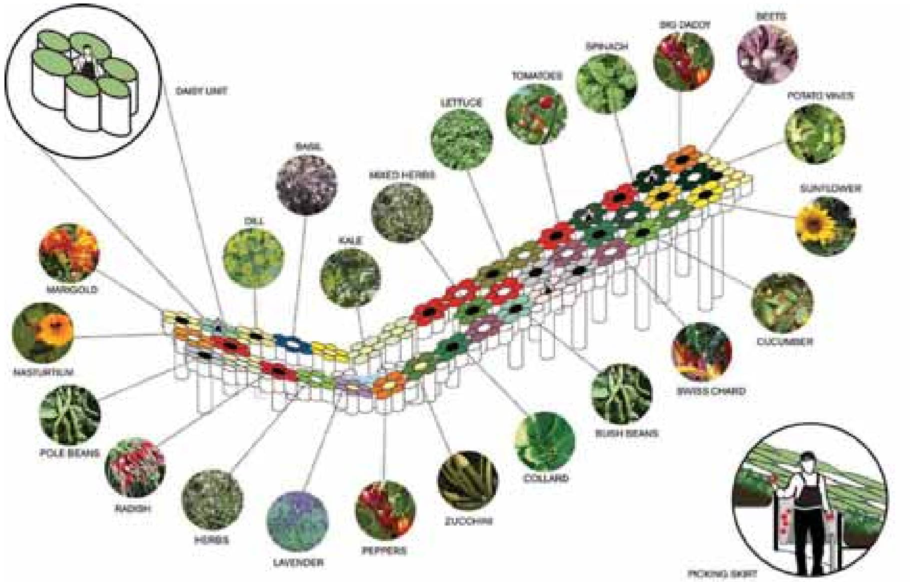
Urban farming is a form of agricultural production aimed at urban contexts, which consists in cultivating, processing, and distributing the products grown, thus obtaining a form of trade. This aspect is what differentiates urban farming from urban gardening, that is a form of cultivation aimed mainly at personal consumption, rather than at the exchange and sharing of cultivated products, especially in the wider forms of community in which it is applied, but always without a commercial form that supports it.

The production of urban agriculture is generally specialized and includes various types of plants, which can sometimes be joined by micro-farms of animals or grasses and plants for ornamental use, thus able to complete in the same place the cycle of production and waste, especially if the cultivation is oriented towards products with a high market value, but at the same time highly perishable.

The most important aspect that characterizes urban cultivation compared to its rural form is the close relationship that agriculture manages to build with the city's economic and ecological system, thus becoming an integral part of it. This relationship includes not only the products to be cultivated and introduced into the trade cycle, but also, and above all, the inhabitants in the form of farmers and the resources introduced into the production cycle (such as organic waste and recycled water), with direct impacts on the sustainability of the urban system itself.

Urban farming and urban gardening are therefore new and, in some ways, innovative forms of production, which arise by looking at the specific context in which they are applied and of which they form an integral part. At the level of spatial organization there isn't a predefined form of them, but it is the specific conditions of the context that determine their configuration; some interventions are developed for example on the roof of existing buildings, inhabited or in disuse, others occupy abandoned and marginal urban areas, thus contributing to their environmental and landscape requalification. Some cases of urban farming can interact with public activities: schools, hospitals, etc.

From the architectural point of view, the most significant aspect that derives from this is the typological innovation of such a hybridization of activities, which merges in the same space of houses, places for work, but also spaces for leisure and commerce, with an environmental matrix to act as a generative structure of the entire built system. By designing new places of mediation between the interior and exterior of the building, the building becomes more permeable and opens its boundaries to the public space of the city.


DAISY UNIT
BASIL
DILL
MARIGOLD
KALE
MIXED HERBS
LETTUCE
TOMATOES
SPINACH
BIG DADDY
BEETS
POTATO VINES
SUNFLOWER
CUCUMBER
SWISS CHARD
BUSH BEANS
COLLARD
ZUCCHINI
PEPPERS
LAVENDER
HERBS
RADISH
POLE BEANS
NASTURTIUM
PICKING SKIRT

