Study of the Dynamic Mode of Architectural Interactive Solar Shading Skin

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Abstract. In the past few decades, the development of building digitization and the demand for architecture performance have made the development of building interactive shading skins become an emerging building envelope. As an active solar shading system, the interactive facade can be programmed to set a series of dynamic patterns to respond to the changing surroundings and achieve the designed effect of interactive solar shading. The research on the dynamic mode of interactive architectural skins can be divided into three parts: the role of dynamic mode, dynamic mode of sunshade construction, and the movement illustration of dynamic modes. In this paper, the author firstly elaborates on the theory of interactive solar shading skin of buildings from two aspects: "the connection between interaction and shading" and "shading" methods, and on this basis combines several different design cases and uses a typological approach to illustrate the design of dynamic patterns of the architectural interactive solar shading skins.

Keywords: interactive architecture, solar shading mechanism, dynamic mode

1 Introduction

Mostly, the solar shading system of traditional architecture is designed as fixed or skins with limited angles, which lack the artistic effect of architectural facades and cannot meet the requirements of solar shading and natural lighting at the same time. And yet, the interactive sunshade skin studied in this paper is a kind of dynamic architectural skin with physical deformation characteristics, and its intrinsic motor control system generates a combination of motion from body deformation to position movement of the interactive skin. For example, the translational skin mechanism can achieve two-dimensional shape change, i.e., linear motion. And the rotating epidermal mechanism can achieve three-dimensional shape change, i.e., rotational motion in the same axis or around different axes. Most of these mechanisms are visualized as translation, folding, rotation, etc. It is highly efficient in terms of various design and performance parameters. The skin with dynamic modes together with mechanical components under computer control can form an interactive solar shading system that allows the shading skin to respond automatically to the changing environmental factors with motion and therefore become an efficient shading system to reduce solar radiation. [1] [2]The content of this paper describes the structural aspects of motion, emphasizing the morphological movement and formal output of the architectural interactive shading skins. The conceptual framework of this paper is motion and structure. The following section shows classic cases of different architectural interactive shading skins and provides the basis for the exploration of

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architectural interactive shading skins by plumbing the projects from the perspective of dynamic patterns. We classify the design content of dynamic patterns of architectural interactive shading skins into five categories: faceted folding pattern skins, rotating pattern skins, twisting pattern skins, triangular opening, and closing pattern skins, and umbrella opening and closing pattern skins. The main motivation of the content is to depict the aesthetic potentials of interactive architectural skins, to define the movement through the classification of forms, to elaborate how to design the movement of interactive architectural sunshade skins, and to convert the design concepts into practical application-oriented projects by studying the details of the dynamic pattern forms of skins. [3]

2 Interactive solar shading skins of architecture

The design of interactive shading skins for buildings is considered a relatively important research topic in the field of interactive architecture. Due to the strict requirements of cities regarding energy saving and emission reduction in buildings, designers are paying increasing attention to the design of building shading skins. [4] Digitization and material innovation have resulted in the creation of a dynamic aesthetic for architectural interactive shading skins. The traditional building skin is "static" and fixed for a long time. This can cause people's visual aesthetic fatigue of the building skin. Instead, the interactive shading skin of a building is constantly changing and can automatically produce dynamic patterns in response to the environment, thus achieving shading or other architectural functions. The ideological groundwork behind the design is derived from the influence of dynamic aesthetics. The skin is expressed in various forms of change in dynamics, mainly by changing scale and proportion to accomplish movement, changing its shape, structure, and geometric patterns in motion. The dynamic modes are specifically categorized as folding, rotating, translating, opening, closing, etc, which create an emerging dynamic art design effect, generating many programmatic dynamic patterns, allowing architecture to achieve more and more fascinating changes in the building skin. It is also enabled to communicate with environmental changes and automatically respond to external climatic conditions, becoming a new generation of intelligent solar shading systems.

