UDC **606:691** DOI: 10.31650/2786-6696-2025-14-9-16

BIONICS AS THE FOUNDATION OF SUSTAINABLE DEVELOPMENT IN CONTEMPORARY ARCHITECTURE: ENERGY EFFICIENCY AND SYNERGY WITH THE ENVIRONMENT

Zinchenko A.G.,
Andrii.Zinchenko@kname.edu.ua, ORCID: 0000-0002-3429-070X
O.M. Beketov National University of Urban Economy in Kharkiv
17 Chornohlazivska str., Kharkiv, 61002, Ukraine

Abstract. The article explores bionics as a scientific and methodological foundation for creating sustainable architecture capable of energy-efficient functioning and achieving synergy with the natural environment. It examines the evolution of bionics from the formal imitation of organic forms to the comprehensive application of biomimetic principles. Through specific examples – such as the passive ventilation system of the Eastgate Centre in Zimbabwe, inspired by termite mound architecture, and façade concepts that mimic photosynthesis – the article reveals mechanisms for implementing bionic design solutions. Particular attention is given to analyzing the energy efficiency, adaptability, and resource-saving characteristics of bio-inspired architectural objects.

The study highlights the contemporary understanding of bionics, which focuses on the principles of cyclicality, adaptability, and zero-waste design derived from natural ecosystems. It provides a detailed analysis of examples ranging from passive ventilation and thermal regulation systems modeled after termite mounds to adaptive façade systems that imitate photosynthesis and plant regulatory mechanisms. Special attention is paid to environmental synergy achieved through efficient resource management – for instance, mimicking water-harvesting strategies of desert insects or adopting lightweight yet durable structural analogues inspired by biological prototypes such as bone or spider silk to minimize material consumption.

The discussion systematizes the advantages of the bionic approach – including enhanced energy efficiency, reduced operational costs, and improved comfort – while also addressing the challenges of its implementation, such as high research costs and the need for interdisciplinary collaboration. The article substantiates the idea that bionics serves not only as a tool for solving engineering problems but also as a catalyst for shaping a new architectural philosophy aimed at fostering harmony between the built and natural environments.

The practical significance of the study lies in its potential use by researchers, educators, graduate students, and practitioners engaged in related scientific and design inquiries.

Keywords: bionics, architecture, energy efficiency, environment.

Introduction. In the context of global climate change and the depletion of natural resources, the issue of energy efficiency and the ecological integration of architecture has become increasingly relevant. Traditional construction practices, which operate as energy-intensive systems that often oppose the natural environment, are progressively demonstrating their inadequacy in addressing contemporary challenges.

The modern construction industry is among the largest consumers of natural resources and a major source of greenhouse gas emissions. Traditional architecture, shaped during an era of abundant energy resources, largely functions according to the principles of a "closed system". It resists climatic conditions, relying on active engineering systems – heating, ventilation, and air conditioning – to maintain interior comfort. This approach inevitably results in high energy consumption, places excessive pressure on ecosystems, and further deepens the divide between the artificial built environment and the natural world.

Such an energy-intensive paradigm, which treats a building as an object isolated from its contextual environment, proves increasingly vulnerable to global challenges such as climate change, resource scarcity, and urban crises. This situation highlights the urgent need for a radical reassessment of design principles and for the creation of architecture that does not confront nature but instead becomes integrated into natural cycles while minimizing its ecological footprint.

Contemporary architecture faces the global imperative of transitioning toward sustainable development principles, which require a drastic reduction in energy consumption and the minimization of environmental impact. In this context, the bionic (biomimetic) approach is no longer merely an aesthetic choice but becomes an effective tool for addressing practical design and environmental challenges.

Analysis of Recent Research and Publications. The issue of the bionic (biomimetic) approach in architecture has gained significant prominence in recent years, as humanity has become increasingly aware of the importance of minimizing environmental impact.

