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Bionic building energy efficiency and bionic green architecture: A review

Yanping Yuan[a,*], Xiaoping Yu[a,b], Xiaojiao Yang[a], Yimin Xiao[c], Bo Xiang[a], Yi Wang[d]

[a] School of Mechanical Engineering, Southwest Jiaotong University, 610031 Chengdu, PR China
[b] School of Civil Engineering and Architecture, Chongqing University of science and technology, 401331 Chongqing, PR China
[c] Key Laboratory of the Three Gorges Reservoir Region's Eco-Environment (Chongqing University) of Ministry of Education, 400045 Chongqing, PR China
[d] School of Environment and Municipal Engineering, Xi'an University of Arch. & Tech., 710055 Xi'an, PR China

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ABSTRACT

Bionic building energy efficiency and bionic green architecture are important means of ensuring harmony between buildings and the natural environment, maintaining ecological balance, and achieving the sustainable development of buildings. Based on a review of bionic technologies for building functions, structures, and materials, the present study analyzes applications and typical cases of bionic building energy efficiency and bionic green architecture. For example, utilizing the wisdom of nature in buildings, architectural innovations using bionic functions have been created based on the favorable natural ventilation system found in termite mounds. Moreover, passive construction technology using solar energy resources can not only improve the indoor thermal environment but also achieve low energy consumption for buildings. Drawing inspiration from mechanical properties, structural relationships, and the material performance of natural objects, and applying this to a building's structure or shape design, large span structures, such as suspension cable and thin shell structure, which imitate cobwebs and eggshell respectively, have been designed to improve the efficiency of building resources. Using polar bear fur, lotus leaves, and other natural animals and plants as bionic building materials, self-compensation, regulation, and maintenance mechanisms have been achieved on building surfaces, allowing the buildings to actively adapt to their environment, thus reflecting the symbiotic relationship between architecture and the environment, and achieving the green development of buildings with high efficiency and low energy consumption. In addition, based on ecological principles and climate-adaptive design rules, the present study proposes an overall design concept for bionic green architecture and further notes that, in future research, it will be necessary to implement the following: strengthen the integration and optimization of diverse green building technologies; manage the energy efficiency of bionic buildings throughout their life cycles; develop bionic technologies for building functions based on the principle of regional suitability; promote innovative bionic technologies for building structures based on the principle of green ecological coexistence; and strengthen the research, development, and application of bionic building materials that regulate, repair, clean, and protect themselves. In short, the development of bionic building energy efficiency and bionic green architecture should follow and respect natural laws. It is necessary to study the mechanisms used in biological systems, which, combined with modern building technologies, should be employed to support building innovation and to realize the rapid development of building energy efficiency and green buildings.

1. Introduction

Buildings have gradually developed from the simple living environments used by humans (e.g., caves) in prehistoric times. Over the ages, humans have used natural resources and technology, based on an understanding of natural law, to construct buildings that meet their living and production needs. The early functions of buildings were to protect humans protect humans from the elements, and to provide humans with living spaces that were more favorable than the external environment. At this early stage, buildings had an essentially harmonious relationship with the natural environment. In the past century, however, the development of heating, ventilating, and air conditioning (HVAC) technology has significantly impacted building forms. The selection of a building site, the structure of the building's envelope, and the materials used are no longer limited by natural conditions. The scale and appearance of buildings have also changed dramatically. However, the development of HVAC technology has not only provided greater freedom in building design but has also brought in significant

* Corresponding author.
E-mail address: ypyuan@home.swjtu.edu.cn (Y. Yuan).

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Table 1
Analogy of building system and biological system.

	Building system	Biological system
System requirements	Building energy conservation, promoting building types with a healthy and suitable building environment and function	Energy conversion and utilization, ensuring survival and reproduction, suitable species categories
Adaptation mechanism	Artificial or automatic control	Internal homeostasis mechanism
Bionic architecture function	Indoor environmental regulation and energy supply system of building	Biological systems adapt to light, wind, temperature, and humidity
Bionic architecture structure	Architecture morphology and structure	Biological morphology and organ structure
Bionic architecture materials	Building surface and building materials	Composition of epidermis and biological tissue

