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THE STUDY OF FACADE COMPOSITION UNIQUENESS OF BIONIC BUILDINGS BASED ON THE COUPLING ANALYSIS OF BUILDING ENERGY EFFICIENCY AND AESTHETIC STRATEGY

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Анотація

У цьому дослідженні досліджується унікальна композиція біонічних фасадів будівель шляхом поєднання енергоефективності та естетичних стратегій. Завдяки міждисциплінарним дослідженням у галузі біології, архітектурної фізики та колористики це наукове дослідження створює основу для перетворення біологічних прототипів на фасад будівлі. Розглянуті численні приклади фасадних та будівельних інженерних систем, що реалізовані у різних країнах за різними біонічними принципами. Доведено, що існуючі наукові дослідження здебільшого зосереджені на застосуванні одного біологічного прототипу. Були запропоновані дослідження мультисистемної синергії різних біонічних принципів для створення унікальних фасадних композицій

Ключові слова: *біоніка, біомімікрія, енергоефективність, сталий розвиток, оптимізація конструктивних форм, біоорієнтовані фасадні системи*

Abstract

This study explores the unique composition of the bionic building facades by integrating energy efficiency and aesthetic strategies. Through interdisciplinary research in biology, architectural physics and color science, this scientific research establishes a framework for transforming biological prototypes into a building facade. Have been considered numerous examples of facade and other engineering systems implemented in different countries according to different bionic principles. Have been proved that existing scientific researches mostly focus on the application of a single biological prototype. Have been offered by the exploration of multisystem synergy of different bionic principles To create unique facade compositions

Key words: *bionics, biomimicry, energy efficiency, sustainable development, optimization of structural forms, bio-oriented facade systems.*

Introduction

The intensification of the global climate crisis poses an unprecedented sustainability challenge to the construction industry. According to the United Nations Environment Program (UNEP), building operations and construction processes account for 36 percent of global energy consumption and 39 percent of global carbon emissions. This data reveals the central position of the construction industry in environmental responsibility. With the frequent occurrence of extreme climate events (such as heat waves and rainstorms) and the acceleration of urbanization, the energy consumption problem of traditional building design has become more prominent. For example, the International Energy Agency (IEA) report notes that global demand for building cooling is likely to triple in 2050, further exacerbating the energy crisis. In this context, as the key interface of the interaction between the building and the environment, it is urgent to achieve the dual goals of energy saving and aesthetics through innovative design.

Bionics provides natural enlightenment for this challenge. After hundreds of millions of years of evolution, the biological system has formed an efficient energy utilization mechanism and morphological and aesthetic logic. For example, the multi-layer thermal insulation structure of polar bear fur maximizes the thermal resistance through the hollow fiber layer, and its thermal conductivity is only 0.026 W / m · K, which is much lower than the traditional insulation material; the transpiration cooling effect of plant leaves regulates the water evaporation rate through stomatal opening, providing a prototype reference for the passive cooling of the building skin. These natural wisdom not only optimizes energy efficiency, but also demonstrates its aesthetic potential through the variety of forms.

The façade of public and industrial buildings is not only a functional carrier (such as heat insulation, ventilation and lighting), but also an important expression medium of urban aesthetics. For example, the super tree structure of Singapore's "Garden of Marina Bay" (fig. 1) enables the integration of technical performance and visual landmarks by mimicking the shading and photovoltaic functions of the rainforest canopy [1].

Figure 1 – General view of Singapore's Gardens by the Bay [1].

However, the existing designs mostly regard energy saving and aesthetics as opposite goals, leading to the dilemma of "high performance but mediocre" or "beautiful but high energy consumption". Therefore, this research focuses on the compositional uniqueness of the facade of the bionic building, and explores the coupling mechanism of its energy saving performance and aesthetic value, aiming to provide both scientific and artistic solutions for sustainable architectural design.

Main part of research

One of the forms of optimization of industrial and civil buildings is implementation the coupling mechanism of biological intelligence and architectural aesthetics of facade design.

The main aspects in which bionics makes a significant contribution to the development of architecture and design are considered in the scientific work [2]: inspiration from nature, adaptive and interactive systems structural optimization, innovative materials, energy efficiency and sustainability, aesthetics and emotional connection with the environment, and an interdisciplinary approach. Thus it allow bionics to be a driving force of architectural and construction progress.

In recent years, the international academia has made remarkable progress in the field of bionic architecture epidermis, with the research direction covering morphological bionic, functional bionic and dynamic response system, (fig. 2).