In the article by X. Wang, L. Xiao, L. Fan, N. A. Mokhtar, and M. K. Azhar Mat Sulaiman, the authors examine bionic architecture through a review of 109 studies published between 2010 and 2024. They propose a classification of biomimetic solutions, dividing them into three categories: façade systems, structural optimization, and energy-generating envelopes. The authors demonstrate the potential of transferring biological principles from living systems into architectural strategies and provide practical recommendations for architects and engineers [1].

In the article "Biomimicry in Architecture: A Review of Definitions, Case Studies, and Design Methods", the authors analyze the transition from simple imitation of natural forms to the development of complex system-oriented approaches. This publication is particularly useful for classifying different levels of biomimicry (form, process, ecosystem) [2].

A. M. A. Faragalla and S. Asadi, in their study "Biomimetic Design for Adaptive Building Façades: A Paradigm Shift towards Environmentally Conscious Architecture", investigate biomimicry as a foundation for designing façades that dynamically respond to environmental conditions. The article focuses on biomimetic methods developed for adaptive façade design and evaluates their effectiveness in comparison with other approaches. The authors conducted a comprehensive literature review and examined early-stage design strategies for such building envelopes [3].

The application of bionic principles in architecture and design has also been explored within the Ukrainian academic context, although it has not yet received as widespread implementation as in international practice. Various aspects of bionic approaches have been studied by researchers such as O. Oliinyk, Yu. Chopyk [4], O. Orlova [5], among others.

Research Aim and Objectives. The aim of this study is to provide a theoretical justification and analysis of bionics as a scientific and methodological foundation for creating energy-efficient architecture capable of synergistic interaction with the environment in the context of sustainable development.

In line with this aim, the following research objectives have been formulated:

– to analyze the evolution of the bionic approach in architecture, tracing the transition from formal imitation to the replication of principles, processes, and systemic interactions;

– to identify and examine key principles of contemporary bionics that are most relevant to addressing sustainability challenges (energy efficiency, cyclicity, adaptability);

– to investigate and systematize concrete examples of successful implementation of bionic solutions in architectural practice;

– to systematize the advantages and identify the main challenges hindering the widespread adoption of the bionic approach in contemporary architectural design.

Research Methods. This study is based on an interdisciplinary methodological framework combining analytical and comparative approaches. The analytical method was used to investigate the theoretical foundations of bionics and its evolution within architectural discourse. Comparative analysis made it possible to identify key similarities and differences between natural systems and their architectural analogues, emphasizing the transfer of biological principles into design strategies.

ISSN 2786-6696 Modern construction and architecture, 2025, no. 14, page 9-16

Case studies of landmark buildings inspired by biological elements provided the empirical basis for evaluating the effectiveness of bionic solutions in enhancing energy efficiency and integrating environmentally derived systems. In addition, methods of systematization and synthesis were employed to generalize the findings and formulate conceptual conclusions. This integrative approach ensured a comprehensive understanding of bionics both as a scientific discipline and as a practical design paradigm that contributes to the sustainable development of architecture.

Research Results. Today, bionics is not merely a stylistic approach but a conceptual framework that enables the transition to a new architectural paradigm – one in which a building functions as a living system in unity with its surrounding ecosystem. Let us examine how the adoption of structural, functional, and energetic principles of living nature can form the foundation for synergistic architecture that interacts effectively with the environment rather than opposing it.

Historically, the interaction between architecture and nature has taken various forms. The initial stage – commonly referred to as biomorphism or formal imitation – dates back to ancient times (e.g., classical orders inspired by plant motifs) and found vivid expression in the Art Nouveau era as well as in the works of notable twentieth-century architects such as Antonio Gaudí and Frank Lloyd Wright [6]. At this stage, the primary focus was on borrowing external, visual, and aesthetic characteristics of natural objects. Buildings could resemble a flower, a shell, or a skeletal structure, yet their functional and engineering essence remained anthropogenic and often energy-intensive.