problems due to the attendant high energy consumption and environmental pollution. The energy crisis in the 1970s prompted the realization that the earth's supply of fossil fuels is not inexhaustible. Since then, the efficient use of resources has become an important issue of global concern [1]. Building energy efficiency and bionic green architecture have become important issues worldwide. With the rapid development of urban construction, the past decades have seen continuous improvement in the standard of living, an increase in the population, and a significant increase in building energy consumption. It is estimated that building energy consumption accounts for 20–40% of the total social energy consumption in developed countries, including the UK, the US, and Australia. In addition, the amount of CO_2 produced by the construction industry accounts for 40% of the total amount of CO_2 emitted globally [2–4]. The rate at which building energy consumption has increased is far greater in some developing countries than it is in developed countries and this increase has also been accompanied by more significant pollutant emissions. As we face the environmental problems and challenges brought about by resource consumption, humans have begun to rethink the relationship between buildings and nature, and to continuously explore means for ensuring the sustainable development of buildings. This in turn provides the impetus for society as a whole to improve energy efficiency, protect the ecological environment, and maintain sustainable development [5–7].

Nature provides an endless storehouse of inspiration for scientists and engineers in different fields. After billions of years of evolution, the internal structures and functions of organisms have improved dramatically; organisms continuously adapt to their surroundings and decrease their negative impacts on the environment [8]. Bionics has already attracted worldwide attention in the construction engineering field and is an encouraging source of innovation that can facilitate the establishment of a sustainable building environment [9]. In recent decades, some researchers have conducted special studies on the mutual relationship between biological structures and buildings, and consequently, increasing numbers of bionic buildings have been constructed worldwide. The term “bionics” was first proposed at a forum held in Ohio, US, in 1960. Bionics, a discipline of technical science, is the study of the structure, characteristics, principles, and behavior of biological systems to provide new design ideas, working principles, and system compositions as well as an interdisciplinary subject that provides new ideas, principles, and theories for scientific and technological innovation [10,11]. Using biological design rules, bionic buildings are constructed with a view to harmonize their relationships with the environment, to achieve environmentally friendly buildings, and to maintain an ecological balance [12]. By studying the functional tissues and morphological structures of organisms in the natural world, bionic architecture includes the application of implicit biological laws to building design. In addition, bionic architecture achieves the goals of energy conservation, land conservation, water conservation, material conservation, and environmental protection throughout a building's life cycle by perfecting both its external morphology and internal functions [13]. Furthermore, bionic architecture provides building users with healthy and comfortable working and living environments that coexist with nature [14]. Thus, it can be said that bionic buildings promote adaptation to the surrounding environment [15].

Just like the essential elements of natural system classification, bionic technologies for shapes, structures, materials, and functions generate different types of bionic building [16]. In comparing building systems and biological systems, the former seek a reasonable use of external energy and resources, study the adaptability of the morphology, physiology, and behavior of the biological system in relation to the environment, and improve the energy and resource utilization efficiency by designing buildings with climate adaptability. This paper presents a review of bionic architecture at home and abroad, based on references that include monographs, theses, journal articles, conference papers, et cetera. The article takes building energy efficiency and green architecture as its key words, and is divided into three types of bionic building according to their bionic architecture function, structure or morphology, and materials. Moreover, we explore the technology principle and development mechanisms of bionic building energy efficiency and bionic green architecture based on the classification research. The analogical framework of this study is shown in Table 1.

Therefore, there are three main applications of bionics in buildings: bionic functions, bionic structures or forms, and bionic building materials [17]. Bionics responds to the problems faced by human society in the course of its evolution by learning from nature and mimicking the structures of biological systems, and, within this field, bionic building energy efficiency is currently the most important issue [18].

2. Bionic architecture function

In biomimicry, the most favored approach is the transfer of functional aspects of a design, stemming from the hypothesis that all existing natural constructions and structures have a functional cause, and that function is the key to the establishment of suitable analogies [19]. Architectural function is often complex, and, in nature, biological organic tissues provide us with examples of success. It is not simply the superposition of single function elements, but also includes the integration of the multi-function development process, resulting in new characteristics at a higher stage of development [20]. In the future, the interior spaces in which we live and work may be designed to function as living organisms, specifically adapted to place, and able to provide all of our energy and water needs from the surrounding environment [21].

Nowadays, the function of modern architecture is more than simply providing a living space, and more is required from a building's structure and function, thus imposing higher demands on architects in the design process. Architectural bionic function provides a way to solve these problems, by giving architects inspiration from various natural organisms and vitalizing the architecture so that the building can make better use of sunlight and other natural resources.

2.1. Bionic utilization of solar energy

Relying on the sun for life, plants and bacteria convert solar energy

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