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Emulating nature's genius: the transformative potential of bio-inspired design for sustainability and innovation

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Abstract: Bio-inspired design, in its intentional meaning (Pasca, 2010), therefore methodologically, represents an innovation that offers a new perspective for addressing current challenges through the emulation of strategies found in nature. Nowadays, human activities cannot ignore the well-being of humans as intimately linked to that of other species and the planet (Murray *et al,* 2022), and therefore, nature becomes a model for the design of digital applications, new materials, and production processes, pedagogical models, forms of social interaction, and the hybridization of practices and contexts. This design approach promotes sustainability, encouraging deeper reflection on the integration between technology and the environment. From the research and application of bio-inspiration, numerous case studies, practical experiences, and theoretical analyses explore the possibilities it offers in all aspects of design. These demonstrate how this approach can reshape the dynamics of interaction between humans and any organization, as well as develop innovative solutions in product and service design, even in a speculative manner. Increasingly, advanced scientific research integrates with grassroots experiences, such as those of the maker culture, in response to the condition of fragility and emergency that characterizes today's society (Rawsthorn & Antonelli, 2022). In this sense, the present contribution aims to strengthen the discussion on the crucial role played by bio-inspiration in the design process, highlighting the need for spaces for experimentation and innovation. Through an analysis of projects ranging from the composition of innovative materials for additive manufacturing technologies (Tang, M., Zhong, Z., & Ke, C.2023) to speculative design, followed by some design experiences and the use of artificial intelligence, the document invites continuous exploration of the riches of the natural world as an inexhaustible source of inspiration and guidance for a more sustainable, resilient, and environmentally harmonious future of design.

Keywords: Bio-inspired Design - Methodology - Sustainability - Nature Emulation - Digital Applications - Artificial Intelligence - Innovative Materials - Production Processes - Social Interaction - Circular Economy

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Bio-inspired circular design

Hybrid approaches for sustainability and innovation

In recent years, there has been an increasing concern about issues such as pollution, climate change, natural resource scarcity, and those new widespread emergencies that now pose threats to society. Calamities and events related to ongoing climate change –often due to the human negligence– such as desertification, melting Arctic and Antarctic ice, water pollution, wildfires, and rising temperatures, are steadily increasing. These emergency events are a great challenge for the project culture, both from a socio-cultural point of view and in terms of the balance between economic development and the production system, in an attempt to manage such emergencies by reducing the impact that even the small gestures of everyday life, can have on ecosystems (Hu *et al,* 2009; Pontillo & Angari, 2021). Worsening conditions related to climate change, often due to factors related to accelerating economic development, highlights the need to take radical measures to reconcile the relationship between humans and the ecosystem. For this reason, design cannot fail to think about the different aspects of major changes, which as sudden and violent as they may be, can often be equally regenerative (Langella, 2020).
The starting point, therefore, should be to outline a globally shared intervention, also based on a greater integration between the artificial and natural worlds (Ranzo, 2007), outlining new ways of acting through design, reversing the trend of productive structures and more generally of the economy, initiating innovative processes based on circularity and sustainability, mending the relationship between people, communities and the surrounding environment (Trapani, 2013).
In this perspective, the growing awareness of the limits of natural resources and the impact that human activities have on the environment, have increasingly led to the outlining of innovative design processes, from conception to production. Such processes are linked to the theme of circular and sustainable development, as they deal with outlining new

production chains, making use of new tools, technologies and materials, in an attempt to reduce the impact of the human footprint on the environmental ecosystem. In parallel, studies conducted on bioinspiration, or inspiration from natural functions and structures, have been shown to influence design activities by incorporating formal or functional performance within different goods or services.

