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Kinetic solar skin: a responsive folding technique

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Abstract

The paper focuses on optimized movements analysed by means of Origami, the Japanese traditional art of paper folding. The study is a way to achieve different deployable shading systems categorized by a series of parameters that describe the strengths and weaknesses of each tessellation.
Through the kinetic behaviour of Origami geometries the research compares simple folding diagrams with the purpose to understand the deployment at global scale and thus the potential of kinetic patterns' morphology for application in adaptive facades. The possibilities of using a responsive folding technique to develop a kinetic surface that can change its configuration are here examined through the variation of parameters that influence kinematics' form. Moreover, in order to perform the shape change without any external mechanical devices, the use of Shape Memory Alloy (SMA) actuators has been tested.

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1. Introduction

Nowadays façades are made up of many layers and materials that allow the envelope to perform many different functions. The increasing interest for adaptive architecture that reconfigures itself to meet environmental mutations and user's needs drives the concept of a new building skin that is multifunctional, responsive and dynamic. Multiple features could be incorporated into façades in order to optimize their response to climate changes [1]. Responsive façades are thus becoming an innovative research topic, due to the necessity of reducing building energy

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consumption and improve architectural integration [2]. Given that, a kinetic shading device can be useful to regulate windows' gains.

The paper brings the attention to the kinematics potential of Origami creased patterns, investigating how those geometries can be modelled so as to optimize the surface displacements. In these terms, the kinetics exploration is developed through the achievement of different ways to fold the surface, exploiting the type of crease pattern and the use of active materials as actuators. Since the latter typically present limited deformation capacity, the hypothesis is that their combination with the Origami technique would deliver a system whose displacements are compatible with façade applications. The use of Origami at different levels fits Origami patterns into several engineered applications; as deployable and reconfigurable structures, folding geometries have been used in biomedical devices [3] and in space and aircraft applications [4]. However, in architecture the use of self-folding Origami is mainly experimental, especially regarding shading devices and façade applications. At building scale, responsive surfaces have different typologies of movement like translation, rotation and scaling. To do so, external forces are required. Current trends in shading device research aim to replace traditional mechanical systems with multifunctional and smart actuators [5]. The use of Shape Memory Alloy (SMA) wires to switch Origami patterns can produce a responsive system with low activation energy. Currently there are no diffused applications of SMA actuators in the building industry; on the other hand, their intrinsic ability to sense and directly respond to the changing conditions with a range of movements makes these materials attractive for application in kinetic solar shading devices.

1.1. Responsive architectures: a bioinspired deployment

Contemporary architecture has adopted kinetic motion as a process of self-adaptation and responsiveness. Responsive façades are expanding and improving thanks to technological enhancement and the use of clever geometries. Coined by Nicholas Negroponte and then revised by Tristan d'Estree Sterk, the term responsive architecture is defined as "a class of architecture or building with the objective of physically reconfiguring themselves to meet changing needs with variable mobility, location or geometry" [6]. Currently, this type of response is used in architecture to regulate solar gains, ventilation and to solve energy saving issues, especially when a massive use of Heating, Ventilation and Air Conditioning (HVAC) systems is needed.

Dynamic systems have already been investigated since 1987, when French Architect Jean Nouvel envisioned what is deemed the first and most famous built kinetic façade. The responsive robotic shading screen of the "Institut du Monde Arabe" represents a particular type of scaling kinetics [7]. The façade is composed of several independent modules individually controlled. The movement performed by each module can be described as a planar rotation of flat elements overlapping with each other. Therefore, the resulting multiple contractions and expansions control the incoming solar radiation. More recently, two other important examples of kinetic shading devices have been developed. Foster and Partners and Hoberman Associated have proposed a dynamic sun-shading system for the new "City of Justice" of Madrid [8]. The adaptive shadings on top are constructed around a triangular grid, where hexagonal sunscreens contract and rotate independently. In the "Showroom Kiefer Technic" designed by Ernst Giselbrecht and partners, kinetics is instead performed by vertical translations with a scaling effect resulting from a folding joint [9]. The solar screens arranged along the curved façade are controlled by a computer system. When actuated, the shading devices show a composite pattern of translating and scaling object that follow the solar path [10]. Kinetic façade systems use a large number of moving components connected to each other to perform movement. This makes the system complicated and, above all, consumes a lot of energy to work. On the opposite, mechanisms in nature are much simpler, as they move changing one of their intrinsic properties. Several plants have developed a variety of mechanisms able to sense and directly actuate the movement to execute vital functions. Sensors and actuators, through controlled geometry changes like turgor pressure, cell growth, swelling and shrinking, are able to solve physiological issues. Spatial reorientation, seed dispersal, ingestion and fixation are some of the natural processes activated to preserve the organism and to protect it from environmental changes. Venus flytrap leaf folding and Mimosa plant [11] highlight a rapid response to external stimuli. Other natural systems, like tree branches, perform very slow movement to adjust organs' orientation.

To find strategies for deploying surfaces, nature is a good place to look. In some leaves and flowers, a folding technique is used efficiently so as to optimize their shapes continuously. Thanks to corrugations, Hornbeam leaves