2.1 Connection between interaction and solar shading

The architectural skin is the transition between the indoor and outdoor environment of the building, as well as the outermost "skin" of the building. In addition to the function of the enclosure, the architectural skin can also improve the existing building environment. In the contemporary world, there are more and more new design methods and technologies for building skins, particularly in the area of architectural shading. Especially in this digital age, the popularity of responsive and interactive design recently has led architects to apply responsive design to solar shading skins, resulting in the emergence of interactive solar shading skins systems in architectural practice. [5] Although the practice of architectural solar shading has long existed, the demand for and use of building performance has increased, prompting the method to be constantly updated and upgraded, allowing traditional shading methods to be supported by new interactive technologies. Since sun shading is an eternal requirement, we should skilfully combine the advantages of both traditional and current methods together to produce new technology systems, cultivate interactive thinking, and apply them to the study of the responsive and interactive architectural solar shading skin design.

2.2 Solar shading mode: from passive to active

While most traditional architectural solar shading is immutable and manually controlled, in the context of sustainable building design and digital technology, architectural solar shading is divided into passive shading and active shading regarding intelligence. Interactive sun shading skin design is a kind of active shading design, where the building skin can actively carry out shading work and residents can adjust its solar shading state and dynamic mode of their wills. [6] Shading based on interactive technology not only breaks the initial "static" state of traditional sunshades but also enriches the design approach of building facades at the same time. The interactive building skin responds to the dynamic changes of the natural surroundings during the design process and automatically adjusts according to climate, season, and time, allowing the energy-saving and regeneration of architectural shading to be achieved and therefore the indoor thermal and visual comfort of the building to be significantly improved and enhanced. [7] [8]Compared with the "static" passive sun shading system, the active shading system, which takes the change of environmental factors as information, interaction as design means, and interactive control system as core power, can respond to changing surroundings instantly. Characteristically, its interactive control system is more complex and the bionic material of the skin is more intelligent, however, the difficulty of shading structure installation and later maintenance will also be greatly increased. In conclusion, within the architectural discipline, the combination of interactive technology and building skin structure can better bring the designing potential of the building skin into full play, while promoting the development trend of building performance and saving building energy, with great research value and development prospects.

3 Study on the dynamic mode of interactive solar shading building skin

Designing dynamic patterns of the building skin from a kinematic perspective is an important aspect of the architectural interactive sunshade skin design. An interactive solar shading skin is a modular dynamic architectural skin that can be physically deformed, and the actuators of the system control the motion of the skin to produce shape deformation. The skin with dynamic mode and mechanical components together form an interactive solar shading system, which is computerized and controlled, so that the architectural sunshade skin can respond to changing environmental factors. From the kinematic point of view, the design methods of skin dynamic modes can be specifically categorized into faceted folding mode skin; rotating mode skin; twisting mode skin; triangular opening and closing mode skin; and umbrella opening and closing mode skin.

3.1 dynamic folding mode

In the design of interactive building skins, folding is the most common dynamic mode to achieve interactive solar shading. Folding dynamic mode can directly adjust the form and size of the building skin, enrich the formal language of the building skin, and coordinate the communication between the building and the environment utilizing two-dimensional or three-dimensional folding.Take the faceted folding pattern skin of Kiefer Technic Showroom— a hybrid exhibition hall in Austria, as an example, it has a shading skin that moves according to weather conditions, with an external frame consisting of 112 shading panels made of tiles that can be folded into motion. The interactive sunshade skin unfolds and contracts as the ambient light changes to ensure comfortable lighting in the room. The framework of the exhibition hall includes steel-clad columns, solid brick surfaces, and a reinforced concrete ceiling. The interactive shading skins are powered by a motor control system, and the motor can trigger perforated aluminum folding panels and automatic blinds. [9] For an example see **Figure 1. [1]**.

In this project, the architects adopted a folding sunshade to cover the exterior wall in order to achieve the solar shading demand of the building and utilized the rocker and slider principle for the faceted folding movement. The whole folding structure can be disassembled into three parts: connecting rod, folding surface, and polyhedron, and each part is connected with fixed hinge support, connecting hinge, and movable hinge support respectively. The fixed rotating support on top is employed as a frame, and the connecting hinge and movable hinge support act as sliders to move along the track. The central latch adjusts the degree of folding between the panels, thus controlling the sunshade to switch between the folded and extended states. [10] For an example see **Figure 2. [2]**.

