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The building façade as an active skin: Water bio-remediation through a probiotic layer system

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Abstract In 2020, the United Nations demonstrated that the building sector is responsible for 38% of all energy-related CO_2 emissions [1]. Architecture as an invasive practice, bears a responsibility and the capacity to minimize its negative ecological impact. This study investigates alternative methodologies of architectural design that employ the upgrading of greywater through the building envelope to integrate the building in the environment's metabolic cycles. The building façade may be treated as an active membrane that controls energy and material resources to carry out energy-related functions. Its performance may be modeled by the operational principles of cell membranes and living organisms. The activation of the membrane is achieved by managing greywater resources, while architectural design is informed by biotechnology and environmental engineering. On a different note, water is a vital resource for the sustenance of life whose scarcity increases rapidly. By upgrading greywater, the building membrane becomes a space for different species to inhabit. Considering the above, an interdisciplinary design method is proposed that: • Allows the envelope to circulate water in a controlled manner. • Incorporates the bio-remediation of greywater. • Adapts the envelope to create living "pockets" activated by water. These pockets host vegetation and microorganisms, serving as a probiotic layer that regulates the micro-climate and supports local fauna.

Keywords: greywater bioremediation, bio-systemic architecture, active architectural membrane, biodiversity restoration, building metabolism

1.1 Introduction

Water is one of the most vital resources for the sustenance of life. Population growth and increasing water demand, industrialization, and water pollution have caused surges of water shortages. Domestic water demand consists of 30-60% of the urban water demand, of which 60-70% is transformed into grey water [2]. Considering that domestic and industrial water demand is predicted to rapidly increase by 2050, we can understand that water infrastructure within the architectural context plays a significant role on the future development of this unfolding crisis. Conventional water management methods within cities, handle rain and greywater as waste that needs to be moved away through drainage systems [3]. However, low impact development methods of water management rely on biological systems to slowly treat water runoff on site [4, 5]. Serving that purpose, the building façade can have an active role in the management and recycling of greywater harvested from rain and daily interior usage such as laundry and dishwashing. Accordingly, the present research explores design strategies to transform the building envelope from a passive two-dimensional barrier into an active component that hosts the circulation, treatment and recycling of greywater. Therefore, the aim is not simply to design an efficiently performing envelope, but to make the envelope a fully functional infrastructural system that also supports the cycles of the natural environment; that is, an intermediate space that can reclaim volume and programmatic use for balanced interspecies symbioses.

1.2 State of the Art

During the recent years, environmental sustainability has become one on the most urgent parameters for urban planning, and so cities are trying to incorporate water managing strategies for rainwater harvesting and storage. Landscape architecture projects –especially those in proximity to wetlands– often employ morphological design strategies in an effort to control, guide and manage water seen as a natural resource, which includes accumulations from rain and other natural phenomena. The purpose is to protect cityscapes from water related-threats (such as floods and droughts) and to enhance the experience of public space by employing urban climate resilience agendas and by merging the natural and the built environment in controlled ways.

An example of this kind has been a joint call from the "Berliner Regenwasseragentur" and the "Berliner Wasserbetriebe" aiming to adopt planning and design strategies for the built urban environment under the concept of "Sponge Cities" [6]. Proposed areas and means for intervention are green roofs, green façades, water re-use methods and the creation of water retention swales (Versickerungsmulden) within the city. The goal has been to create an infrastructure to store rainwater that can be later guided by demand during dry seasons to support the local fauna and flora. Other projects focus on environmental sustainability by adapting the principles of the ecosystem to the design scheme. A place's fauna, flora and climate are studied so that human activity and biodiversity may co-inhabit the public landscape on equal terms [7]. Water management is vital for this approach, but the design process also considers the use of plants, micro-organisms and predicted cycles of the biodiversity as functional elements that create a living, autonomous and circular landscape [4]. This holistic methodology incorporates environmental engineering and biology into landscape architecture, often combined with animal-aided design strategies to serve human and non-human agents [8].

In the building scale, the focus is on the preservation of water by installing rainwater harvesting modules and attachments onto existing buildings. Such systems are usually singular product-based solutions that depend on water run-off and wind-driven rain. In other more innovative solutions however, the entire design methodology and conception are guided by treating water as a thermodynamic factor, consequently as a resource for growth of life and an element for recreation. For example, in the "Primary School for Sciences and the Biodiversity" at Boulogne-Billancour in France (2014), the exterior façade is an articulation of pre-fabricated concrete blocks with different types of textures, indentations and calculated positionings to channel and store rainwater for fauna and flora and to provide shelter as intermediate growing spaces for moss and vegetation [9].

