

# BIOMIMETIC AND BIO-INSPIRED ARCHITECTURE: A COMPARATIVE ANALYSIS OF SELECTED CONTEMPORARY BUILDINGS IN CHINA

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## ABSTRACT

Humanity has learned fundamental principles from nature, understanding which has enabled the creation of numerous inventions, such as the parachute and helicopter, as well as numerous optimisations, such as the aerodynamic shape of the Japanese high-speed train (Shinkansen). Plants, in addition to their morphological characteristics, possess a remarkable ability to adapt to environmental changes. Biomimicry architecture draws inspiration and processes from nature, utilising these principles to optimise design, improve energy efficiency, and dynamically respond to the environment. The study was conducted using purposive sampling on three Chinese projects: Lotus Building in Changzhou, Pearl River Tower in Guangzhou, and Comprehensive Service Pavilion of the 2024 Chengdu International Horticultural Expo, which were selected according to Pohl and Nachtigall's classification. The analysis indicates that natural inspiration can occur at three levels of transfer: formal inspiration, process mapping, and implementation of adaptive strategies. Case studies show the gradual transition of biomimetics applications from symbolic formal inspiration to advanced strategies responding to climate changes. Biomimetic architecture, combined with parametric design and interdisciplinary design, has the potential to deliver innovative solutions to achieve international climate neutrality goals.

**Keywords:** architecture, bionics, biomimetic, biomimicry, sustainability, environmental protection

## INTRODUCTION

Rapid economic development and high energy consumption are leading to higher carbon dioxide emissions, which contribute to environmental degradation and climate change (Sharif et al., 2023). Architects and urban planners must seek solutions that address this issue when designing new types of cities adapted to rapid population growth (Piętocha et al., 2025). Buildings are among the main energy consumers, making sustainable design a key element of all efforts (Piętocha & Koda, 2025). To achieve the international climate neutrality goals by 2050, significant changes in the construction sector are necessary (Sommese et al., 2023). Design inspired by nature is reflected in the definitions: bio-inspired, bionics, biomimicry, and biomimetics (Dixit & Stefańska, 2023). The word bionics is a combination of the words “BIOlogy” and “techNICS”. The term was coined in the late 1950s during attempts to study bat echolocation using emerging radar technology. At that time, engineers and architects such as Richard Buckminster Fuller and Frei Otto were also exploring designs inspired by natural structures. Thanks to this technology, those buildings performed functions similar to those found in nature (Pohl & Nachtigall, 2015). Biomimetic architecture therefore provides innovative solutions. Plants possess a remarkable ability to adapt to their environment, including changes in light, temperature,

and humidity (Bijari et al., 2025), and their potential is evident in optimising energy consumption and design. Observing nature and skilfully translating its processes can make buildings less burdensome for the planet and consume fewer natural resources (Gastman, 2024). This study highlights the potential of biomimicry in sustainable architectural design, offering designers insights on how to implement nature-inspired strategies to reduce the environmental impact of buildings. The aim of the study is to evaluate biomimic design as a design tool, identify its potential and limitations, and address contemporary challenges in architectural design.

## **MATERIAL AND METHODS**

The study was based on a literature review of publications on biomimetic architecture. This was followed by a comparative analysis of three case studies, selected architectural projects located in China: Lotus Building in Changzhou, Pearl River Tower, and Comprehensive Service Pavilion of the 2024 Chengdu International Horticultural Expo. A purposive sampling method was used to represent three types of biomimetics, according to Pohl and Nachtigall's classification, but with respect to architecture: structural biomimetics, process biomimetics, and developmental or evolutionary biomimetics. The selection criteria included the source of biological inspiration, a clear method of transfer, and the achieved effect. Next, a description of the biological inspiration and its translation into the architectural solution was provided. Finally, a brief evaluation of the results was conducted. The study was qualitative and interpretative in nature, focusing primarily on the conceptual and functional analysis of the adopted solutions. The relationship between the tested living organism and the implemented architectural solution was examined.