The essence of contemporary bionics (or biomimicry – a term popularized by Janine Benyus [7]) lies in a fundamental shift in focus: from visually copying natural forms to imitating natural principles, processes, and systems. This approach views nature not as a source of aesthetic references but as a highly sophisticated laboratory that, through millions of years of evolution, has arrived at the most efficient and resource-conserving solutions. Modern bionics in architecture is an interdisciplinary process that integrates biology, engineering, materials science, and design to develop solutions that are both innovative and deeply adapted to environmental conditions.

The analysis of natural systems allows us to identify several fundamental principles that directly correspond to the goals of sustainable development and are critically important for designing energy-efficient architecture.

Energy efficiency and the use of environmental conditions. Living systems operate using available energy (primarily solar) and adapt to local climatic conditions. They rely on passive mechanisms for thermoregulation, lighting, and ventilation. In architecture, this translates into the prioritization of passive design, the optimization of building form for interaction with solar radiation and wind flows, as well as the use of geothermal energy and natural lighting.

Zero-waste operation and cyclicality. In ecosystems, the concept of "waste" does not exist – waste from one organism becomes a resource for another. The principle "waste = food" is the foundation of biological metabolism. For architecture, this means a transition toward the principles of the circular economy: designing buildings as materials banks, using biodegradable or fully renewable materials, and integrating closed-loop systems for water and nutrient cycles (e.g., water purification systems, integrated green infrastructure).

Adaptability and responsiveness. Nature does not produce static or monolithic solutions. Living organisms constantly respond to environmental changes in real time – leaves orient themselves toward the sun, stomata open for gas exchange, animals' fur adjusts its density. In architecture, this translates into kinetic and adaptive façades capable of altering their configuration, transparency, or thermal conductivity in response to weather conditions, time of day, or user needs, thus optimizing microclimate and energy consumption.

The theoretical principles of bionics find practical embodiment in concrete architectural and engineering solutions that enable a radical reduction in building energy consumption and significantly improve the quality of the indoor environment.

One of the most widely cited and recognized examples of the successful implementation of a bionic principle at the scale of an entire building is the Eastgate Centre in Harare, Zimbabwe (architect Mick Pearce, 1996) [8]. The architectural task involved creating a large office complex in a hot climate without relying on expensive and energy-intensive air-conditioning systems. The architect turned to an analysis of the mounds built by the African termite species Macrotermes michaelseni. These termites are able to maintain a stable internal temperature (approximately 30–31 °C) within their nests, enabling the cultivation of fungal gardens, despite the significant fluctuations in outside temperature, which range from 3 °C at night to 42 °C during the day. They achieve this through a sophisticated system of ventilation channels and the use of stack effect. Warm air generated inside the mound rises and exits through an opening, creating a pressure differential that draws cooler air in through the porous lower sections of the structure. At night, the cool outside air chills the massive walls of the termite mound.

Mick Pearce employed this principle in the design of the Eastgate Centre as follows:

Passive ventilation. The building consists of two blocks separated by an atrium covered with a glass roof. Ventilation operates through natural stack effect. Fans (which consume significantly less energy than air-conditioning compressors) draw in cool night air from outside.

Thermal mass. Air circulates through cavities in the concrete floor slabs, cooling the building’s massive structure (similar to the role of soil mass in a termite mound).

Daytime cycle. During the day, the ventilation system is largely switched off. The concrete mass, cooled overnight gradually absorbs heat generated by occupants, lighting, and office equipment, maintaining a comfortable indoor temperature (23–25 °C). Warm air from the offices rises and exits through exhaust shafts on the roof, creating a draft that promotes the inflow of fresh, cooler air from below.

As a result of this bionic strategy, the Eastgate Centre consumes less than 10 % of the energy that would be required for a conventional building of similar size equipped with full air-conditioning in a comparable climate [9]. This example clearly demonstrates the economic and environmental effectiveness of bionics.