Towards systems integration

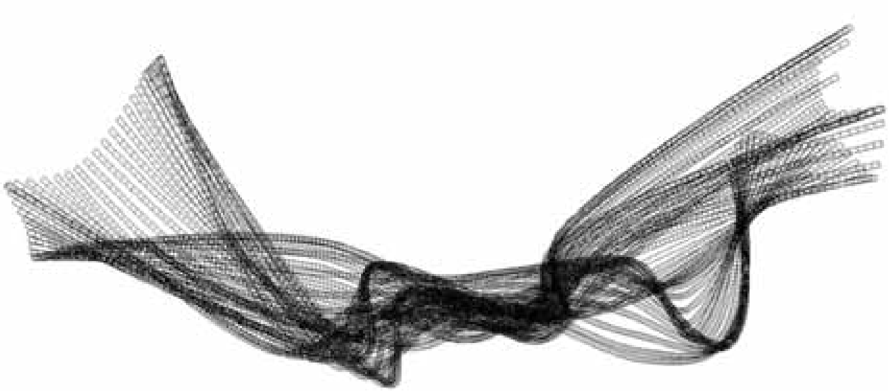
Generative principles

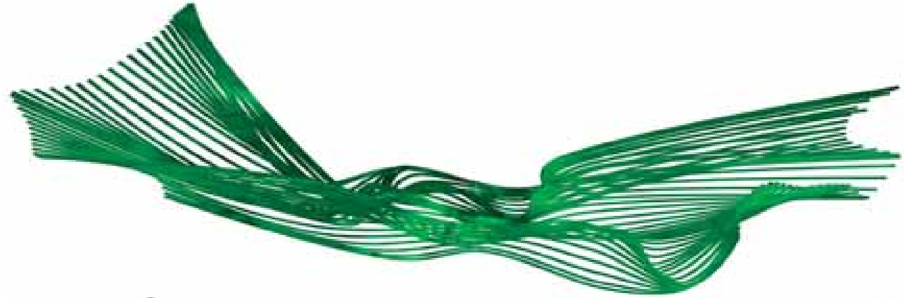
aggregation_proliferation_transformation_recursion_self-similarity [points, lines, surfaces, shelf system, tubular systems, with spongy geometry, minimal surfaces...]

Design requirements

a) modularity of the system _ from the single base unit to their aggregation in functional sets;
b) differentiation between structure / frame, with the related systems for irrigation and wiring of the sensors, and the modules for the support of vegetation;
c) flexibility of cultivation, providing both the possibility of cultivating more edible species, each with a specific consumption of water, and the possibility of integrating the system with ornamental types;
d) easy access, maintenance and movement of elements (single and aggregated).

(*Design by Attilio Nebuloni and Matteo Meraviglia*)

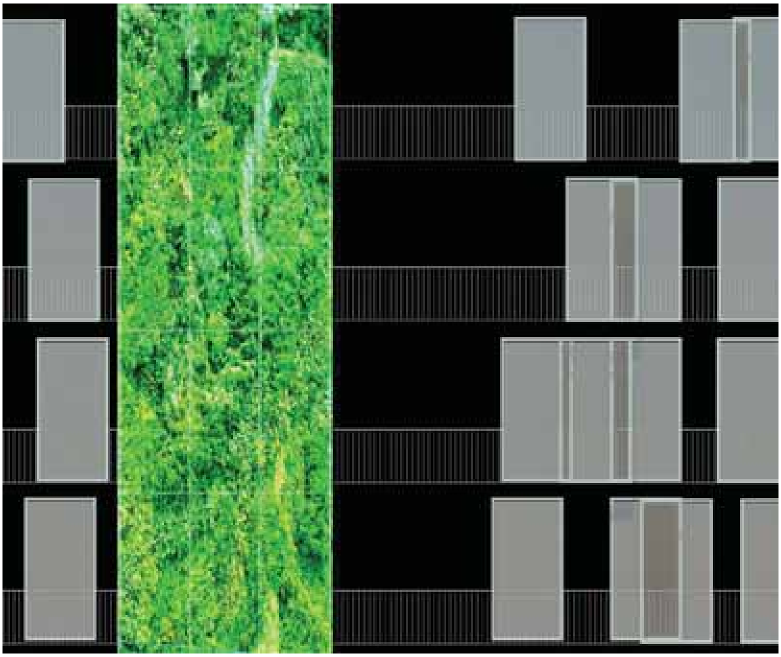


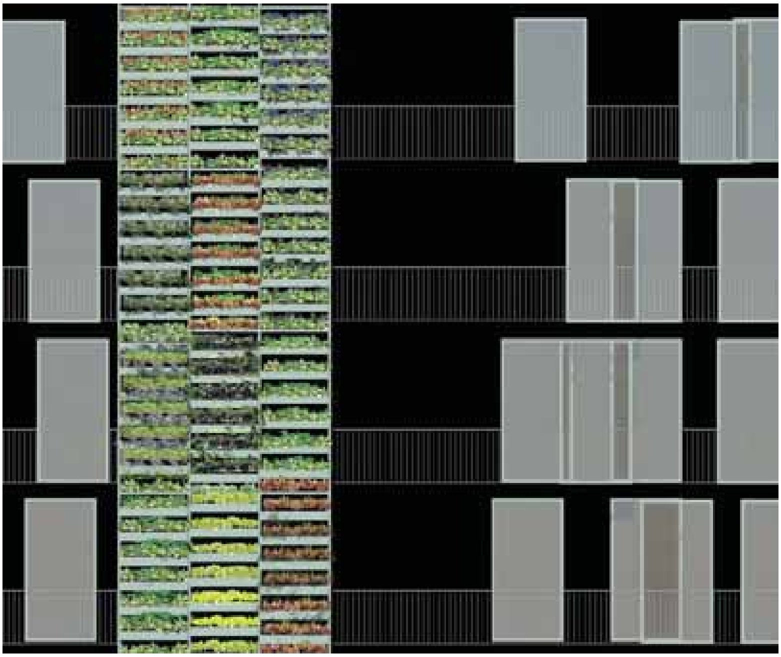


Application

The Shutter
(*design by Attilio Nebuloni and Matteo Meraviglia*)