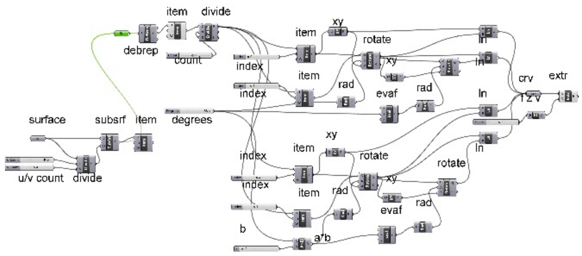

Fig. 1. Dynamic folding mode

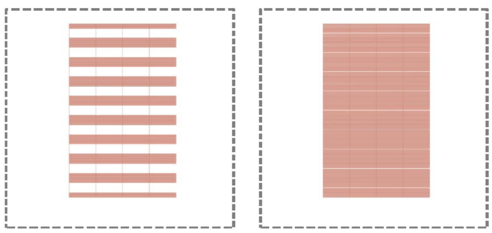

Fig. 2. Movement illustration of dynamic folding mode

3.2 Dynamic rotating mode

The use of rotating morphological pattern skins to cope with solar shading was originally inspired by the design of louvers. With the help of technology, the limitations of simple strip blades have been broken through and a dynamic pattern of multi-directional rotation has been used to produce a skin texture on the building facade that can rotate in all directions. Rotational motion is often applied in engineering to achieve dynamic facades, and the most common system to achieve rotational motion is the pulley system. Although this application is commonly known in engineering, it is rarely used in architecture. Taking RMIT Design Center as an example, the architectural shading skin perfectly combines sustainable technology and dynamic design to improve the interior environment of the building. The building's interactive solar shading skin is designed double-skinned, with the inner skin being a high-performance glass layer and the outer skin made of 17,000 pieces of high-performance tempered laminated glass, which are partly automated and partly fixed. Meanwhile, the use of glass discs provides an iconic façade for the building. The architectural sunshade skin is computerized to track the movement of the sun and thus rotate to achieve the designed interactive solar shading effect .The architectural shade skin is computerized to track the movement of the sun and thus rotate to achieve an interactive shading design effect. This rotating shading system provides a full range of adjustments to better accommodate changes in sun height angle and light incidence. [11] For an example see **Figure 3. [3]**

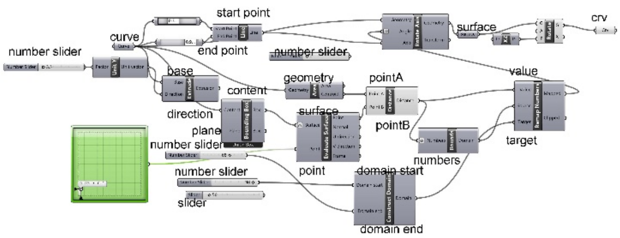

Fig. 3. Dynamic rotating mode

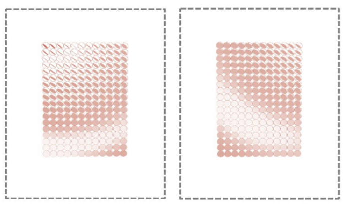

Fig. 4. Movement illustration of dynamic rotating mode

The building façade is pre-assembled into 1.8 x 4.2m panels, each with 21 discs. [12] Twelve of them are operable and nine are fixed. The operable discs open 90 degrees and rotate on horizontal axes on the north-south façade and vertical axes on the east-west façade, giving the façade a direction-specific response. Each panel is automatically controlled by individual motorized actuators, controlled by a Building Management System (BMS), programmed to close to prevent direct sunlight from reaching the main curtain wall and to close in the event of strong winds. For an example see **Figure 4. [4]**

3.3 Dynamic torsion mode

Often when we mention torsional motion, we generally think of softer materials. With the rapid development of digital fabrication and building materials in the present day, interactive solar shading achieved by torsional motion on the skin has become a new way of designing architectural skins.