While the Eastgate Centre illustrates the imitation of a natural system, adaptive façades represent the imitation of processes and reactions characteristic of living organisms. An innovative direction involves integrating living biological processes directly into the building envelope. A striking example is the BIQ Building (Hamburg, Germany, 2013) [10]. The façade of this building consists of glass panels that function as photobioreactors. Within these panels, microalgae are cultivated in a nutrient-enriched aqueous solution. The system performs several functions simultaneously:

Adaptive shading. In sunny weather, the algae grow actively (photosynthesize), making the suspension denser and greener, which effectively shades the interior spaces and prevents overheating.

Energy production (biomass). The algae are periodically harvested, and the resulting biomass is used in a cogeneration unit to produce biogas (methane), which supplies the building with heat and electricity.

Thermal energy. The water inside the panels is heated by the sun. This heat is captured by heat exchangers and used for space heating and domestic hot water.

Thus, the façade transforms from a passive envelope into an active, metabolic element that generates resources and adapts to external conditions, much like a plant leaf.

Other approaches to adaptation involve creating systems that respond to environmental changes without energy input, relying instead on the intrinsic properties of materials.

One such mechanism is the "pinecone principle" (hygroscopicity). Pinecones open their scales in dry weather (to release seeds) and close them in humid conditions. This movement occurs passively due to the differing fiber structures in the two layers of each scale, which expand differently when absorbing moisture (the hygroscopic effect). In architecture, this principle is applied in hygromorphic envelopes. For example, the research pavilions of the ICD/ITKE at the University of Stuttgart feature façades made from composite wooden panels. These elements are engineered so that they change their curvature (opening or closing) solely in response to variations in relative humidity, thereby regulating ventilation and daylight without any sensors, motors, or power sources [11].

Another biomimetic strategy is the "porous leaf principle". Microscopic pores on a leaf’s surface open and close to regulate gas exchange depending on light levels and humidity. This concept

ISSN 2786-6696 Modern construction and architecture, 2025, no. 14, page 9-16

has also been translated into architecture and has inspired the development of mechanical kinetic façades. The most well-known example is the Al Bahar Towers in Abu Dhabi. Their façade consists of thousands of individual modules. These "umbrellas" automatically open and close throughout the day in response to the sun's movement. They block direct solar radiation while allowing diffuse light to enter, which, according to calculations, reduces heat gain by more than 50%, significantly decreasing the need for air-conditioning [12]. It should be noted that this system is mechanized (unlike the passive "pinecone principle" described above), yet it directly emulates the biological strategy of adapting to extreme conditions through dynamic changes in form.

The examples presented illustrate how the shift from merely copying natural forms to imitating natural processes and systems enables the creation of architecture that enters into a synergistic, productive interaction with the environment – an essential principle of sustainable development.

Examining how bionic principles optimize the use of other key resources – namely water and materials, and how they support the creation of closed-loop systems, several factors can be identified. In the context of global freshwater scarcity, architecture must transition from simply consuming water resources to actively harvesting and managing them efficiently. Nature offers unique strategies for survival in extremely arid environments.

A classical example is the Namib Desert beetle (Stenocara gracilipes). This insect is capable of collecting drinking water from fog carried inland by ocean winds. Its elytra possess a unique microstructure: hydrophilic bumps alternate with flat hydrophobic channels coated with a wax-like substance [13]. Moisture from the fog condenses on the hydrophilic peaks, forming microscopic droplets. Once a droplet reaches a critical size, it detaches and, landing on the hydrophobic surface, easily rolls along the channels directly toward the beetle's mouthparts.

This mechanism has inspired the development of fog-harvesting systems. While similar systems existed earlier, the bionic approach makes it possible to optimize their performance by creating surfaces with controlled hydrophilic and hydrophobic structures. In addition, façade panels and roofing materials capable of passively collecting atmospheric moisture (condensation, fog, dew) and directing it into a building's rainwater harvesting system are being developed. The principle can also be integrated into supply-air systems for passive dehumidification or humidification, reducing the energy required for air treatment. Such technologies have the potential to enable autonomous water-supply systems in arid and coastal regions.