In the first scenario (architectural level) the aim is to rethink a traditional facade shutter, to integrate cultivation or decorative plants. The result is a sort of brise-soleil, at the same time technological element of facade and farming place. The new green panels maintain the kinematic nature of shutter systems as well as the dynamic image deriving from the growth cycle of plants. This solution allows to create a small vertical garden for domestic use, flexible, implementable (from a few panels to an entire facade solution), and easily integrable with other building spaces, even in contexts where it is not possible to realize more traditional urban gardening solutions.

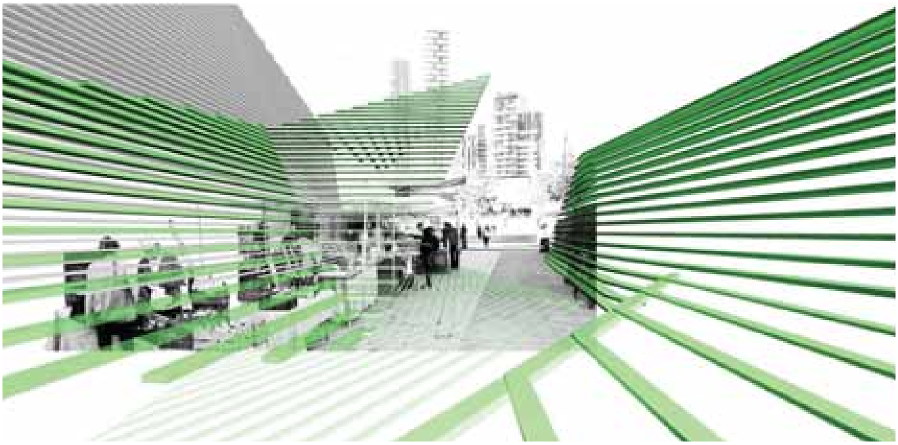


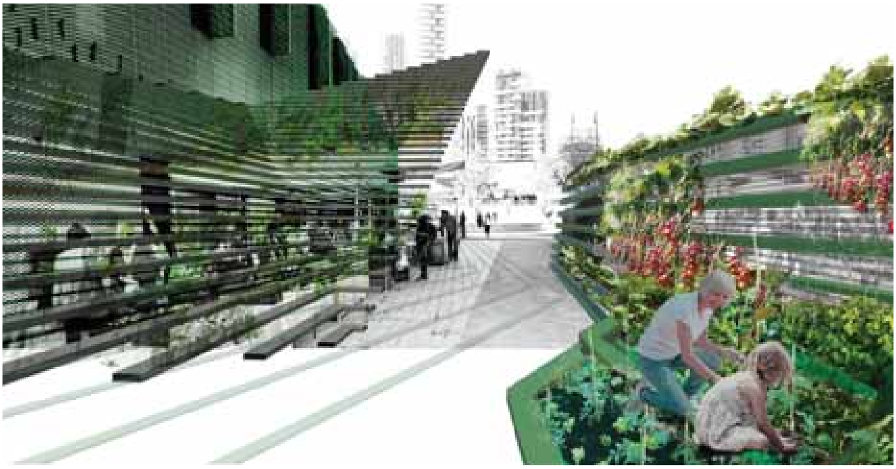


Application

Garden to lose
(*design by Attilio Nebuloni and Matteo Meraviglia*)

In addition to the design requirements in the first scenario, in the architectural-urban scale one, the focus is on the issues of socialization and rethinking of living spaces. A series of shelf structures sustain and host spaces for cultivation. The system is conceived as an element in adherence to small / medium sized commercial activities and aggregative spaces, following the idea of a "vegetable garden to lose" (from a parallel rural solution implemented in places where the fauna is damaged or in danger, providing the animals with help in the form of food), where to promote an idea of an open and shared cultivated area.





The book aims to investigate the up-cycling of domestic effluents for plant production, bringing together a series of considerations by an interdisciplinary group of researchers from the Politecnico di Milano, Università Statale di Milano and Università di Roma Tor Vergata, ranging from biology to design through sociology and architectural composition.

Integrating vegetable cultivation in the domestic environment with reusing kitchen wastewater for irrigation is a promising strategy for reducing freshwater consumption, limiting the amount of wastewater to be treated producing healthy plant food and, ultimately, raising environmental awareness among citizens. A first step in this direction is the experimental project to reuse dishwasher effluents in living spaces (kitchen, household, and community level), as described in the book. Dishwasher effluents were chosen as an initial bench test because of their high nutrient content, low harmful elements and constant wastewater quantity and quality, where treatment may consist of a combination of several chemical, physical and biological processes. Studies for the development of a domestic biofilter containing a consortium of microalgae and heterotrophic bacteria are also presented.

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FrancoAngeli
La passione per le conoscenze