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Strategies to control daylight in a responsive skylight system

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ABSTRACT

This research aims to develop a skylight system that responds to both external, environmental conditions and adjustable internal functional demands. The system adapts to different geometries, uses, locations, times and sky conditions. In the design process, the disposition and size of skylights are customized to the context. After construction, the apertures of the skylights control interior conditions. This paper focuses on the dynamic process to control daylight using a case study. The goal is to assure adequate illuminance and low visual contrast. Parametric and environmental software analysis is used to generate and assess solutions. Heuristics strategies are developed to find adequate configurations, given that optimization methods are time and resource consuming. The performance of such configurations is evaluated in specific conditions. An interpolation method is proposed to find configurations adequate to other conditions. A friendly-interface allows selecting the best configuration in real-time using multi-criteria.

1. Introduction

The current research is part of a larger research concerned with the use of digital technologies in the Architecture, Engineering and Construction (AEC) sector. The ultimate goal is to improve the ability of buildings to respond to the context, by enabling local adaptation and customization. To study the use such technologies in different stages of the building's life cycle, namely, design, production, and operation, current research is focused on the development of a system of responsive skylights. The idea is to use generation, simulation, fabrication, and automation techniques to conceive skylight systems adapted to different geometries, uses, locations and weather conditions. The process of finding an adequate configuration involves two form-finding processes: first, manipulating the skylight shape and tessellation according to the input geometry at the design stage, and then altering the aperture of its skylights at the operation stage. These processes are called static and dynamic customization, respectively. A simplified pavilion structure, called TetraScript, is used as a case study to guide the development of the system. The present article focuses on the identification of the design requirements to ensure good response to daylight requirements through dynamic customization.

1.1. Biological influences: natural evolution and behavior

The current research was inspired at several levels on features of biological systems. The static and dynamic customization processes referred to above have a parallel in natural systems. In nature, organisms evolve adapting to the environment in the long run, using the process of natural selection. This is the case of certain vegetables whose shape and surface texture enable them to control their inner temperature in hot climates (Fig. 1). The process of finding an adequate configuration for a building using static adaptation can be compared to natural selection over time. Some organisms have behavior mechanism and respond to changes in local conditions, in real-time. Some plants, like the snow buttercup follow the sunlight direction to receive more sun, in a heliotropic response. Other plants like the King Protea, open more to get sunlight, reacting to the quantity of light, responding to non-directional stimuli in a photonasty response. The process of changing the apertures of the skylights can be compared to such responses (Fig. 1).

The goal is to propose responsive system, using the principles of existing natural systems, in order to improve performance according to local conditions. A parametric system is proposed to generate multiple skylight configurations, as it will be described in Section 1.2. For the current study the TetraScript pavilion (Fig. 2) is used as a case study.

1.2. Static and dynamic customization

The problem of adapting the pavilion to the context is a matter of manipulating its shape in response to internal and external conditions (both long-term as short-term conditions). In the context of the current

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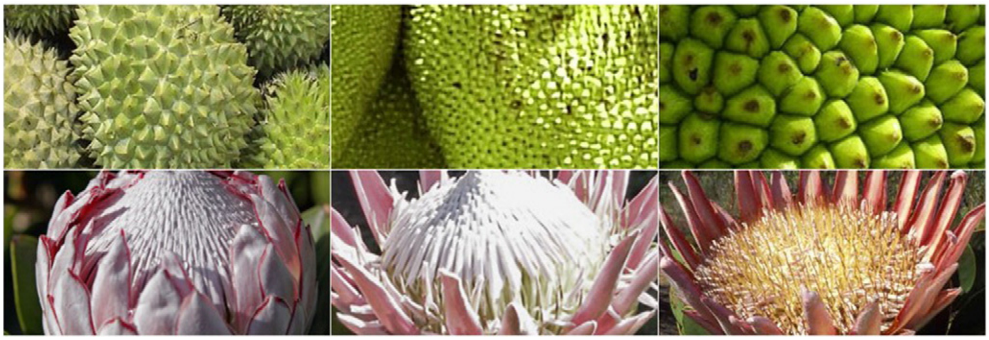

Fig. 1. Examples of vegetal customization to environmental conditions in the tropics: skin texture of Durian and Jackfruit (above) resulting from natural adaptation; behavior mechanism of the king Protea that reacts to the presence of daylight by opening (below).