The proposal of the contribution presented, is to start from the need to find points of contact between circular and sustainable development, and bioinspiration, in an attempt to identify a way to integrate the slow times of the earth with the dynamics imposed by progress (Ranzo, ibidem). To do this, thanks to the study of new technologies and materials, it has been possible to identify some logics downstream of which the orientation of the contemporary production scenario is moving, from which to trigger possible vectors of change toward future scenarios. The choice to propose an approach based on the convergence of circularity and bioinspiration, also making use of digital manufacturing and rapid prototyping, emerges from the understanding of how this relationship can affect not only the quality of products, shortening and making more efficient the chain from creation to production of a good or service, but also the relationship that individuals establish with products and with the environmental system that surrounds them, highlighting the need to define a less ephemeral and more anthropological dimension of the project (Branzi *et al*, 2103), going beyond the sole issue of the ecological reconversion of production systems, and favoring the sustainable use of local resources and promoting the potential of networks (Manzini, 2009).

From this point of view, design, thanks to digital innovation –understood as both environment and design technology– and sustainable practices and social innovation, has the capacity to generate new forms, but above all, the responsibility to support more and more sustainable innovations, consistent with the new social, economic and cultural contexts, in which design operates. While the definition of Eco-Design, helps us to understand the necessary introduction of environmental variables within the design (De Benedetti *et al*, 2009), identifying –for example– new applications for pre-existing materials or alternative materials and technologies, bioinspired design is capable of influencing the creation of human-generated systems but replicating natural structures, even incorporating biological components and prompting researchers and designers to better understand complex living systems. Bioinspired design, therefore, takes the form of a methodological innovation that proposes a new design perspective based on the imitation and adaptation of nature's evolutionary principles, leading to a profound reflection on the integration of technology and the environment with human well-being in relation to the planet at the center.

From the perspective of the circularity, analysis of the scientific literature on the topic highlights how strategies that facilitate its principles, can be applied to ecodesign (Ellen MacArthur Foundation & McKinsey, 2015). This involves combining product design strategies to maintain product function and value at the highest level (Bocken *et al*, 2016) for as long as possible while reducing waste and facilitating recycling, remanufacturing, and reuse (Evans & Bocken, 2014; Saunders *et al*, 2009).

Several academics have attempted to outline a possible definition of the circular economy, generally understood as an industrial system designed to be restorative and regenerative by intention and design. This system abandons the concept of 'end-of-life' in favor of restoration, promotes the use of renewable energy, eliminates the use of toxic chemicals that hinder reuse, and aims to eliminate waste through superior design of materials, products, systems, and business models (Ruiz-Pastor *et al.*, 2023). According to others, the circular economy is defined as a regenerative system in which resource use, waste, and losses are minimized by slowing, closing, and shrinking the cycles of matter and energy (Geissdoerfer *et al.*, 2017). This can be achieved through durable design, repair, reuse, remanufacturing, and recycling.

Although there is a lack of a single definition of circular economy, it clearly emerges that it is one of the pillars on which design activity is based, particularly in terms of its relationship to the issue of sustainability, which is why there is a growing development of circular ecodesign strategies and methods aimed at facilitating the integration of environmental aspects into the product development process (Bocken *et al*, ibidem; Baumann *et al*, 2002) to which are linked additional tools for life cycle assessment, such as LCA (ISO, 2006) or the Circularity Indicator (MacArthur, 2015). Although there are a number of methods for evaluating circularity, most of them focus on fully developed products rather than new hypotheses, a fact that makes such tools difficult to use in cases where the parameters to be applied fall outside the conceptual evaluation of the product, a stage at which actual dimensions, exact weights, etc. are often still lacking. Nonetheless, there are methods and tools to facilitate the implementation of circularity, and which derive precisely from inspiration from the principles and systems found in nature, where optimization of resources, both from a structure and function point of view, is perhaps one of the most interesting aspects to investigate from a design perspective.

This particular interest towards bioinspiration, results in some open questions. One wonders, for example, whether biomimicry can guide and encourage creativity from precisely what are natural inspirations, and, consequently, whether through such natural inspirations, it is possible to promote circularity to an extent sufficient to achieve greater respect for sustainability and environmental protection. Resolving these research questions, is an integral part of an evolutionary process of the design approach, both from a creative point of view and from the point of view of solving the requirements of the project, and will be decisive in establishing priorities from the earliest stages of design, balancing between lor creativity and the possibility of realization of the design solutions obtained (Ruiz-Pastor *et al*, ibidem).