As we can see from the below picture, the sun-shading system of Tony's Organic House designed by Shanghai Mengjia He's team is composed of two layers of different color ropes. The overlap of the two layers of ropes creates a moiré effect, which enhances the textile aesthetics of the skin while providing sun-shading functions. The facade consists of a series of panels, each panel consisting of 46 cords. The use of a single rope, rather than a continuous fabric, allows the panels to be controlled by the power to twist or move in a controlled and specific way. The constantly twisting shape of the panels becomes an ideal condition for the sun-shading while remaining a perfect view facing the outdoor landscape. For an example see **Figure5. [5]**

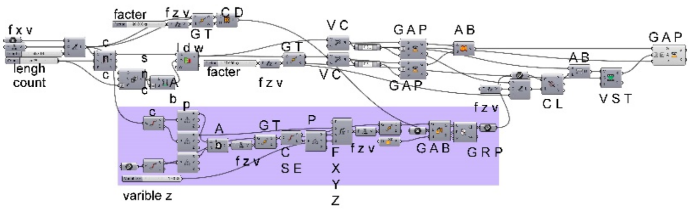

Fig. 5. Dynamic torsional mode

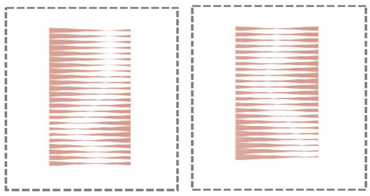

Fig. 6. Movement illustration of dynamic torsional mode

Torsional deformation is a rod being subject to a force couple of equal magnitude and opposite direction and the plane of action is perpendicular to the axis of the rod so that the cross-section of the rod is deformed by rotation around the axis after the angle of rotation around the rod axis between each longitudinal section of the rod is called the angle of torsion. The whole skin system consists of two layers of linear rope, motor, and connecting rod, the upper end of the linear skin is fixed and the lower end is controlled by the motor to rotate towards the outside of the building (the side facing the street). According to the equilibrium condition, the two ends of the textile ropes must produce counter moments of equal size and opposite direction, thus putting the linear skin in a torsional state and producing a dynamic torsional mode. For an example see **Figure 6. [6]**

3.4 Triangle opening and closing dynamic mode

The skin form of the regular grid consists of three main orthogonal polygons (triangle, square, and hexagon) that dominate the movement structure. The triangular opening and closing skin enable the building to respond differently to variable light conditions, forming different internal spatial light environments; the logic behind the triangular opening and closing dynamic pattern is mainly derived from the bionic design and dynamic aesthetics. [13] In the case of AL-Ula Kinetic Wall, the TODO creative team and Defini Group jointly designed an interactive sunshade inner skin composed of 139 "flower petals", which can move synchronously or be sequenced by computer control according to different algorithms, and the movement patterns are similar to waves. Indoor visitors can see the outdoor street through the interactive skin. The triangle shape will be more stable from the point of the design. The triangle is not an isosceles, but an equilateral obtuse triangle chosen as the basic unit of the metal plate variable blade. The mechanical components to achieve the opening and closing movement include the triangular metal sunshade, the torque tube, the torque tube bearing, and the hydraulic mechanism to ensure stable movement. When the intensity of the sunlight becomes stronger, the triangular sunshade will close to block the sun, and vice versa the sunshade opens. for an example see **Figure 7. [7]**

The power to drive the mechanical movement is supplied by the motor to the support rod, which then rotates the torque tube, and the torque tube drives the movement of the triangular sunshade to realize the opening and closing movement of the skin. The whole motion system is controlled by a computer program system. For an example see **Figure 8. [8]**