## **RESULTS AND DISCUSSION**

### **Literature review**

Bionics is a discipline specialising in the study of the structure and function of biological systems. The goal of bionic research is to find inspiration in nature to solve technological challenges (Jiang et al., 2024). The term "biomimicry" was popularized by Benyus in 1997, identifying three types of drawing from nature: model, measure, and mentor. The first refers to the study of natural models and the acquisition of knowledge from ongoing processes to solve problems (Benyus, 2009). Gruber emphasises that the goal of exploring areas common to architecture and biology is to explain what is happening in overlapping fields. The researcher also points out that biomimetics and related innovations can help solve current problems in architecture and the environment (Gruber, 2011). Pohl and Nachtigall define biomimetics as the capture of natural principles to facilitate the understanding of analogous and technological problems, which can then be solved through the application of optimised technologies. Researchers divide biomimetics into structural, process, and developmental. Issues related to climate, energy, structural, and architectural design fall into the second category. Pohl and Nachtigall emphasise that when an architect or engineer understands fundamental principles of nature, such as termite-based thermoregulatory ventilation systems, these inspirations can contribute to bolder technological and biological adaptations and their biomimetic applications in engineering sciences (Pohl & Nachtigall, 2015). Pawlyn argues that biomimicry, understood as design inspired by the way challenges operate in biology, is the best way to perceive solutions that will enable the creation of an ecological future (Pawlyn, 2019). Previous research shows that biomimetics in architecture can influence the shape (form), structure, construction, functional mechanisms, and systemic interactions between building elements. Pohl and Nachtigall place architectural design within the process of biomimetics. However, a systematic classification of biomimetic building types in an architectural context is lacking. Contemporary biomimic design is possible thanks to the use of modern tools, including parametric design, which enables the creation of complex and optimised structures. Badarnah points out that biomimetics, understood as the process of emulating strategies from nature, is a discipline that is developing very dynamically in engineering and constitutes a new, rapidly developing field of architecture (Badarnah, 2017).

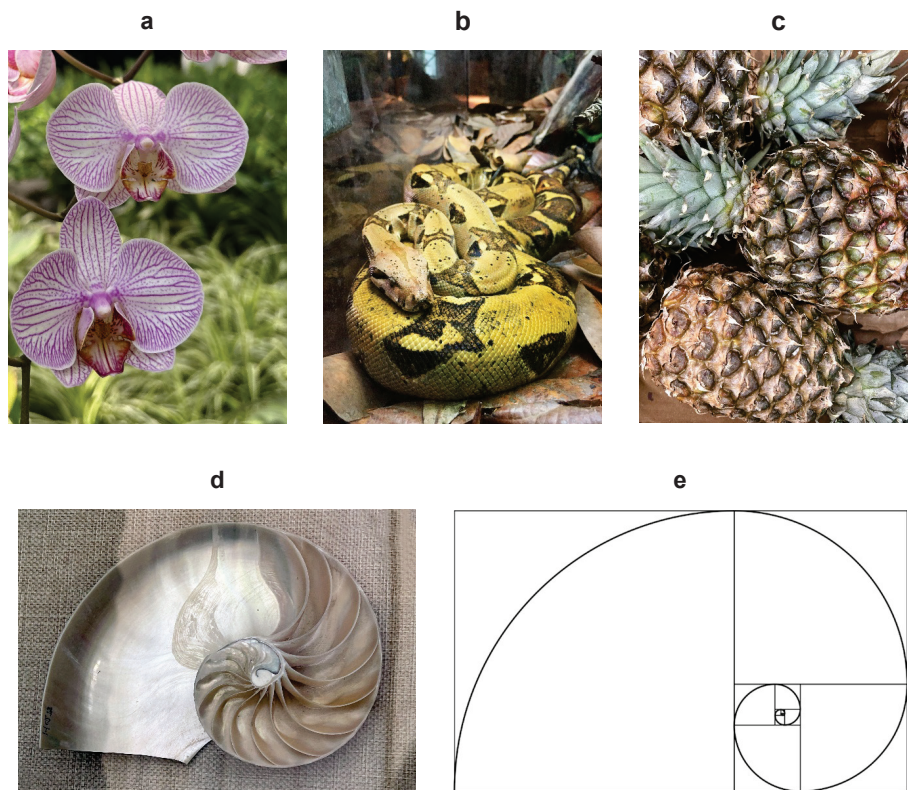
### **Nature as inspiration and the principles of mathematics**