Certainly, through the principles, patterns and systems found in nature, the intersection of the disciplines of design, biology, and engineering, has made it possible to begin to investigate how these "natural solutions" can be translated into applications that meet the implementation stage from different perspectives.

The bio-inspired approach can adopt different strategies to draw inspiration from nature. These levels vary from the most intuitive and immediate, such as formal and aesthetic features, to the most complex, which include self-organizing and learning capabilities (Langella, 2019).

Of particular interest in regard to the theme of the relationship between circularity and bioinspiration, are the structural level, applying the principles of structural optimization based on specific loading conditions, the construction level, transferring logics of aggregation of components and growth modes of natural organisms, and the material level, employing and/or mimicking natural materials to replicate their properties. For example, it is possible to reproduce the chemical structure or performance of a natural material while ensuring environmental biocompatibility and biodegradability, allowing artifacts to reintegrate into ecosystems at the end of their useful life.

Alongside the natural characters, the relationship and multidisciplinary synthesis become even more effective, thanks to the methodologies of Human Centered Design (HCD) and Design Thinking, which are proper to the discipline of Design, and which prove to be able to help the process from ideation to the configuration of new design and production models, as well as of individual artifacts. In fact, biodesign, born from the intersection of biology and design as it integrates organic processes and materials in the production of products and structures through an innovative approach, considers individual objects in relation to a system, as if they were particles that are part of an organism, the reason why, drawing inspiration from the efficiency and precision of nature, represents a strategic choice to be able to determine an advancement over traditional design and production models, and which today no longer respond exhaustively to what are the needs both from the point of view of the performative nature of objects, and of their sustainability.

The now-historic case of the Bone Chair, designed by Joris Laarman in 2006, is still one of the most emblematic examples of the morphological inspiration to nature's structures. The chair, designed through the use of digital modeling software, uses data that simulate the natural growth patterns of bones and trees, highly efficient structures that redistribute their mass to specific points in response to physical stress, thus creating a chair that, however durable, makes minimal use of material. The entire structure, right from the base, seems to emerge organically from the floor, generating a form that balances natural geometries with the human and industrial manufacture of the product, in a perfect marriage that dispels the false dichotomy between these seemingly distant dimensions. Nonetheless, the Bone Chair also integrates digital technology and nature, so that although it is born from a computer-generated formula, it takes the human body as a direct point of reference, through structural elements inspired by bones, sharing both its organic aesthetics and structural optimization, pandering to a logic of material reduction, without affecting the strength of the chair's structure. Given the innovativeness of the process of conception and generation of the form, even from the production point of view the Bone Chair was made through a technology that was still in its infancy for that time: CAD modeling software was followed by 3D printing, used to build the ceramic molds through which the final object was made. In fact, that of the Bone Chair, represents a pioneering example of the application of synthetic biology to design, capturing the attention of the international design community, as evidenced by the presence of this object in several international exhibitions, including the Museum of Modern Art in New York and the Vitra Design Museum in Germany (Baker, 2022).

In recent years, thanks to biodesign, it has been possible to witness significant progress toward sustainable innovation. The challenge of global sustainability presents enormous opportunities for product innovation while also achieving a creative response. One possible example is related to the use of biological materials, such as mycelium, the vegetative part of fungi, which can be grown on organic substrates to create alternative materials to plastics. Of particular relevance to precisely this type of experimentation is the case of the innovative company Ecovative Design, which has developed a range of environmentally friendly packaging materials by growing fibers on waste such as cotton seeds, wood fibers, and buckwheat hulls. Through these materials, the company has developed a biodegradable and environmentally friendly solution, and a sustainable alternative to the materials already used for packaging, offering a response to concerns about the growing volume of waste due to packaging, starting with the redefinition and redesign of conventional products in the packaging industry (Kim & Ruedy, 2019).

