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Light management lessons from nature for building applications

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Abstract

The increasing environmental awareness in the building context has raised the demands towards more efficient use of resources and the development of renewable energy solutions. Buildings are exposed to solar radiation at different intensities throughout multiple timescales, which requires efficient management of light. Managing light becomes more challenging when several elements are considered simultaneously, e.g. minimizing heat gain, while maximizing daylight, yet considering glare. Living organisms are equipped with unique strategies to manage light for survival, communication, and energy matters. In this context, developing biomimetic design solutions for buildings have a great potential for innovation.

The current work focuses on the initial phase of a biomimetic design process, presenting a structured framework of light managing strategies that facilitates the search for, and the selection of, appropriate strategies from the large database of nature. The framework encapsulates a basic array of strategies for managing light; elaborates on the involved factors; and lists examples of organisms and systems from nature, for the analogical development of biomimetic designs that respond to light.

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Keywords: light-interception; nature; buildings; architecture; biomimetics; design; harness; daylighting.

1. Introduction

Buildings are exposed to solar radiation at different intensities throughout the day, which requires systems to manage light conditions in a space for comfort, among others. Managing light becomes very challenging when

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several elements are considered simultaneously, e.g. minimizing heat gain, while maximizing daylight, yet considering glare. A common solution for managing solar radiation is a shading system. Shading systems are attached to buildings in order to control light intensities in the occupied spaces next to windows. Current shading technologies deal, primarily, with extensions either vertically or horizontally, or by adding an extra cladding to protect against radiation from glazed openings. Other solutions, based at the molecular level, have also emerged to control the amount of light penetrating inside, e.g. reflective and selective coatings, and thermo-chromic glass [1].

Responding to light is one of the common abilities of many forms of life [2]. The rotation of sun and earth creates unique light habitats on earth, where various strategies and mechanisms that manage light intensity and interception have evolved. Morphological, behavioral, and physiological means influence light management efficiency [3, 4]. For example, some plants tend to optimize light harvesting by solar tracking and enhancing body exposure, while others are able to transmit light due to their intricate structural assembly.

Exploring and learning from strategies and techniques found in nature can inspire the development of new light management systems for buildings [5, 6]. This discipline, where solutions are obtained by emulating strategies and principles from nature, is called biomimetics. Biomimetics is a rapidly growing field in engineering and materials science, though the application to architecture is still a challenge. One of the major challenges is the search for and the selection of relevant strategies from the vast database of nature [7]. Several attempts have been carried out to represent biophysical information systematically in analog context to buildings, e.g. [8-10], yet a systematic representation of light management strategies for applications to buildings is limited.

In this paper we distinguish three main functions for light management: illuminate spaces, filter light intensities, and harness light for energy purposes, see Fig. 1. The corresponding processes for light management are identified and several strategies from nature are presented in the following sections. Furthermore, some morphological means for light interception, particularly in plants, are distinguished, and their potential application to buildings is indicated.

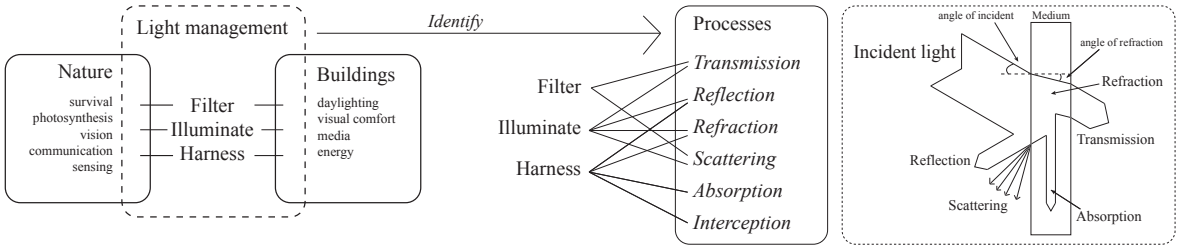

Fig. 1. Schematic diagram of the biomimetic design framework for light management. Left: three main functions and their corresponding processes are identified for buildings and natural systems. Right: the different processes of light when interacting with a medium.

2. Light management in nature

Solar radiation is the main source of light, which changes throughout various scales of time (i.e., hours, days, and seasons). Organisms perceive light for various purposes, such as gaining information from the surrounding environment for adequate response, or for energy matters [11]. Adaptation strategies to light are diverse, where plants and eye architectures dominate in literature for unique light interception adaptations. Compound eyes are a special case of eyes, which are either superposition or apposition. Superposition eyes are more sensitive to light than apposition eyes, and found in animals that are active at night (such as moths and fireflies) or organisms that inhabit the deep oceans with limited light [12]. The following processes introduce some examples found in nature for filtering, illuminating, or harnessing light.

2.1. Transmission

The molecular structure of a substance influences the fraction of radiation passing through, which is described as transmittance. In dark environments, organisms need to adapt to the very limited radiation available, thus a high transmittance substances are advantageous. For example, the Venus flower-basket a deep-sea sponge, *Euplectella*,