Humanity has been observing the fundamental principles of nature for centuries, and the origins of biomimic design in architecture can be found in vernacular architecture, where these observations stemmed primarily from the search for solutions to protect against surrounding threats. Over the years, this type of architecture has evolved to reflect the environmental, cultural, technological, and historical context of the place where it was built (Nguyen et al., 2019). Patterns and structures visible in nature have inspired architects since ancient times, long before the terms bioinspiration or biomimetics were invented (Knippers & Speck, 2012). The most famous inspiration – the acanthus leaf motif – appears in many styles throughout architectural history; for example, it adorned the capitals of Byzantine columns, Greek Corinthian columns, Gothic cathedrals, and appeared in the Renaissance, Baroque, and Rococo periods. Meanwhile, Art Nouveau drew inspiration from a wide repertoire of plants and organic forms. The mathematical golden ratio, which involves dividing a line segment into two parts so that the ratio of the longer to the shorter is the same as the entire line segment to the longer part, has been a symbol of ideal proportion for centuries. It was used by architects since ancient times as a tool for designing harmonious proportions. It was incorporated, among other things, in the designs of Greek buildings, such as the façade of the Parthenon. Adolf Zeising, a German psychologist living in the 19th century with an interest in mathematics and philosophy, discovered that the golden ratio is also expressed in the arrangement of branches on a tree trunk and in the veins of leaves. The principles of mathematics also manifest themselves in nature, in symmetry (Fig. 1a), in spiral lines, the arrangement of plants, and the shape of shells (Fig. 1d). Another element is the Fibonacci sequence (Fig. 1e), which can be seen on a pineapple (Fig. 1c). Its surface has eight lines running in one direction and five or 13 in the opposite direction. Similar principles can be observed on the disc of a sunflower, where 55 of the 89 spirals can intersect. Another mathematical example found in nature is fractal structures found in snowflakes (crystalline dendrites) or in the form of Roman cauliflower.

Biomimetics is common in many fields of science. Engineers have found answers to their problems therein, resulting in designs such as the parachute (inspired by the dandelion), the helicopter (inspired by the dragonfly), and the aerodynamic shape of Japanese high-speed trains inspired by the kingfisher's beak (the Shinkansen bullet train) (Xiao & Seong, 2025). Bionic design has played a significant role in the automotive industry. The Aston Martin DB10 was inspired by the shape of a shark. Designers are extensively analysing the eyes of various animals to create car headlights with a subtle or predatory expression. Animal patterns are often referenced in the fashion world, such as snakeskin (Fig. 1b), cheetah patches, or zebra stripes. Biomimetics is gaining popularity in robotics and medicine, with specialists creating artificial muscles, a wasp-inspired needle, reusable medical tape, and adhesives inspired by the structure of gecko toe pads, among other things.

### **Case studies**

Lotus Building in Changzhou (Fig. 2a) was designed by the Australian architectural firm studio505 and completed in 2013. The building is an example of structural biomimetics, clearly imitating the form and structure of the lotus flower (Fig. 2b). The flower's morphology is reflected in the building's form and spatial division. The complex consists of elements symbolising the stages of lotus flower development: a young bud, a mature flower, and a fully developed flower with widely spread petals. The transfer of principles occurs primarily at the formal level. However, to minimise energy consumption, 2,500 geothermal piles were driven into the lakebed. The water mass and the ground beneath it are used to pre-cool in summer and pre-heat in winter for air conditioning systems. The designers also incorporated a mixed system of natural ventilation and evaporative cooling from the lake surface, which is fed into a thermal chimney located within the main flower reservoir. Designed as a cultural haven and landmark, this building has become one of Wujin's most popular attractions, contributing to the social and cultural life of Chengdu. This example can be classified as structural biomimetics, a form of design inspired by formal inspiration.



**Fig. 1.** Examples of mathematical principles, patterns, and structures found in nature: a – symmetry, b – snakeskin, which is a common inspiration in the fashion world, c – the Fibonacci sequence visible on a pineapple, d – seashell, illustrating the principles of the Fibonacci sequence, e – the Fibonacci sequence

Source: own work.



**Fig. 2.** Biomimetic architecture in China: a – Lotus Building in Changzhou, b – lotus flower as an architectural design inspiration

Source: <sup>a</sup>Parametric Ideas for Architects (2025), <sup>b</sup>photo by Anna Piętocha, 2025.