study, this problem was simplified by means of using a case study — the design of a small pavilion. The internal conditions depend on the particular use intended for the pavilion; several different uses are possible such as leisure, exhibition, office-type or even greenhouse. Obviously the use has an important impact on spatial and daylighting requirements. The relevant external conditions for lighting analysis are mainly the geographical location, time of the day and year, and weather conditions, which impact on the direction and amount of available sunlight. So, the problem becomes one of finding an adequate configuration for the pavilion, i.e., the set of values for the shape control variables that yield adequate indoor lighting conditions. The configuration of the pavilion is determined by a small set of variables including basic form, tessellation and texture in what regards static adaptation, and the degree of aperture of the skylight panels in what regards dynamic customization. The adequate values for these variables can be determined through two processes in two different stages described next.

Static customization is used in the design phase to adapt the shape of the building to its particular use and location at the moment of construction. The variables that can be controlled at this stage are basic form, tessellation, and texture and the corresponding values are found at the design stage. To control the universe of possibilities and focus the study on lighting aspects, the basic form was limited to closed elliptical domes and the manipulation of the correspondent variables determines the specific shape and dimensions of the pavilion. Tessellation is then used to decompose the dome's shape surface into discrete elements for fabrication and to define the orientation and size of the skylights. The surface's texture is created by the pyramidal shape of the skylights. The case study considers a dome solution with $6 \times 4 \times 3$ m at a 41.2°N, −8.62°W. The process of finding the shape of the pavilion following a static adaptation process is described elsewhere [1].

Dynamic customization is used to adapt the shape of the building to changing internal and external conditions in its daily operation after built. At this phase the only shape variable that can be controlled is the degree of aperture of the skylights, which therefore determines the pavilion configuration. This process of dynamic customization for the pavilion concept will be developed in Section 2.

Besides the inspiration in biological systems referred in Section 1.1, static and dynamic customization find also significant background in the vernacular architecture. To a certain extent, vernacular architecture can be seen as the result of a static adaptation process in which spatial and formal solutions were fine-tuned after hundreds or even millennia of years of evolution. Vernacular architecture has examples of static adaptation in which ornamentation is used to solve multi-task problems and qualify space with attributes. An example can be found in Islamic Architecture with the use of mashrabiya screen walls [2]. Such screens enable ventilation, provide shade and modulate the luminous environment of the interior. There are also examples of dynamic customization, for instance, in the use of movable shading devices such as lattices and shutters [3]. However, even if the desire of a responsive architecture is an old human aspiration, the advent of digital technologies brings an increased opportunity in this regard. With the development of computation, more powerful tools are now available for designing spaces that respond to the users and the environment following static and dynamic processes. Computational media can be used to simulate processes of

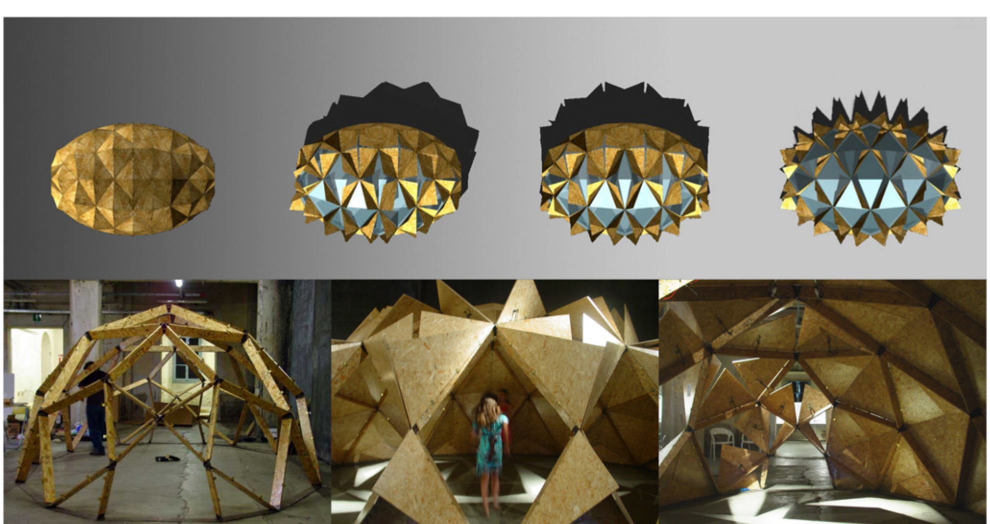

Fig. 2. The TetraScript pavilion concept and prototype, presented at the Beyond Media Festival, Florence 2009.