K2: Architecture that grows: from Petri dish to the building façades

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Abstract

The building sector is a major water consumer across its lifecycle and plays a critical role in accelerating global urbanisation and the growing water crisis. While architectural approaches have traditionally aimed to exclude moisture, emerging strategies reframe water as an active design parameter. This research explores bioinspired and biologically integrated materials that interact dynamically with moisture. Focusing on Engineered Living Materials, it examines fungal biofilms and microbial inks as responsive, regenerative surface systems. This reshapes the perception of microorganisms in the built environment and advances probiotic, circular, and climate-resilient architecture.

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1. Introduction/Background

The built environment represents a significant water consumer across its entire lifecycle, from raw material extraction and manufacturing, through construction, to service life operation and demolition. In parallel, global urbanisation is projected to accelerate rapidly over the next several decades, marking the largest wave of city growth in human history [1]. These overlapping trends situate the building and construction sector as a key actor in the context of the global water crisis. In response to these challenges, this research explores emerging strategies in architecture that reimagine moisture not merely as a threat, but as a design opportunity. The scope encompasses both bioinspired and biologically integrated material systems that offer dynamic modes of interacting with environmental moisture. By transition from passive bioinspired materials to active, living architectural systems, this work outlines a conceptual and technological shift in how the built environment engages with the surrounding environment. It contributes to the growing discourse on regenerative materials, circular design, and the integration of life sciences into architecture, with implications for sustainable urban futures.

1.1. Bioinspired approach

Moisture-related considerations in architecture have traditionally focused on protection, insulation, and damage prevention [2]. However, broader environmental pressures have drawn attention to alternative strategies that engage with water in more dynamic and adaptive ways. Biological systems offer a diverse range of passive and active mechanisms for water collection, transport, and retention. Organisms such as the Namib Desert beetle, various cactus species, and certain epiphytic plants have evolved highly efficient strategies for interacting with atmospheric moisture in arid or variable climates. These mechanisms have informed research in bioinspired material science and architectural design, leading to the development of surfaces and structural forms that mimic biological hydrodynamics and microtextures [3]. In architectural applications, such concepts have influenced façade systems, coatings, and structural materials aimed at modulating condensation, enhancing ventilation, or collecting water from fog and rain. These approaches translate biological principles into engineered solutions, often using synthetic or composite materials.

1.2. Beyond biomimicry

While bioinspired systems replicate select functions observed in nature, recent advances in synthetic biology and materials science have enabled a new class of materials that integrate living organisms as active components. Engineered Living Materials (ELMs) incorporate microorganisms or cellular systems into the structure of the material itself, facilitating behaviours such as self-repair, sensing, or interaction with environmental stimuli. ELMs are dynamically researched in various fields, including architecture [4]. The ARCHI-SKIN project, supported by the European Research Council, explores the potential of fungal biofilms used as living coatings for architectural surfaces. These thin biological layers are developed to interface with various substrates in the built environment, with particular emphasis on moisture response, UV protection and environmental adaptation. Initial research investigates the biofilm's properties, adhesion mechanisms, and interactions with environmental factors. This system presents an alternative approach to surface protection and moisture management, shifting from inert barrier coatings to biologically active, self-regenerating skins.

Following the development of fungal biofilms in the ARCHI-SKIN project, the REMEDY project, supported by the European Innovation Council, explores a further step toward biologically integrated architecture through the design of living inks and archibiome tattoos - engineered microbial patterns that enable bespoke, high-resolution decoration and functionalisation of building surfaces. This approach combines advances in microbiology, biomanufacturing, and materials science to create interkingdom microbial inks that function similarly to probiotic treatments. These living inks are designed to generate beneficial surface microbiomes capable of performing environmental functions such as bioremediation, carbon sequestration, and protection against pathogenic organisms. By introducing metabolically active systems into architectural materials, REMEDY positions microbial consortia as both aesthetic and functional agents, contributing to a new concept of probiotic and circular architecture.

1.3. Challenges and perspectives

The integration of biologically active systems into the building envelope introduces a new conceptual framework, one that treats façades not solely as static protectors, but as dynamic interfaces. Fungal coatings and interkingdom microbial living inks exemplify a shift toward material systems capable of adapting their function over time in response to environmental conditions. This line of research contributes to a broader dialogue around regenerative materials, biologically integrated architecture, and climate-resilient design strategies. While implementation remains in early stages, experimental results indicate that fungal biofilms can perform protective and regulatory functions in moisture-sensitive environments, with potential applications across a range of climatic and material contexts. However, such living systems also raise questions related to durability, maintenance, regulatory standards, and integration with existing construction practices.

The convergence of architecture, microbiology, and materials engineering opens new possibilities for building surfaces that respond to, rather than resist, environmental conditions. From bioinspired water collection systems to engineered living coatings and inks, these approaches illustrate an expanding material vocabulary to active, dynamic, and resilient. Within this landscape, living architectural materials such as fungal biofilms or living inks suggest alternative pathways for sustainable and responsive design.

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