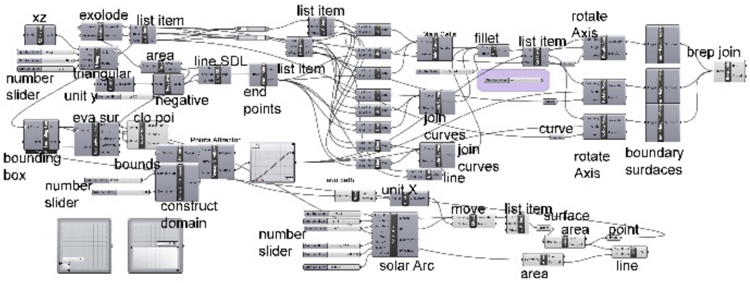

Fig. 7. Triangle opening and closing dynamic mode

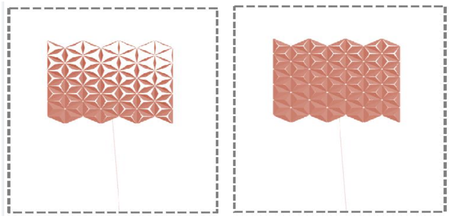

Fig. 8. Movement illustration of triangle dynamic mode

3.5 Umbrella Retractable Dynamic Mode

In the architectural practice of interactive solar shading skins, some responsive skin structures have experimented with umbrella-like structures for their design. In the words of these architects, they got the idea from umbrellas, which are the most common objects people use for shading. Umbrella structures are complex physical movement structures with a central configuration that adds emphasis to the center of the shape. The movement is in the form of lifting and lowering motion of the central support rod to drive the surrounding folded structure to form a telescoping motion, when the central support rod is raised, the structural form opens, and when the central support rod is closed, the structural form closes.

In the case of Al-Bahr Towers, the building shading skin consists of a series of transparent umbrella-like modules that open and close according to the path of the sun. Each of the two towers contains more than 1,000 individual units of shading skins. For an example see **Figure**

9. [9]The interactive architectural skin undergoes an umbrella-like contraction movement to adapt to changing environmental conditions. The dynamic mode of the architectural epidermis is programmed to have three kinetic states. The first state is completely closed, the second is the mid-open state and the last one is a completely open state, which describes the type of scaling of the dynamics. The control system of the architectural epidermis uses a piston mechanism that employs a sliding motion mode. In terms of the kinetic mode of the whole composition, it creates an effect of expansion and contraction, generating random surface patterns in response to the complex local climatic conditions. [14] For an example see **Figure 10. [10]**

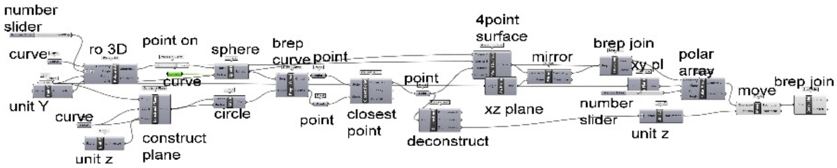

Fig. 9. Umbrella-retractable dynamic mode

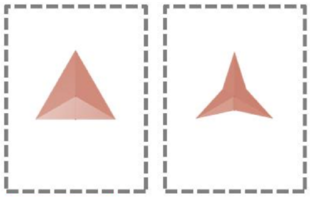

Fig. 10. Movement illustration of umbrella-retractable dynamic mode

4 Conclusion and Discussion

Architectural interactive solar shading skins with dynamic patterns go beyond the shading effect and formal aesthetics of traditional movable shading elements. The interactive sunshade structure can carry out the architectural performance of sun-shading, but it is also a carrier for the display of motion patterns, i.e., the design transformation with dynamic images as the core in the skin. The design of motion pattern strategies for architectural interactive shading skin structures involves a series of changing formal variables, including changes in size, shape, and orientation. The transformation of size is mainly accomplished by changing scale and proportion to accomplish movement; the transformation of shape depends largely on its geometric pattern and modularity; and the transformation of orientation is primarily repositioned in spatial form through translation, rotation, and folding. When one or more form variables are transformed within the framework of the building skin, the entire type of transformation depends on the performance requirements of the building facade. [15] The building performance and the aesthetic expression of the form are optimized through the interactive solar shading skin of the building. Especially in summer, when the external light intensity is too strong, the architectural interactive shading skin automatically generates movements that effectively block solar radiation most of the time through a series of dynamic pattern changes. It achieves the design effect of interactive response while satisfying the functional requirements of shading and establishing a connection with the surroundings. [16] In terms of aesthetics, the interactive skin has a dynamic architectural aesthetic. The first expression of architectural aesthetics is reflected in the outermost skin, whose artistic image directly affects the first impression of the whole building. Compared with the traditional skin, which is single, fixed, and static, the interactive sunshade skin creates a "pixelated" visual aesthetic effect that is full of changes and adds art and vitality to the urban fabric.

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