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How plants inspire façades. From plants to architecture: Biomimetic principles for the development of adaptive architectural envelopes

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ABSTRACT

Façades have an important role in the control of energy waste in buildings, nevertheless most of them are designed to provide static design solutions, wasting large amounts of energy to maintain the internal comfort. However, biological adaptation solutions are complex, multi-functional and highly responsive. This paper proposes a biomimetic research of the relationship that can be developed between Biology and Architecture in order to propose innovative façade design solutions. We focus on plants, because of plants, like buildings, lack of movement and remain subject to a specific location. Nevertheless, plants have adapted to the environment developing special means of interaction with changing external issues.

This paper provides a methodology to create a data collection of plant adaptations and a design mapping to guide the transfer from biological principles to architectural resources, as well as two design concept cases, opening new perspectives for new possible technical solutions and showing the potential of plant adaptations to environmental conditions at a specific climate. Further step is the transformation of some design concepts into technical solutions through experiments with new technologies that include multi-material 3D printing or advances in material science.

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1. Introduction

"Cities are part of the climate change problem, but they are also a key part of the solution." [1]. Currently cities consume the larger part of global energy and are therefore major contributors of greenhouse gas emissions. Moreover, cities' authorities have the power to act on climate change by handling urban issues in a responsible way over urban sectors such as buildings. According to European Council estimates, buildings are currently responsible for 40% of the European Union's energy consumption and 36% of its CO2 emissions and is committed to reducing greenhouse gas emissions to 80–95% below 1990 levels by 2050 [2]. This is shown by how the European Union has been developing a large number of funding building efficiency programmes for research and innovation, such as Horizon 2020 framework [3]. It proposes that energy efficiency to be raised to a higher level through '*the coherent application of passive and active design* strategies *in order to reduce the heating and cooling loads*', '*raising equipment energy efficiency*', and '*the use of renewable energies*' [4]. Some of these programmes focus on building retrofitting, or the installation of energy-efficient technologies, especially on façades. Better insulation materials, greener energy sources, more efficient financing, and better use of information and communication technology are just some of the main paths being explored [5].

The building envelope, without distinction between walls and roof, is the interface between exterior environmental factors and the interior demands of the occupants [6]. The building envelope separates the indoor and outdoor environments of a building, and is the key factor that determines the quality and controls the indoor conditions irrespective of transient outdoor [7]. Therefore, building envelopes, architectural skins or façades have an important role in the regulation and control of energy waste, since they act as intermediary filters between external environmental conditions and between external environmental conditions and the desired requirements inside. Building envelope is one of the most important design parameters determining indoor physical environment, thus affecting energy usages in buildings [8,9]. Due to this decisive role, in recent years, envelopes have been the subject of numerous studies and research around the world, always trying to achieve greater efficiency and performance, in terms of energy, comfort or structure. An increasing number of projects about improvements, challenges and possibilities in the building envelope and their impact on building energy usage, has seen significant progress in recent years, because a suitable architectural design of an envelope can significantly lower the energy usage and 'the reduction of energy consumption' and 'enhancing the indoor comfort' are the two most important goals that are necessary to be realized as the result of smart building performance [10–12].

Adaptation is the evolutionary process whereby an organism becomes better able to live in its habitat [13].

Nowadays, biology is no longer just a matter for biologists, but it is a new inspiration for technological thinking. Some of these studies have looked at nature as a source of inspiration for subsequent application to architecture. This trend known as biomimicry is a discipline that has been developing for some time in other fields, such as engineering or medicine, and it is only in recent years where we begin to see its application to architecture. Systems found in nature offer a large database of strategies and mechanisms that can be implemented in biomimetic designs.

This paper is about the transfer of plant adaptation strategies into technology for innovation. In the first part of the paper, a review of advances in adaptive architectural envelopes are presented, including those based on biomimetic principles. In addition to the built projects reviewed, other academic research works are analyzed and compared. In the second part of the paper a broad overview of plant adaptations are provided. Furthermore, novel concepts for optimizing energy efficiency in building envelopes, abstracted from plants that respond to different environmental issues, are also introduced and discussed for possible application in adaptive systems for building envelopes that respond to changing environmental conditions. To achieve the objectives of designing an adaptive architectural envelope using lessons from natural systems, the following questions have been proposed:

1. How can lessons from plant systems be utilized to create a envelope that incorporates and functions like nature?
2. Is it possible to generate design concepts for building envelopes that regulate environmental aspects, based on adaptation strategies from plants?
3. Is it possible to obtain greater energy efficiency in the construction of exterior walls in buildings by mimicking nature as opposed to building façades according to the traditional processes?

2. Adaptive architectural envelopes: a review

2.1. Adaptation

Adaptation is the evolutionary process whereby an organism becomes better able to live in its habitat [13].

Most of definitions of a building envelope establish it as an enclosure, a separation between the interior and exterior environment, that provides the following functions: support, control, finish (aesthetics) and distribution of services. However, we are more interested in the building envelope, without distinction between walls and roof, as an interface and not a separation, between exterior environmental factors and the interior demands of the occupants [6]. Building envelope as an environmental moderator [14].

The environment is constantly changing and producing new challenges to cope with. Light (solar radiation), temperature, relative humidity, rainwater, wind (air movement), noises and carbon dioxide (air quality) are the basic environmental issues affecting the building. These issues significantly affect occupant comfort demands as well as building performance. Despite the fact that the climatic characteristics of the area are variable parameters, conventional façades are largely static; so, we use large amounts of energy in order to control internal comfort. Energy consumption for space heating and cooling makes up 60% of the total consumed energy in buildings [15].

The current solutions of managing the external environmental changes have caused a great deal of energy to be wasted in heating, cooling, ventilating or lighting our buildings between quite well defined limits, while external environmental factors can change considerably, resulting in existing solutions of static building envelope and dynamic building services. In consequence, the building sector is responsible for approximately two-thirds of

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