For instance bionic dynamic shading system the "Flectofin" developed by the University of Stuttgart, Germany, inspired by the opening and closing mechanism of Venus flytrap, can achieve adaptive shading through elastic deformation, which can reduce the amount of solar radiation heat by 30% [3].

The building of "Eastgate Centre" (Zimbabwe) designed on principles of functional bionics wich based on the ventilation principle of termite mounds in the Middle East, using the chimney effect to achieve passive cooling and reduce the energy consumption of air conditioning by 90% (fig. 3) [4].

The Eastgate Centre's design by the architect Mick Pearce, is a deliberate move away from the big glass block design principles. Glass office centers are typically expensive to maintain at a comfortable temperature, needing substantial heating in the winter and cooling in the summer. They tend to recycle air, in an attempt to keep the expensively conditioned atmosphere inside, leading to high levels of air pollution in the building.

Figure 2 – The facade shading system based on the Flectofin produced in collaboration with the industrial partner Clauss Markisen [3].

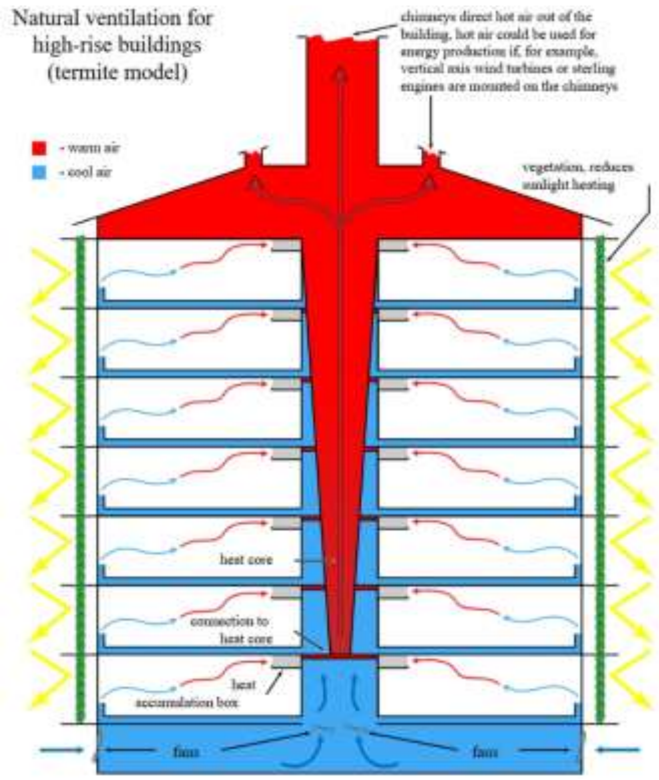

Figure 3 – The scheme of natural ventilation of "Eastgate Centre" (Harare, Zimbabwe) including facade wind and solar deflectors [4].

Artificial air-conditioning systems are high-maintenance, and Zimbabwe has the additional problem that the original system and most spare parts have to be imported, squandering foreign exchange reserves. Pearce, took an alternative approach. Because of its high altitude, Harare has a daily typical temperature swing is 10° to 14°C. This makes a mechanical or passive cooling system a viable alternative to artificial air-conditioning [4].

The Dutch "Biointelligent Facade" (BioSkin) project mimics the thermal regulation mechanism of human skin, and achieves real-time energy consumption optimization through phase change materials and adjustable shading components. This project implemented the dynamic response principle [5].

The correlation research between biological systems and building energy conservation mainly focuses on research of the coupling of morphology of system and its function. In the modern engineering ventilation projects is used fractal structure (such as biological pulmonary bronchial branch) to optimize the ventilation path of the building and improve the efficiency of airflow distribution by 20%. The porous structure of coral bones have been inspired scientist to develop of light and high-strength concrete with its thermal conductivity reduced to 0.1 Watt / m · K. Have been realized the bionic principles of structure material innovation. The light tracking mechanism by sunflower is applied to the photovoltaic panel auto adaptive deformation and rotation system, increasing the power generation efficiency by 15% realized the energy interaction principle.

From this thorough analysis of the current experimental implementation of bionics principles in building construction, it follows that existing studies focus on single performance optimization, and the systematic coupling mechanism of physical biological intelligence and building performance is still lacking. For example, how to combine plant transpiration with a dynamic shading system to achieve comprehensive energy saving has not yet formed a clear technical path.

Bionic architectural aesthetics has gradually shifted from concrete imitation to abstract reformation, forming the following two types of design paradigms as well as natural metaphor and modular design.