Similar to the previous case, is that of organic cement, developed by BioMason, through the use of bacteria mixed with sand to activate a chemical reaction that transforms the material into cement without the use of high temperatures, thus reducing carbon dioxide emissions associated with the traditional production of this material. The company, in particular, is in the business of making tiles, satisfying wide market demands, as evidenced by its agreements with the H&M group, for the use of bio-based flooring within new stores and to renovate pre-existing ones, as well as with a considerable number of investors, who believe on experimentation and the use of recycled or sustainably sourced materials, leading to advancement for the industry sector as well (Feldman, 2021).

The presence of greenery in indoor spaces has emerged as a significant trend in new post-pandemic lifestyles, reflecting a growing interest in healthier, more comfortable and resilient environments. With an increasing number of people working from home, the presence of greenery in interiors has emerged as a practice to make home environments more welcoming and adaptable for work and relaxation. It is within this framework that biophilic design projects fit, an approach that integrates natural elements into built environments to improve human well-being, based on the idea that humans have an innate connection with nature (Y. Afacan, 2023). In this context, Hexagro has designed a modular, automated vertical garden system for indoor environments named Living Farming Tree. Inspired by the principles of biophilic design, this vertical garden does not require soil or large spaces, minimizes water consumption through aeroponic technology, and facilitates nutrient uptake by cultivated plants. Plants are arranged in modules at different heights, and the roots absorb water and nutrients sprayed directly onto them, enabling growth up to 3 to 5 times faster than traditional crops. The entire system is controlled by automated management software that monitors and adjusts the garden's agricultural parameters, including water dosage and light intensity, through an IoT system. A smartphone and tablet application allows users to easily manage their crops, even remotely (V. Lempi, 2022).

Similarly to the previous experience, that of Chicago-based architecture firm SOM –Skidmore, Owings & Merrill– saw the development of Bio-Block™ spiral bricks, made with microalgae, offering a more durable and sustainable alternative to traditional concrete blocks. The material, in fact represents a significant step toward carbon-negative architecture by potentially reducing carbon emissions from the construction industry. Underlying the process of making Bio-Block™ Spiral are two natural mechanisms for obtaining and storing carbon in material form: photosynthesis (absorption and accumulation of CO_2 during algae growth) and carbonate mineralization (CO_2 reacts to form a mineral in the process). Through this process, the company's idea is to make buildings function like trees, capturing CO_2, purifying the air and regenerating the environment, making this material the basis of a new carbon removal economy. The material, currently under patent, was created through a photosynthetic bio-cementation process that gives Bio-Block several advantages over concrete:

- It is more sustainable: it has a much smaller carbon footprint than cement, reducing CO2 emissions by 8%.
- It is more durable than conventional cement.
- It is lighter: it weighs less than cement, making it easier to transport and handle.
- It is more breathable: because it is more breathable than concrete, it helps improve indoor air quality.

With these characteristics (R. Totaro, 2023), Bio-Block could bring benefits for both the construction industry, as this material can be used to build a wide range of structures, from housing to commercial buildings, which are strategic for the evolution of cities in the perspective of Smart Cities.
Another interesting area of focus is on the reuse of biological waste. The case of the Reef Rocket, a structure designed by industrial designer Mary Lempres to encourage the regeneration and protection of coral reefs, particularly those created by oysters, aims to so to preserve and improve marine ecosystems. The project consists primarily of a plant-derived bio-cement made by pouring plant enzymes onto an aggregate composed of shredded glass and oyster shells from New York City restaurant waste. This natural process creates a cement-like substance that can be molded, without the use of heat or harmful chemicals. Once placed in the oceans, Reef Rocket mimics natural coral reefs, providing refuges for marine life and contributing to marine biodiversity by creating a natural-like habitat that helps protect shorelines, filter harmful algae from seawater, and support local marine life (J. Englefield, 2024; N. Kahil, 2024). In addition to its practical function of regenerating coral reefs, the Reef Rocket demonstrates how creative design can be employed to address environmental challenges and promote the conservation of marine ecosystems.

