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Parametric-based designs for kinetic facades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns

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Abstract

Recent literature shows that experimentation in kinetics and architectural skins is more widely introduced as a solution for environmental-related design issues. Facades and elements are transformed in kinetic living creatures changing in synchrony with the surrounding environment. Through the lens of morphology, this research explores the possibilities of kinetic composition afforded by facades in motion. It presents a method for the evaluation of kinetic facades system performance using experimental approach. The experiments investigate improving daylight performance through the design and motion of kinetic facades using various integrated software. The impact of kinetic motion of hexagonal pattern on south-facing skin to control the daylight distribution in an office space is studied using parametric simulation technique. Results demonstrate the analysis of rotational and translation kinetic motions at the early design stage compared to a traditional window (base case). Finally, possible configurations to enhance daylight performance are suggested.

Keywords: Kinetic facade; Daylight; Parametric design; Building skin

1. Introduction

Recent studies highlighted the significant effect of façade design on indoor day lighting quality (O'Brien et al., 2013; Sherif et al., 2012a; Shen and Tzempelikos, 2012; Freewan, 2014). A high integration of design and research between architects, computational designers, and consultants is important to address limitations associated with incorporating performance criteria in the design of façade by integrating different simulation tools (GhaffarianHoseini et al., 2013). Yet, it is still important to explore kinetic skin patterns for such integrated design (Baldinelli, 2009). Kinetic skin patterns are formed by multiple singular movements. Through the lens of morphology, this research explores the possibilities of kinetic composition afforded by façades in motion in terms of rotation and translation motion. Composition is analyzed in terms of pattern, defined as the relative movement of individual kinetic parts in time and space – the way in which multiple singular kinetic events cluster, or propagate, across a facade over time. Few studies investigated the impact of kinetic facades on indoor day lighting. There is a need to experimentally

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investigate such kinds of patterns. This study will be carried out to evaluate the performance of kinetic façades that integrate different motions in response to dynamic day lighting.

Through applying parametric modeling as a generative design and analysis tool, this paper examines the technical details linking system variables with daylight quality. Two hypotheses will be investigated. Firstly, kinetic skins can be designed and animated to reach optimal daylighting performance of buildings using the parametric modeling and simulation at early design phase. Secondly, rotation motion provides better illumination levels than translation motion in southern facade.

2. Background

2.1. From Façade to skin

Integration of elements produces a combined functionality that transcends the traditional notion of design. The concept of facade radically changed this process (Rafael, 2010). The façade is not just a neutral elevation that separates the inside and the outside of the building. Far beyond, the façade becomes an active element that makes the building interact with its context and the environment (Tzempelikos et al., 2007). This element is now considered as a continuous envelope of tectonic, environmental and aesthetical relationship between the interior and the exterior: *the skin*. (Bougiatioti et al., 2009; Rafael, 2010).

The design logic of architectural skins is based on a more sustainable approach through improving the energy performance of a building (Bougiatioti et al., 2009). The decisions about the geometrical forms, the materials, or the construction details, are made to moderate the energy exchange. The contemporary emphasis within architectural design on environmental performance has led to a renewal of interest in the capacity for a facade to be kinetically responsive (Ramzy and Fayed, 2011). A range of environmental sunscreens have been constructed, and new systems are continually being developed. At present the kinetics is basic, but there is no doubt that the current trajectory of research into responsive building facades will continue, with the result that more sophisticated technical solutions will be available (Favoino et al., 2014). Within these environmental systems there is a growing recognition that the aesthetics of the technology needs to be considered, alongside the technical performance (Moloney, 2011).

Research on the impact of solar screens on day lighting performance has received growing attention recently. Empirical study of day lighting performance was conducted for an existing typical government office in a hot-humid climate in Malaysia (Lim et al., 2012). This study indicated that simple modification of window glazing and shading device provides significant improvement in tropical day lighting quantity and quality for visual comfort. Previous studies in hot dry climates investigated the design of the influence of perforation percentage of Solar Screens on day lighting performance in a typical residential living room of a building in a desert location (Sherif et al., 2012c). They suggested minimum perforation percentages for Solar Screens for specific design cases that encompassed different orientations. Another study investigated the influence of changing the perforation percentage and depth of these screens on the annual energy loads, hence defining the optimum depth/perforation configurations for various window orientations (Sherif et al., 2012b). This study concluded that compared to traditional screens, lighter and deeper solar screen configurations were found to be more efficient in energy consumption. Most studies were based on static, rather than dynamic, solar screen systems. This research argues that utilizing dynamic (e.g. kinetic) solar screen system in the building envelope would contribute to day light and energy performance in buildings.

2.2. Kinetic envelope systems

In recent architectural design practice, kinetic architectural design can primarily be found in building envelopes or skins. This approach to designing architectural skins comprises the adoption of kinetic mechanisms for environmental adaptation and responsiveness. The term "Kinetic architecture" was introduced by William Zuk and Roger H. Clark in the early seventies when dynamic spatial design problems were explored in mechanical systems (Ramzy and Fayed, 2011).

Kinetic structures at a scale beyond media or environmental screens can be classified to three significant approaches (Moloney, 2011). The first approach is for Hoberman Associates, arguably the leading international design and construction consultancy in kinetics. He developed a mechanical, light and flexible structural system using a group of hinged units, to form movable designs. His aesthetic is dominated by a distinctive approach to engineering, which produces a singular, minimal motion as the structural component folds in on itself.

The second approach was founded by the MIT Kinetic Design Group, it provided a taxonomy of control systems for kinetics. Fox (2003) taxonomy of control systems outlines the various ways kinetic structure may be controlled. In terms of broad general kinetic categorization, Fox and Kemp (2009) grouped them into three categories: deployable, dynamic, and embedded. He describes the embedded system as one that exists within a larger architectural whole in a fixed location; the deployable as existing in a temporary location, which is easily transportable; and the dynamic system as existing within a larger architectural whole, but acting independently with respect to control of the larger context. The kinetic façade systems studied will be of the embedded type. The embedded system can be directly measured, and comparatively analyzed for quantitative values; it also has the most direct impact on the building users and their comfort by controlling such factors as light, thermal comfort, and ventilation.