An example of the embodiment of the first paradigm (natural metaphor) is the Aliyev Cultural Center (Azerbaijan), designed by architect Zaha Hadid which is a fluid metaphor for natural landforms [6]. The curved structure not only reduces the wind load, but also creates dynamic light and shadow effects. An example of the embodiment of the second paradigm (modular design) is the honeycomb hexagon motif is widely used in the curtain wall system (such as Beijing Daxing International Airport [7]), its compressive performance and geometric rhythm to achieve the balance between performance and aesthetics, fig. 4.

Figure 4 – Beijing Daxing International Airport [7].

The influence of color on building thermal performance have been long time neglected, but recent research has revealed its potential value of providing a facades reflectivity, creation a comfortable indoor temperature, regional adaptability and implementation of nanotechnology.

As an example, white coating (LRV> 80%) can reduce the surface temperature by 10 … 15°C, but high reflectivity may cause glare problems. The tropical area should adopt high reflective cool color, while the cold zone area needs to balance the heat absorption and aesthetic needs. Biomimetic structure color coating (such as a color of Morpho butterfly wings) can achieve infrared reflectivity of more than 90%, but durability and cost are still the bottleneck.

However, present scientific studies are mostly focused on the application of a single biological prototype and lack the exploration of multisystem synergy. For example, the integrated design of dynamic shading systems with thermal reflective coatings is still rarely reported. Besides the most of the studies still remain in the aesthetic expression of morphology, and the translational research of biological prototypes in the perceptual dimensions such as color and texture is relatively weak. For example, the structural color of butterfly wings can achieve high reflectivity through nano-coating technology, but its application in building facades is still limited to the experimental stage. At present, there are still gaps in the construction of biomimetic color maps and the quantification of thermal reflection characteristics of nanostructured color coatings in different climatic zones. In addition, the collaborative optimization strategy of color aesthetics and energy-saving performance has not yet formed a systematic framework.

Prospects for further research

Continued research in this field is necessary to form a theoretical and methodological foundation that will help overcome current challenges and move towards a sustainable future. Overall, bionics opens new horizons for architecture and design, offering numerous opportunities for sustainable and innovative building facades design, which makes further research in this field extremely necessary.

The core of future innovation of authors study will be the "biological intelligence-aesthetic coupled design model", which will be embodied in function-form synergy and dynamic-color interaction.

Future function-form synergy of building facades will be included parametric shading components mimicking the cascade strategy of plant leaves, which not only achieve 70% radiation occlusion rate (energy saving), but also form a rhythmic facade (aesthetic) through modular arrangement.

Will be carried out dynamic-color interaction of building facades based on the principle of chameleon epidermis pigment cells, electrochromic glass is developed to automatically adjust the light transmittance and color saturation according to the sunshine intensity to balance thermal comfort and visual comfort.

By integrating biological prototype analysis, building physical performance simulation and color science experiment, future study constructs an interdisciplinary research framework (biology – physics – coloristic).

A) Biological level. It consists in the extraction the morphological and functional characteristics of biological systems, such as the hexagon compressive structure of the hive and the gradient thermal insulation mechanism of the polar bear fur.

B) Physical level of building. Initial shading coefficient, solar heat coefficient, visible light transmission and other parameters to establish performance evaluation model.

C) Color level. Testing The LRV and infrared emission rate of different colors by the spectrophotometer to build a climate-responsive color database.

The study will be adopts a two-step progressive technical path.

Step 1. Prototype extraction on the base of screening of prototypes with significant energy saving and aesthetic potential based on biological taxonomy (banyan gas root shade structure, chameleon epidermis pigment cells).

Step 2. Parameter simulation on the bases of use software platform for parametric modeling, simulate sunshine radiation and thermal performance; verification the structural feasibility.

Conclusions and architectural suggestions

Thus, the implementation of architectural bionics opens new horizons for the architecture and design of facade systems for industrial and public buildings, offering a number of opportunities for creating sustainable, adaptive and innovative solutions. The authors analyzed the world experience of implementing the principles of bionics in architecture and have been proved that existing scientific researches mostly focus on the application of a single biological prototype and lack the exploration of multisystem synergy which is offered by the authors of this scientific work. The authors outline the direction of further scientific research on the implementation of a comprehensive dynamic approach to building design. Have been formulated the main postulate of future innovation of authors study in view of the modelling aesthetic coupled design on the base of biological intelligence, which will be embodied in function-form synergy and dynamic-color interaction implemented within the building's facade system. The model which offered by research authors will destroy the traditional separation of performance and form in the traditional design, and provides an integrated design paradigm of "natural inspiration, performance drive and aesthetic guidance" for the building facade.

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