Digital Technologies for innovative biodesign

Additive Manufacturing and Generative AI

The field of new technologies, and the potential related to their use, represents another area of experimentation for biodesign from a circular perspective. We know that since its earliest uses, and especially thanks to rapid advances in recent years, Additive Manufacturing technologies have enabled the creation of complex morphologies and structures, often drawing inspiration from the natural world, recreating intricate geometries, plant patterns, skeletal or beehive-like structures that would be extremely difficult to achieve with traditional manufacturing methods or techniques (C. M. Spadaccini, 2019). Several 3D printing techniques, such as fused deposition modeling (FDM), direct ink writing (DIW), selective laser sintering (SLS), stereolithography (SLA), multijet printing (MJP), and selective laser melting (SLM), are optimal for addressing the fabrication challenges associated with bioinspired designs (C. M. Saratti *et al*, 2018). Nevertheless, several researchers are inves-

tigating innovative methods for additive printing, inspired by organisms or employing natural materials.
An innovative 3D printing method inspired by chameleons has been developed by a team of researchers led by Ying Diao of the University of Urbana-Champaign in Illinois (USA). Typical materials used in 3D printing with Direct Ink Writing (DIW) technology generally come in single colors. When a color change is needed, the machine must be stopped to replace the cartridge, introducing possible errors and slowing down production time, resulting in higher overall costs. The study led to the use of photonic crystals to produce different colors without the need to change ink cartridges. Photonic crystals reflect visible light based on the thickness of the material, allowing the reflected wavelengths to be adjusted to create a variety of colors. This process is inspired by the ability of natural organisms, such as chameleons, to change color. The ink used in this technology is composed of cross-linked polymers, which are characterized by two chemically distinct segments that bond together. Before printing, the polymeric material is dissolved in a solution that binds the polymer chains. During the printing process and following drying of the solution, separation of the components occurs at the microscopic level, which are organized into nanometer layers. The key to achieving different colors lies in controlling the speed and temperature during ink deposition. These parameters influence the thickness of the nanometer layers formed, determining the final color of the ink. This method allows a wide range of colors to be produced using a single ink cartridge, eliminating the need for interruptions during the printing process to replace color cartridges (M. Tang *et al*, 2023). This innovation not only simplifies the 3D printing process, reducing the risk of errors and production time, but also helps reduce overall costs, enabling greater efficiency and versatility in additive manufacturing, making it more sustainable and versatile.
A derivative extension and evolution of 3D printing, current 4D printing technology combines new types of smart materials that can change shape, size or function over time in response to external stimuli and with the use of parametric modeling. This approach has interesting applications in bioinspired design with the use of advanced materials such as hydrogels or responsive polymers to make objects that self-assemble or transform in response to environmental stimuli such as temperature, humidity or light (S. Zeng *et al*, 2022). This makes the structures dynamic, as the manufactured artifacts can adapt and change their shape over time, mimicking biological processes of growth and adaptation.
Through the 4D printing technique, researchers at the Universities of Freiburg and Stuttgart have developed a process to produce self-adjusting mobile material systems using standard 3D printers. These systems can undergo complex shape changes, contracting and expanding under the influence of moisture in a pre-programmed manner. This has allowed the creation of a first prototype forearm splint designed to dynamically and self-adjust to the patient's body. This splint exploits bio-inspired design principles taken from nature, particularly the adaptive capabilities of climbing plants such as the aerial potato (Dioscorea bulbifera), a climbing plant that can climb trees by wrapping its stem around the host's trunk. In the case of the project, the splint structure is designed with fold lines that allow the material to contract or expand in response to moisture. This is achieved using a wood-polymer composite that can easily absorb and release moisture, thus activating the self-regulating mechanism. In addition to the fold lines, the splint includes swelling