2.1 Bio-systemic Envelope

Driven by the same intention, the research project discussed next addresses the theme of interspecies co-habitation in cities by carrying the eco-systemic design principles of landscape architecture to the scale and volume of the building envelope, in that case activated with water. This challenge is divided into three main parts that serve as design parameters for the envelope:

1. The design of a water circulation network, informed by water management strategies of the model of "Sponge Cities".
2. The study and selection of vegetal species and micro-organisms that can bio-remediate water to make it safe for re-use and dispersion to the environment [10, 11].
3. The morphological investigation and materiality of the envelope for the support of biological growth as a living "probiotic" layer [12].

The principles and functions mentioned above are visualized in **Fig.1**. Human activity and rain provide a continuous influx of water, then used for continuous but controlled watering for vegetation schemes and micro-organisms that perform bio-remediation. As the mosses and plants grow, they absorb/degrade pollutants from the air while outputting oxygen. The growing plants and flux of water regulate sun radiation, temperature and humidity, creating a unique micro-climate that is beneficial for all species.

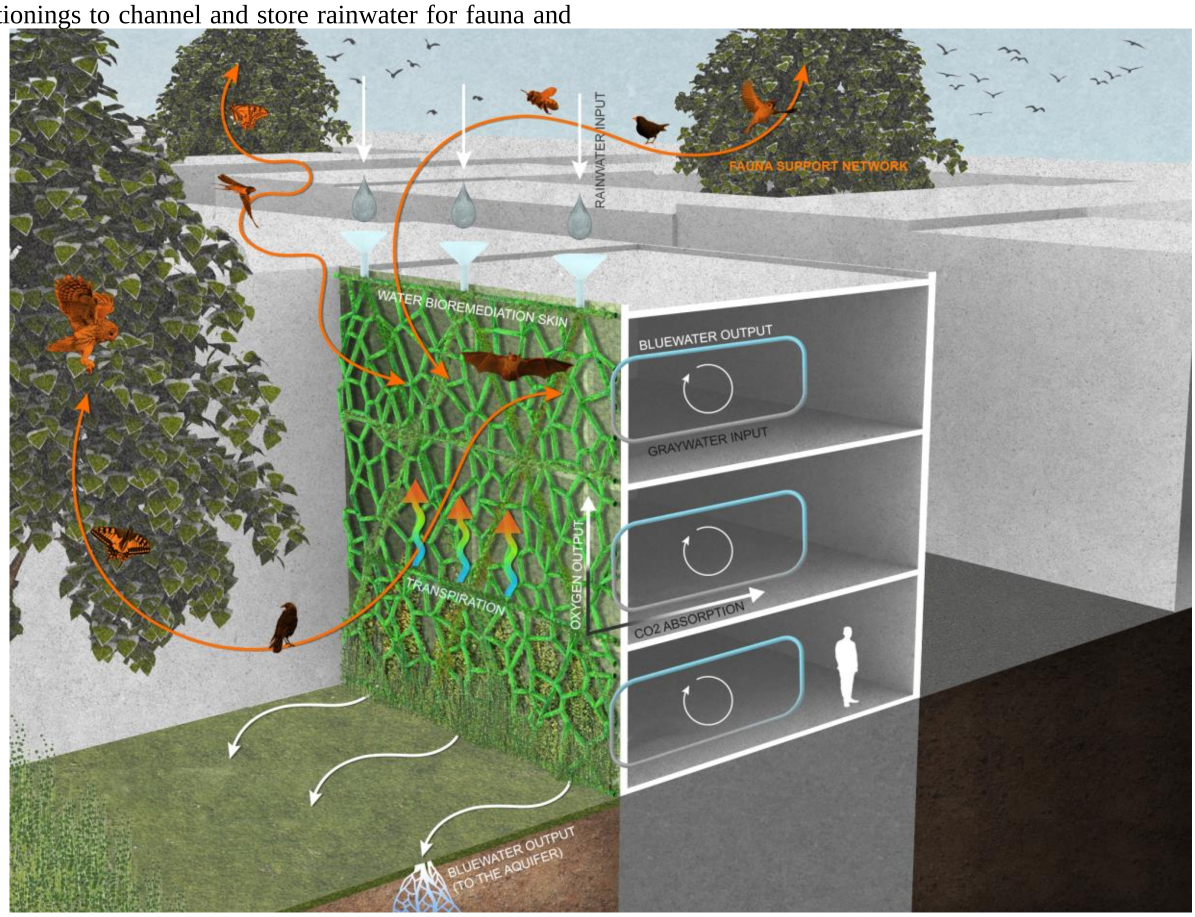

Figure 1. Material and energy relationships and negotiations diagram. Informed by the way cells function in living organisms, the skin is understood as a membrane that allows exchanges between the outside and the inside.

The project explores alternative models of living where the user is engaging in the infrastructural process of water treatment and is in an everyday interdependent symbiosis with different species. Starting from a smaller scale than the building envelope, a concept was designed for an indoor water bio-remediation and air-filtering system (**Fig.2**). A device has been developed whose purpose is to test alternative methods of water and air filtration as well as bio-monitoring systems [13] that rely on natural biological processes aided by biotechnology. That device is a shelving system with consecutive levels that correspond to the following steps in the water remediation process:

1. Influent grey water collection, 2. Physical filtering of larger suspended particles, 3. Phyto/bio-remediation vessels, 4. Sphagnum moss planted plates, 5. Effluent water release.

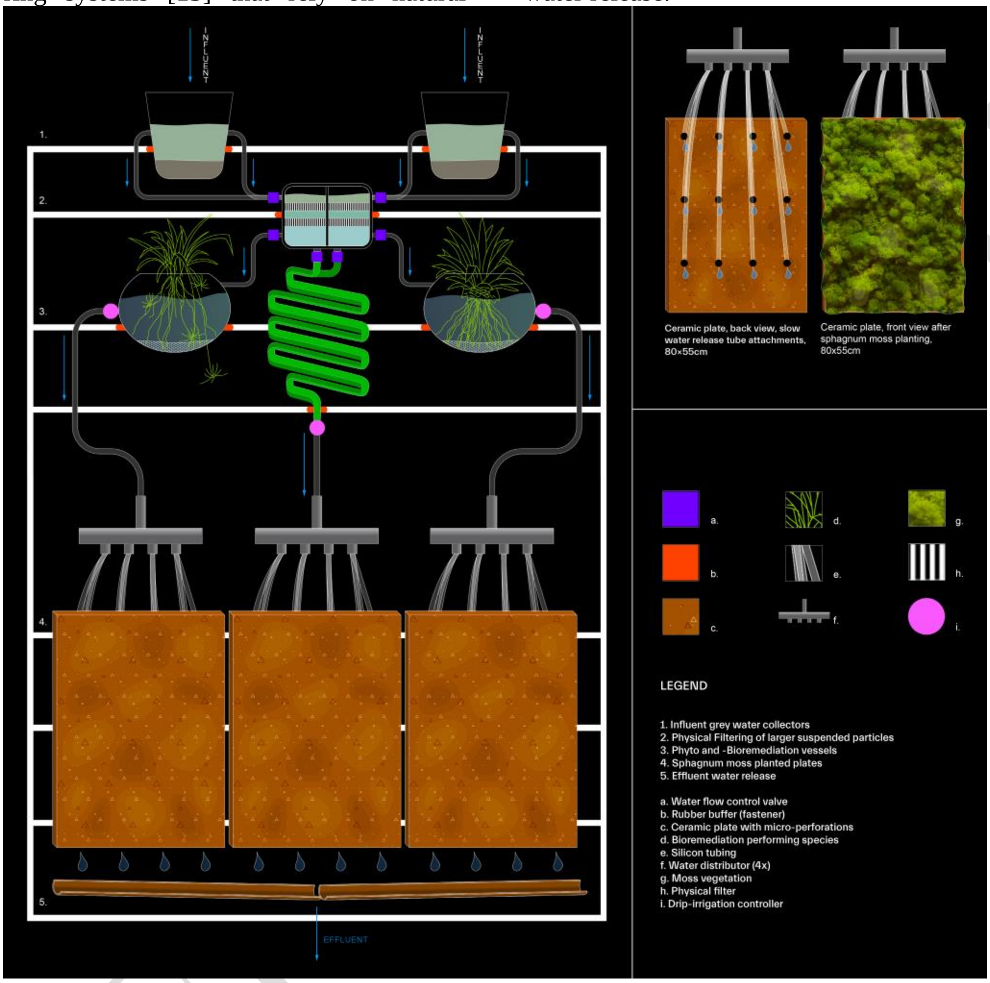

Figure 2. Indoor Water Bio-remediation System.