Pearl River Tower in Guangzhou (Fig. 3a) is an example of an office building biologically inspired by a sea sponge. Sea sponges (Porifera) are among the simplest multicellular organisms, yet they are also characterised by a highly efficient structural organisation. Their porous structure allows for the continuous flow of water through a system of channels, enabling effective filtration, gas exchange, and temperature regulation. A key characteristic of sea sponges is their ability to maximise contact while minimising flow resistance, which is why they are a common reference in aerodynamics and flow studies. Designers Skidmore, Owings & Merrill, along with Adrian Smith and Gordon Gill, utilised this ability to achieve energy and water efficiency (AlAli et al., 2023). The goal was to minimise environmental damage and utilise energy from natural and passive forces surrounding the building. Efficiency strategies included four steps: reduction (low-pressure ventilation, daylight control, cooling, demand-side mechanical ventilation, and high-efficiency glazing), absorption (using wind turbines, daylight-sensitive controls, and integrated photovoltaic cells), remediation (recovering heat from exhaust air through chillers), and generation (generating sufficient energy on-site using micro-turbines). Thanks to Guangzhou's relatively predictable wind patterns (blowing from the south 80% of the year), the tower was designed with its widest side facing the wind. This maximises wind capture and energy generation. Channelling the wind to four large wind turbines allows for 15 times more energy production than with standalone turbines. Completed in 2011, the building was recognised as the world's largest radiantly cooled office building and the most energy-efficient supertall building in the world. The analysed example can be classified as process biomimetics, because the key element of biological transfer is the mapping of the flow process.



**Fig. 3.** Biomimetic architecture in China: a – Pearl River Tower (building on the left) in Guangzhou, b – Comprehensive Service Pavilion in Chengdu

Source: <sup>a</sup>Anna Piętocha, 2025, <sup>b</sup>Build Design Awards (2024).

The Comprehensive Service Pavilion of the 2024 Chengdu International Horticultural Expo (Fig. 3b) is in Chengdu, the capital of Sichuan Province, classified as a megacity with a population exceeding 21 million. Its unique geographical location and natural environment make Chengdu a key water conservation zone (Li & Li, 2025). The building's biological inspiration came from the hibiscus flower, a plant typical of humid climates. Its structural characteristics are the result of long-term adaptation to heavy rainfall and strong sunlight. The hibiscus flower has a radial arrangement of petals and is characterised by a funnel-shaped, slightly

concave geometry. It has a natural tendency to direct rainwater toward the centre of the flower. This structure enables efficient water management and regulates access to light and moisture. Furthermore, the hibiscus petals are very thin despite their large surface area. The sun-shading structures of the Comprehensive Service Pavilion of the 2024 Chengdu International Horticultural Expo, shaped like canopies with radial geometry, also serve as water retention systems. They are equipped with rainwater harvesting systems, accumulating approximately 2,500 tonnes of rainwater in underground reservoirs. The building under analysis should be classified as an example of developmental or evolutionary biomimetics, as biological transfer involves the adaptation strategies of plants to climatic conditions resulting from evolutionary processes. The building functions as a system that responds to the environment over time, creating solar protection, collecting water, and shaping the microclimate.

### Comparison of results

The analysis of three selected projects confirms that biomimetics is a flexible and multidimensional design tool. The study results align with the definitions presented by Pohl and Nachtigall and can be applied at three different levels of transfer: from formal inspiration (Lotus Building in Changzhou), through process mapping (Pearl River Tower), to the implementation of adaptive strategies (Comprehensive Service Pavilion of the 2024 Chengdu International Horticultural Expo). The Lotus Building in Changzhou references the morphological and geometric characteristics of the lotus flower in its form, but none of its strategies were incorporated into the design. Despite this, the building incorporates pro-environmental features, such as geothermal piles and natural ventilation systems. Like a sea sponge, the Pearl River Tower was designed as a flow system. Environmental energy (wind, solar radiation, and temperature differences) is captured and appropriately channelled within the building. Integrated channels and the location of turbines within the building structure reflect the principle of a sponge as a filtering system. The Comprehensive Service Pavilion of the 2024 Chengdu International Horticultural Expo represents a design approach based on developmental/evolutionary biomimetics. This is the most advanced approach, involving the transfer of plant adaptation strategies to climatic conditions. In this case, the building complex responds to the surrounding climate, representing an example of architecture resistant to extreme weather events. This is an extremely important feature for developing Asian megacities. A summary of the analysed selected Chinese implementations (Table 1) confirms that biomimetics in architecture can refer to various levels of biological transfer. The examples discussed indicate that this can include morphological inspiration, process mapping, or the implementation of adaptive strategies developed through evolution.

