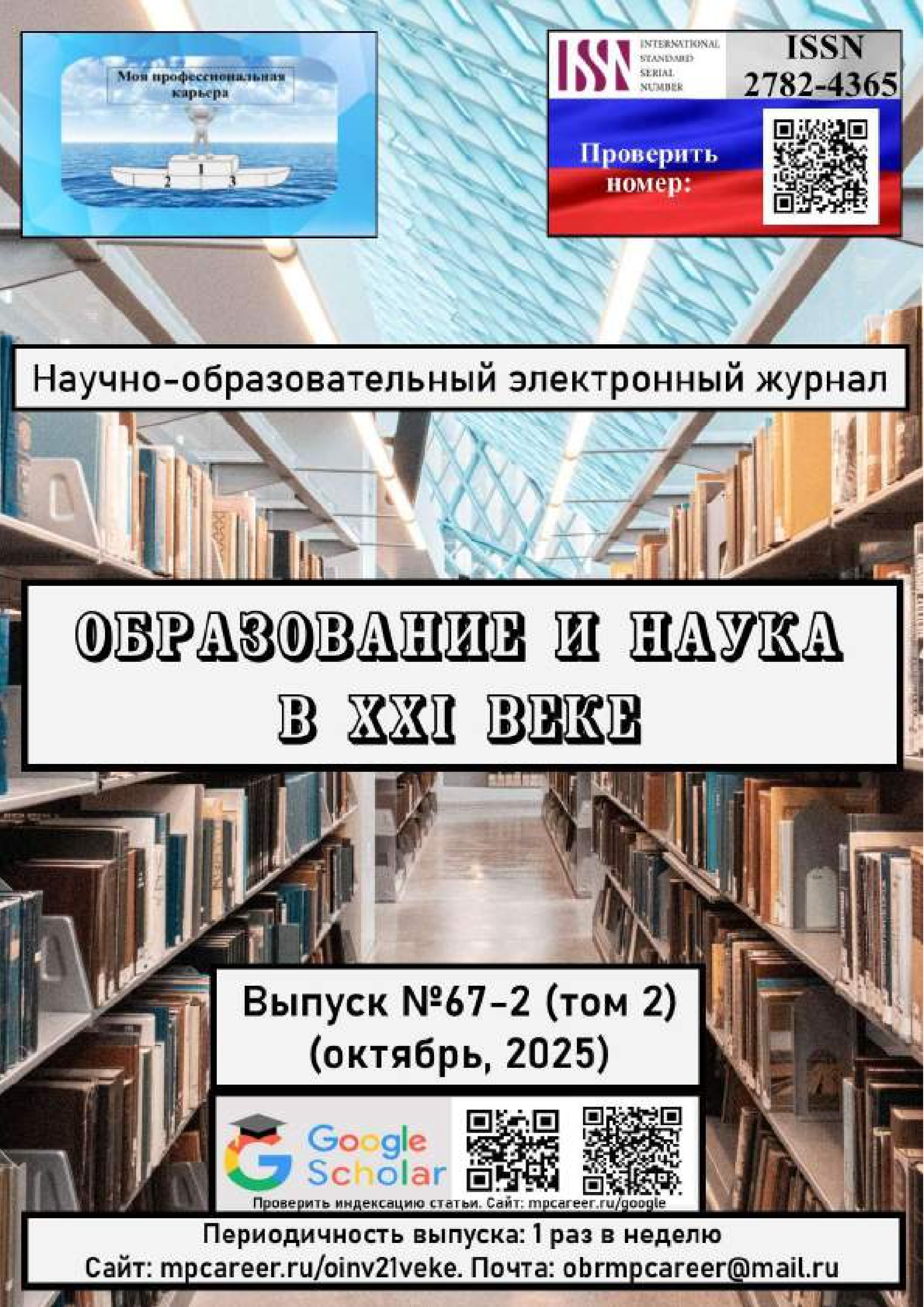

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ISSN INTERNATIONAL STANDARD SERIAL NUMBER
ISSN 2782-4365
Проверить номер:

Научно-образовательный электронный журнал

ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ

Выпуск №67-2 (том 2)
(октябрь, 2025)

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Международный научно-образовательный
электронный журнал
«ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ»

ISSN 2782-4365
УДК 37
ББК 94

Международный научно-образовательный электронный журнал «ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ». Выпуск №67-2 (том 2) (октябрь, 2025). Дата выхода в свет: 13.10.2025.

Журнал объединяет авторов на территории стран СНГ и помогает обмениваться передовыми научно-образовательными исследованиями.

Содержит научные статьи отечественных и зарубежных авторов по экономическим, техническим, философским, юридическим и другим наукам.

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Название публикации: «BIOMIMETIC TEXTILES: A COMPREHENSIVE SCIENTIFIC REVIEW OF PRINCIPLES, APPLICATIONS, AND FUTURE PROSPECTS»

Introduction

Biomimetics, an interdisciplinary field, involves the imitation or replication of structures, functions, and processes observed in natural systems to develop innovative technological solutions. In the context of the textile industry, biomimetic approaches are gaining significant importance as they enable the creation of materials with enhanced functional properties, such as superhydrophobicity, self-healing, thermal insulation, and structural coloration, while minimizing the environmental footprint of production. Biomimetic textiles not only improve product performance and sustainability but also contribute to the transition toward a circular economy, where resources are used efficiently, and waste is minimized.

This review provides a detailed analysis of the historical development of biomimetics in the textile industry, key principles of its implementation, specific examples of bio-inspired structures, current applications, existing challenges, and promising research directions. The analysis synthesizes data from leading scientific publications, highlighting the potential of biomimetics for sustainable advancements in the textile sector.