The principle of "doing more with less" is fundamental to biomimicry. Nature does not rely on excessive material; instead, it optimizes form and structure to achieve maximum efficiency with minimal expenditure of energy and matter.

For example, the internal structure of bones – particularly trabecular, or spongy, bone – is not solid. Its latticed configuration corresponds precisely to the lines of load and stress acting upon the bone, a principle known as Wolff's law. Material is present only where it is structurally necessary.

Another example is spider silk. In terms of specific strength, it can surpass steel while remaining exceptionally lightweight and flexible. This performance arises from the complex hierarchical arrangement of its protein molecules [14].

Plant structures such as leaf morphology (e.g., the ribbed structure of the Victoria amazonica water lily) or the form of tree trunks are likewise optimized to provide stiffness and resistance to wind loads.

Modern computational modeling techniques allow architects and engineers to adopt this biological approach to design. In such processes, the software grows the structure by adding material only where it is required to carry loads, while removing it from areas where it is unnecessary. The resulting components are lightweight, filigree-like elements that can save 40–60% of material compared to conventional beams or columns.

The architectural work of Frei Otto serves as a classic example of bionics. His design for the roof of the Munich Olympic Stadium is a materially efficient tensile structure whose form is dictated solely by the forces of tension.

Additive manufacturing technologies (3D printing) in construction make it possible to realize complex, optimized geometries that would be impossible – or prohibitively expensive – to produce using traditional methods. This opens the door to directly replicating efficient natural structures. Minimizing the use of primary materials, creating lighter structures (which reduces foundation loads and transportation costs), and the potential application of biopolymers for 3D printing are all steps toward a zero-waste, closed-loop construction paradigm.

Thus, analyzing evolution, principles, and concrete examples of bionic architecture makes it possible to systematize its advantages and identify the key challenges that hinder its widespread implementation.

The implementation of a bionic approach offers a range of multifaceted advantages that extend far beyond purely aesthetic or engineering considerations, including:

1. Energy efficiency and reduced operational costs. The example of the Eastgate Centre demonstrates that passive bionic thermoregulation systems can significantly (up to 90%) reduce energy consumption for heating, ventilation, and air-conditioning – typically the largest component of a building's operating expenditures.

2. Enhanced comfort and indoor environmental quality. Passive ventilation systems ensure a continuous supply of fresh air, while adaptive façades optimize natural daylight. Together, these features create a healthy and productive indoor microclimate for occupants.

3. Resource efficiency. Structural optimization based on bionic principles substantially reduces material intensity in construction – and consequently, the energy required for raw material extraction, manufacturing, and transportation.

4. Resilience and adaptability. Buildings capable of passively responding to climatic shifts (such as hygroscopic pavilions) or autonomously harvesting water are less vulnerable to energy crises or disruptions in centralized infrastructure networks.

Despite these evident benefits, the widespread adoption of bionics faces several notable challenges:

High cost of research and innovation. Bionic solutions require extensive preliminary research, computational modeling, prototyping, and testing (as in the Al Bahar façade or the BIQ bioreactors). This increases initial project costs, which may deter investors who are not prepared to evaluate full life-cycle benefits or long-term savings.

Need for deep interdisciplinary collaboration. Effective bionic design cannot be achieved within traditional linear project structures. It requires close cooperation among architects, biologists, materials scientists, engineers, and climatologists from the earliest design stages [15]. This poses organizational and communication challenges for the construction industry.

Issues of scaling and standardization. Many innovative solutions remain at the level of experimental prototypes. Transforming them into standardized, certified, and economically viable construction products remains a complex technological and market challenge.

Regulatory constraints. Building codes are inherently conservative and typically focus on established materials and systems. The integration of dynamic and adaptive mechanisms requires the development of new standards and evaluation methods to ensure reliability and safety.

Thus, bionics offers a shift from the industrial paradigm of opposing nature toward a paradigm of learning from nature and integrating its most efficient solutions. The future potential lies in moving from the imitation of isolated biological principles to the emulation of entire ecosystems.