2.2 Biological organisms as design models for water activated building envelopes – Poriferans

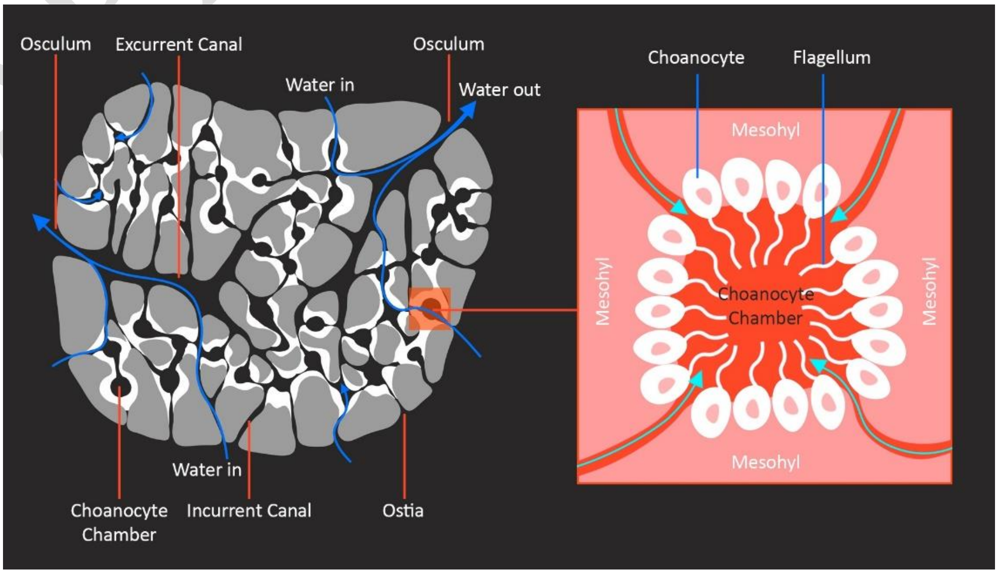

Figure 3. Anatomy of a leuconoid sponge structure.

	Structure	Movement	Metabolism	Moderation
Macro scale - Urban Planning Strategy	Sponge city-Urban systems	Sponge City – Urban Systems	Landscape Architecture-Natural Systems	Animal aided Design – Ecosystem
Meso scale - Building Function	Envelope scaffolding	Reception, circulation and effluence network	Phyto/bioremediation vessels	Multi-species growth and biomass pods - Probiosis
Micro scale –Mechanism	Structural Silica spicules	*Ostia*, canal system & *Oscula*	Choanocyte nutrient consumption	Connective tissue & endosymbionts

Table 1. Study of correspondences across different properties that are achieved in systems of three different scales, the urban fabric, the building and the micro-organism [15, 16].

Following up with the above, this research concludes at this stage on the design of the building envelope informed by biological systems that depend on filter-feeding, and especially by the survival mechanisms and anatomy of poriferans. The primary functions of poriferans (circulation, respiration, digestion, excretion) are actualized through water flow (**Fig.3**) [14]. The building envelope is thought as an active infrastructural system that circulates, filters and re-utilizes water through the employment of a biomimetic design approach. This façade system may thus serve to articulate the components arrayed in **Table 1** to address the design parameters set in paragraph 2.1. Therefore, the building envelope is the field where microorganisms and urban interventions may inform one another to suggest a cross-scalar comprehensive design methodology.

3. Challenges and the opportunity for interdisciplinary collaborations

Beyond the above-described goals, this research promotes interdisciplinary collaborations between architecture, design and scientific fields such as biology, biotechnology, environmental engineering and material science. Interventions in the built environment are highly invasive, and so architect and planners, as well as urban and landscape designers may no longer rely on their work alone to meet responsible, resilient and autonomously functional results. At the same time, they have the tools to design, visualize and build projects by understanding the complexities, conflicts and opportunities of the public sphere and into the future. It is therefore critical to promote extensive knowledge-sharing through interdisciplinary dialogue, common tools and integrated workflows.

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