Historical Overview

The origins of biomimetics trace back to ancient civilizations, where attempts to replicate natural materials, such as the Chinese production of artificial silk over 3,000 years ago, demonstrate early forms of imitation. During the Renaissance, Leonardo da Vinci drew inspiration from the forms of fish and birds to design ships and flying machines, laying the groundwork for systematic observation of nature. A pivotal breakthrough in textile biomimetics was George de Mestral’s 1955 patent for Velcro, inspired by the hook-like structure of burdock seeds adhering to fur and clothing.

The term "bionics" was coined by Jack Steele in 1960, followed by "biomimetics" by Otto Schmitt in the same decade, marking a shift from empirical observations to a scientific methodology. In textiles, early applications included water-repellent coatings patented by Norman F. J. in 1945 (US Patent 2,386,259) and plasma treatment of polymers to reduce contact angle hysteresis, as described by Morra et al. in 1989. Since the 1990s, the discovery of the "lotus effect" by Barthlott and Neinhuis (1997) has propelled biomimetics into a robust discipline, integrating nanotechnology and biotechnology to develop multifunctional fabrics.

Principles of Biomimetics in the Textile Industry

Biomimetics relies on two fundamental approaches: "copying from nature" (direct replication of structures) and "integrating nature into new devices" (using biological elements in synthetic systems). In the textile context, the key principles include:

- **Hierarchical Structuring**: Nature employs multilevel architectures (micro- and nanoscale) to achieve multifunctionality, as seen in the epidermis of lotus leaves or gecko setae. This enables textiles with combined properties, such as hydrophobicity and adhesion, with minimal energy expenditure.
- **Sustainability and Circularity**: Biological systems follow a "cradle-to-cradle" principle, using renewable resources (e.g., proteins, polysaccharides) and ensuring biodegradability. In textiles, this translates to the development of biodegradable fibers inspired by spider silk, reducing reliance on petrochemical-based materials.
- **Adaptivity and Multifunctionality**: Modeling dynamic processes, such as the hygroscopic movement of pinecones or the photosensitivity of Chlamydomonas algae, enables the creation of "smart" fabrics responsive to external stimuli (temperature, light, pressure).

These principles are implemented through top-down (abstracting general natural patterns) and bottom-up (detailed molecular-level analysis) strategies, reinforcing the interdisciplinary nature of research that bridges biology, materials science, and engineering.

Specific Examples of Bio-Inspired Textile Structures

Biomimetic textiles draw inspiration from diverse natural prototypes. Key examples include:

- **Lotus Effect (Superhydrophobicity and Self-Cleaning)**: Lotus leaves exhibit a hierarchical microstructure with epicuticular wax, resulting in a water contact angle >150° and low hysteresis. In textiles, this is replicated through nano-/microstructuring of cotton with fluoropolymer coatings, as described by Hoefnagels et al. (2007). Applications: outdoor clothing and self-cleaning carpets.
- **Gecko Adhesion**: The dry adhesion of gecko feet relies on van der Waals forces from hierarchical setae and spatulae. Synthetic analogs using carbon nanotubes or polyurethane create fabrics with high stickiness, though preventing fiber collapse remains a challenge.
- **Spider Silk and Silk Fibers**: Dragline spider silk combines strength (1.1 GPa), elasticity (30%), and toughness, surpassing Kevlar. Biotechnological production (e.g., via transgenic bacteria) enables fibers for parachutes and protective clothing.
- **Shark Skin Riblets**: Micro-riblets reduce turbulence, decreasing drag by 8–10%. In textiles: Speedo Fastskin swimsuits, improving swimming performance.
- **Butterfly Structural Coloration**: Morpho butterfly wings use photonic crystals for iridescence without pigments. Analogs: Morphotex fibers for energy-efficient textile dyeing.

Additional examples include duck feathers for hydrophobic insulation and firefly bioluminescence for glowing fabrics.

Current Applications

Biomimetic textiles are applied across various sectors:

- **Sports and Mobility**: Fibers mimicking silk or shark skin for gear with enhanced strength and reduced drag (Aggrotech, Mobiltech).

- **Protection and Camouflage**: Hygroscopic fabrics inspired by pinecones for adaptive waterproofing; camouflage based on Batesian mimicry (Medtech, Indutech).
- **Medical and Hygiene**: Self-healing fabrics modeling mammalian tissue regeneration for bandages; photosensitive fibers for health monitoring (Clothtech, Hometech).
- **Environment and Construction**: Thermal insulation materials inspired by penguin feathers for energy-efficient building facades (Buildtech, Geotech).

These applications highlight a shift from aesthetic to functional innovations, promoting sustainability.

Challenges and Limitations

Despite its potential, biomimetics faces obstacles: the complexity of replicating hierarchical structures at an industrial scale, high costs of nanotechnology, and durability issues (e.g., supercontraction of spider silk in humid conditions). Environmental challenges include the use of petrochemicals in synthetic analogs (e.g., nylon in Velcro) and energy-intensive processes, contradicting natural principles. Additionally, interdisciplinary barriers and patent restrictions slow commercialization.

Future Directions

Future prospects include the development of "living materials" (ELMs) integrating biological systems for biocatalysis and self-repair, as well as genetic engineering for reproducible bio-fibers. The integration of AI for modeling natural processes and a focus on circular economies (e.g., combining kenaf and polymers) promise a revolution in sustainable textiles. Research into photonic fabrics and adaptive coatings will open new markets, from space apparel to smart cities.

Conclusion

Biomimetic textiles embody a synergy of nature and technology, offering solutions to global challenges in sustainability and functionality. Transitioning from historical analogies to cutting-edge innovations, this field requires further interdisciplinary efforts to overcome barriers and realize its full potential. Ultimately, biomimetics not only enriches the textile industry but also fosters harmonious human-environment interactions.

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