**Table 1.** Comparison of biomimetic strategies in selected buildings in China

Strategy	Lotus Building in Changzhou	Pearl River Tower in Guangzhou	Comprehensive Service Pavilion of 2024 Chengdu International Horticultural Expo in Chengdu
Source of inspiration	lotus flower	sea sponge (Porifera)	hibiscus flower
Type of biomimetics	structure biomimetics	process biomimetics	development/evolution biomimetics
The nature of biological transfer	morphological and geometric features	energy flow and exchange processes	transfer of adaptation strategies
A key biological principle	radial symmetry and layered structure of the flower	Continuous wind flow and minimised energy loss	water and daylight regulation in response to environmental conditions

Source: own work.

## CONCLUSIONS

Nature optimises its functioning by using the minimum amount of energy necessary for its operation. Biomimetics is an engineering discipline that mimics natural processes to create a more sustainable planet (Amer, 2019). Designers are increasingly using living organisms to create alternative design solutions focused on environmentally friendly solutions (Chayaamor-Heil et al., 2024). The growing importance and interest in biomimetics suggest that engineers are beginning to realise the possibilities offered by nature to improve the way systems are designed (Vincent & Mann, 2002). The evolution that has occurred with the development of design tools such as Rhino+Grasshopper and Catia enables the creation of complex, curvilinear forms. Contemporary building technologies encompass multiple disciplines simultaneously, each of which is complexly dependent on the others. Therefore, parametric design provides an advanced way to explore and understand these relationships (Eltaweel & Su, 2017). The biomimetic design process requires designers to possess deep interdisciplinary knowledge and insightful insights to understand plant morphology, structure, and functional characteristics, and then isolate and refine key design elements. This involves constantly testing and refining ideas. This is limited by the fact that many designers lack sufficient biological knowledge, hindering their ability to deeply understand how living organisms function (Jiang et al., 2024).

The analysis indicates that biomimetics can be an effective tool for pro-environmental design, focused on reduced energy consumption and combating climate change. The research results led to the conclusion that biomimetic design must be a subject of interdisciplinary research. Parametric design is a tool that allows the creation of complex structures, increasing energy efficiency and optimising construction. Biomimetics, understood as design based on evolutionary processes observed in nature, has the potential to deliver innovative solutions in the construction industry.

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## **BIOMIMETYKA I ARCHITEKTURA INSPIROWANA PRZYRODĄ: ANALIZA PORÓWNAWCZA WYBRANYCH WSPÓŁCZESNYCH BUDYNKÓW W CHINACH**

### **STRESZCZENIE**

Od natury ludzkość uczyła się fundamentalnych zasad, dzięki zrozumieniu których możliwe było stworzenie wielu wynalazków, takich jak spadochron czy helikopter, a także dokonanie wielu optymalizacji, na przykład opracowania kształtu aerodynamicznego szybkiego pociągu japońskiego (*Shinkansen*). Rośliny, oprócz cech morfologicznych, mają niezwykłą zdolność adaptacji do zmian środowiskowych. Architektura biomimetyczna czerpie inspirację i procesy z przyrody, wykorzystując poznane zasady w celu optymalizacji konstrukcji, poprawy efektywności energetycznej i dynamicznej reakcji na środowisko. Badanie przeprowadzono metodą doboru celowego na trzech przypadkach chińskich realizacji: kompleks architektoniczny Lotus Building w Changzhou, wieżowiec Pearl River Tower w Guangzhou i kompleks architektoniczny Comprehensive Service Pavilion na 2024 Chengdu International Horticultural Expo, które zostały wybrane zgodnie z klasyfikacją Pohla i Nachtigalla. Przeprowadzona analiza wskazuje, że inspiracje naturalne mogą odbywać się na trzech poziomach transferu: inspiracji formalnej, odwzorowania procesu i implementacji strategii adaptacyjnych. Studia przypadków pokazują stopniowe przejście zastosowań biomimetyki, od symbolicznej inspiracji formalnej do zaawansowanych strategii reagujących na zmiany klimatu. Architektura biomimetyczna w powiązaniu z projektowaniem parametrycznym i projektowaniem interdyscyplinarnym ma potencjał dostarczania innowacyjnych rozwiązań w celu osiągnięcia międzynarodowych celów neutralności klimatycznej.

**Słowa kluczowe:** architektura, bionika, biomimetyka, rozwój zrównoważony, ochrona środowiska