and stabilizing layers that work together to create a helix-like spiral shape. On the splint surface there are pockets that help push the helix outward, generating tension in the device and allowing the structure to tighten around the arm for a customized fit. The goal of this forearm splint is to provide orthopedic support that dynamically adapts to the patient's needs without requiring manual adjustments or frequent physician visits for adaptations (T. Cheng *et al*, 2021). The potentials of this technology include the advanced creation of customized orthopedic devices, the integration of sensors for constant monitoring of the patient's condition, and the exploration of even more responsive materials, with the goal of profoundly innovating the orthopedic and medical fields, leading to significant improvements in the quality of care and the lives of patients.
Among current technological and digital innovations peculiar to bio-inspired system design, generative design represents an advanced design method that uses computational algorithms, including those based on artificial intelligence (AI), to create optimized design solutions automatically, including the use of nature-inspired geometries and topologies, innovative materials, and integration of porous structures (R. K. Luu *et al*, 2024). This automated process relies on user-defined rules, parameters, and constraints to generate different variations, allowing a wide range of possible solutions to be explored. Key features of generative design include:

- Automation: through the use of software and algorithms, generative design automates the design creation process, reducing manual work and improving the efficiency of the creative process.
- Optimization: generative design algorithms, supported by artificial intelligence, work to maximize or minimize specific design goals, such as structural strength, weight, or energy efficiency.
- Variant Exploration: generative software generates different design options based on specified parameters, allowing users to examine and choose the solution best suited to their needs.
- Rapid Iteration: with the ability to quickly explore multiple options, generative design enables fast iterations in the design development process, accelerating the design cycle.

Artificial intelligence is integrated into generative design through data-driven machine learning and data-driven optimization techniques. This allows software to learn from historic data or simulations, improving its capabilities over time and producing more effective and adaptable designs. Combined with 3D printing, generative design offers additional opportunities. 3D printing enables the production of complex, lightweight geometric shapes that would be difficult to achieve with other production methods and minimizes material use while maintaining structural integrity, which is particularly advantageous in industries such as aerospace and automotive. In addition, 3D printing enables customization and rapid prototyping, allowing the production of custom components or rapid iteration on different design variants, such as optimized cooling systems or porous structures for improved fluid diffusion. Finally, the bioinspired approach in generative design takes its cues from nature to develop innovative and functional solutions (M. S. Aziz *et al*, 2016).

A peculiar example of this innovative design approach is the case study of a 2016 project, resulting from a collaboration involving Airbus, Autodesk, The Living (an Autodesk studio) and APWorks (an Airbus subsidiary specializing in additive manufacturing), to design and manufacture a bionic aircraft partition, employing technologies such as generative design, SLM (Selective Laser Melting) 3D printing and the use of innovative materials. The use of biologically derived algorithms in this project acted on two levels of scale: macro and micro. At the macro level, an algorithm inspired by adaptive mucilaginous mold networks was used to optimize the structural arrangement, minimizing the number of connections and ensuring robust redundancy. At the micro level, a logic similar to bone growth was applied to reinforce regions subject to high stress, improving the strength of the partition (M. Gralow *et al*, 2020). SLM 3D printing technology enabled the partition to be fabricated using Scalmalloy, an innovative metal alloy composed primarily of aluminum, magnesium, and scandium (S. I. Shakil *et al*, 2023). This alloy was chosen for its ability to combine light weight with remarkable mechanical strength, making it ideal for aerospace applications where it is critical to reduce weight without compromising structural integrity. Partition geometry was optimized through Autodesk's Dreamcatcher software, which explored thousands of design layouts to maximize structural efficiency, reduced weight, airflow, and overall partition aesthetics. The use of Scalmalloy in manufacturing helped to significantly reduce the overall weight of the aircraft (about 45 percent less than traditional Airbus A320 partitions), with a direct impact on reducing fuel consumption and carbon emissions, supporting sustainability goals in aerospace (R. Deplazes, 2019). This case study demonstrates how the combined application of biological algorithms, advanced 3D printing, optimized geometry, and innovative materials can lead to highly efficient, lightweight, and sustainable solutions in advanced design, paving the way for new possibilities to reduce environmental impact and improve the performance of artifacts and technologies.