The architecture of the future will employ "living" materials (e.g., mycelium-based insulation, self-healing bacterial concrete); function as a metabolic system integrated into urban cycles (purifying air, managing stormwater, sequestering carbon); and generate more clean energy and water than it consumes [16].

Conclusions. Contemporary bionics has progressed from formal imitation (biomorphism) to the deep adoption of principles, processes, and interconnections characteristic of entire ecosystems. This transition is precisely what makes it relevant for addressing the complex challenges of today.

The principles of natural energy efficiency (passive strategies), cyclicality, and adaptability (response to environmental changes) form the foundation for implementing sustainable development in construction. The analysis of examples such as the Eastgate Centre (passive termite-mound thermoregulation), the BIQ Building (façade bioreactors), the Al Bahar Towers (kinetic shading), along with strategies for water harvesting and structural optimization, confirms the practical viability of bionic solutions. They make it possible to drastically reduce energy and resource consumption while simultaneously improving indoor environmental quality.

The main advantages lie in comprehensive optimization, reduced operational costs, and increased comfort. At the same time, significant barriers remain, including high initial costs, the need for deep interdisciplinary integration, and regulatory hurdles.

In summary, the bionic approach directly contributes to achieving key goals of sustainable development. Bionics extends beyond a purely engineering methodology; it forms a new architectural philosophy based on learning from, interacting with, and integrating natural models. It provides a pathway toward designing adaptive and efficient systems capable of genuine synergy between the built and natural environments.

References

[1] X. Wang, L. Xiao, L. Fan, N. A. Mokhtar, and M. K. A. M. Sulaiman, "Application of bionic architecture in low-carbon design: a systematic review from nature inspiration to architectural practice", *Front. Built Environ.*, vol. 11, 2025. doi: 10.3389/fbuil.2025.1652481.

[2] N. Verbrugghe, E. Rubinacci, and A. Z. Khan, "Biomimicry in Architecture: A Review of Definitions, Case Studies, and Design Methods", *Biomimetics*, vol. 8, no. 1, p. 107, 2023. doi: 10.3390/biomimetics8010107.

[3] A. M. A. Faragalla and S. Asadi, "Biomimetic Design for Adaptive Building Façades: A Paradigm Shift towards Environmentally Conscious Architecture", *Energies*, vol. 15, no. 15, p. 5390, 2022. doi: 10.3390/en15155390.

[4] O. P. Oliinyk and Yu. M. Chopyk, "Rozvytok orhanichnoi arkhitektury na suchasnomu etapi", *Teoriia ta praktyka dyzainu: Dyzain arkhitekturnoho seredovyshcha*, vol. 18, pp. 82–89, 2019.

[5] O. O. Orlova, "Ekolohichnyi faktor formoutvorennia v dyzaini", avtoref. dys. kand. mystets. Kharkivska derzhavna akademiia dyzainu i mystetstv, Kharkiv, 2003.

[6] P. Steadman, *The Evolution of Designs: Biological Analogy in Architecture and the Applied Arts*. Routledge, 2008.

[7] J. M. Benyus, *Biomimicry: Innovation Inspired by Nature*. William Morrow Paperbacks, 1997.

[8] M. Pearce, "The Eastgate development, Harare, Zimbabwe", *in Proceedings of the Institution of Civil Engineers: Civil Engineering*, vol. 120, no. 3, pp. 116–126, 1997.

[9] D. Gissen, "The biological model", *Thresholds*, no. 26, pp. 58–61, 2003.

[10] L. Wurzer, "The BIQ House: Facade as Productive Skin", *CTBUH Journal*, no. II, pp. 26–31, 2014.

[11] A. Menges and S. Reichert, "Material Capacity: Responsive Material Systems in Architecture", *AD Architectural Design*, vol. 82, no. 2, pp. 52–59, 2012.

[12] M. Arbabzadeh, I. Etessam, and S. M. M. Shemirani, "Passive Thermoregulation in Vernacular and Biomimetic Architecture in Hot and Arid Climate", *Int. J. Architect. Eng. Urban Plan*, vol. 30, no. 2, pp. 198–211, 2020. doi: 10.22068/ijaup.30.2.198.

[13] A. R. Parker and C. R. Lawrence, "Water capture by a desert beetle", *Nature*, vol. 414, no. 6859, pp. 33–34, 2001.

[14] A. Goyes-Balladares, R. Moya-Jiménez, V. Molina-Dueñas, W. Chaca-Espinoza, and T. Magal-Royo, "What Inspires Biomimicry in Construction? Patterns, Trends, and Applications", *Biomimetics*, vol. 10, no. 5, p. 259, 2025. doi: 10.3390/biomimetics10050259.

[15] A. Rahim, Ed., "Radical Collaboration: The Second Digital Turn", *AD Architectural Design*, vol. 88, no. 4, 2018.

[16] N. Varshabi, S. A. Selçuk, and G. M. Avinç, "Biomimicry for Energy-Efficient Building Design: A Bibliometric Analysis", *Biomimetics*, vol. 7, no. 1, p. 21, 2022. doi: 10.3390/biomimetics7010021.

БІОНІКА ЯК ОСНОВА СТАЛОГО РОЗВИТКУ В СУЧАСНІЙ АРХІТЕКТУРІ: ЕНЕРГОЕФЕКТИВНІСТЬ ТА СИНЕРГІЯ З НАВКОЛИШНІМ СЕРЕДОВИЩЕМ

Зінченко А.Г.,
Andrii.Zinchenko@kname.edu.ua, ORCID: 0000-0002-3429-070X
Харківський національний університет міського господарства імені О.М. Бекетова
вул. Чорноглазівська, 17, м. Харків, 61002, Україна

Анотація. Стаття присвячена дослідженню біоніки як науково-методологічної основи для створення архітектури сталого розвитку, здатної до енергоефективного функціонування та синергії з навколишнім середовищем. У статті досліджується еволюція біоніки від формального наслідування органічних форм до комплексного застосування біоміметичних принципів. На конкретних прикладах, таких як система пасивної вентиляції будівлі Eastgate Centre у Зімбабве, запозичена з архітектури термітників, або концепції фасадів, які імітують фотосинтез, у статті розкриваються механізми реалізації біонічних рішень. Окрема увага приділена аналізу енергоефективності, адаптивності та ресурсозберігаючих якостей біоінспірованих об’єктів.

У статті також розглянуто сучасне розуміння біоніки, яке фокусується на принципах циклічності, адаптивності та безвідходності, які запозичені у природних екосистемах. У дослідженні детально проаналізовано конкретні приклади: від пасивних систем вентиляції та терморегуляції за прикладом термітників, до адаптивних фасадних систем, які імітують фотосинтез або механізми регуляції у рослин. Окрему увагу приділено синергії з довкіллям, яке можливе завдяки ефективному управлінню ресурсами. Зокрема, запозиченню механізмів збору води у пустельних комах та використанню легких та міцних структур за аналогією до біологічних прототипів (кістки, павутина) для мінімізації матеріалоємності.

У ході обговорення систематизовано переваги біонічного підходу (енергоефективність, зниження експлуатаційних витрат, підвищення комфорту) та проаналізовано виклики, які пов’язані з його впровадженням (такі як висока вартість досліджень, потреба у міждисциплінарній співпраці). У статті обґрунтовано, що біоніка виступає як інструмент для вирішення інженерних завдань, а також як драйвер формування нової архітектурної філософії, спрямованої на синергію між рукотворним середовищем та природним.

Практичне значення даного дослідження полягає в тому, що його матеріали можуть бути використані науковцями, дослідниками, викладачами, аспірантами та студентами у процесі наукових досліджень на суголосну тематику.

Ключові слова: біоніка, архітектура, енергоефективність, навколишнє середовище.

Стаття надійшла до редакції 7.11.2025
Стаття прийнята до друку 18.11.2025
Дата публікації статті 25.12.2025