Conclusions

The innovations described are only part of an increasingly rich panorama of experiences, which emphasize a circular and bio-inspired approach to design, an integral part of a process turned toward sustainability and innovation, where biological materials and natural structures, result in a reduction of environmental impact throughout the life cycle of a product, helping to reduce the footprint that the manufacturing industry has on the environmental ecosystem. For this reason, and by virtue of the fact that design culture cannot avoid confronting the urgent and emerging issues of contemporary times, which are increasingly related to the management of production chains and the impact they have on ecosystems, the definition of a hybrid approach that can be a driving force for the evolution of the design and production process is crucial in order to be able to establish priorities from the earliest stages of design, improving production and behavioral standards in the manufacturing sector in general, shortening the supply chains through rethinking that passes through the interpretative filter of bioinspiration.

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Resumen: El diseño bioinspirado, en su acepción intencional (Pasca, 2010), por lo tanto metodológicamente, representa una innovación que ofrece una nueva perspectiva para abordar los desafíos actuales a través de la emulación de estrategias que se encuentran en la naturaleza. Hoy en día, las actividades humanas no pueden ignorar el bienestar de los humanos como íntimamente ligado al de otras especies y al planeta (Murray et al, 2022), y por tanto, la naturaleza se convierte en un modelo para el diseño de aplicaciones digitales, nuevos materiales y producción, procesos, modelos pedagógicos, formas de interacción social y la hibridación de prácticas y contextos. Este enfoque de diseño promueve la sostenibilidad, fomentando una reflexión más profunda sobre la integración entre tecnología y medio ambiente. A partir de la investigación y aplicación de la bioinspiración, numerosos estudios de casos, experiencias prácticas y análisis teóricos exploran las posibilidades que ofrece en todos los aspectos del diseño. Estos demuestran cómo este enfoque puede remodelar la dinámica de interacción entre humanos y cualquier organización, así como desarrollar soluciones innovadoras en el diseño de productos y servicios, incluso de manera especulativa. Cada vez más, la investigación científica avanzada se integra con experiencias de base, como las de la cultura maker, en respuesta a la condición de fragilidad y emergencia que caracteriza a la sociedad actual (Rawsthorn & Antonelli, 2022). En este sentido, la presente contribución pretende fortalecer la discusión sobre el papel crucial que juega la bioinspiración en el proceso de diseño, destacando la necesidad de espacios para la experimentación y la innovación. A través de un análisis de proyectos que van desde la composición de materiales innovadores para tecnologías de fabricación aditiva (Tang, M., Zhong, Z., & Ke, C., 2023) hasta el diseño especulativo, seguido de algunas experiencias de diseño y el uso de inteligencia artificial. El documento invita a la exploración continua de las riquezas del mundo natural como una fuente inagotable de inspiración y guía para un futuro del diseño más sostenible, resiliente y ambientalmente armonioso.

Palabras clave: Diseño bioinspirado - Metodología - Sostenibilidad - Emulación de la naturaleza - Aplicaciones digitales - Inteligencia artificial - Materiales innovadores - Procesos de producción - Interacción social - Economía circular

Resumo: O design bioinspirado, no seu sentido intencional (Pasca, 2010), portanto metodologicamente, representa uma inovação que oferece uma nova perspectiva para enfrentar os desafios atuais através da emulação de estratégias encontradas na natureza. Hoje em dia, as atividades humanas não podem ignorar o bem-estar dos humanos como intimamente ligado ao de outras espécies e do planeta (Murray *et al*, 2022) e, portanto, a natureza torna-se um modelo para o design de aplicações digitais, novos materiais e produção processos, modelos pedagógicos, formas de interação social e hibridização de práticas e contextos. Esta abordagem de design promove a sustentabilidade, incentivando uma reflexão mais profunda sobre a integração entre tecnologia e meio ambiente. A partir da pesquisa e aplicação da bioinspiração, numerosos estudos de caso, experiências práticas e análises teóricas exploram as possibilidades que ela oferece em todos os aspectos do design. Estes demonstram como esta abordagem pode remodelar a dinâmica de interação entre os seres humanos e qualquer organização, bem como desenvolver soluções inovadoras no design de produtos e serviços, mesmo que de forma especulativa. Cada vez mais, a investigação científica avançada integra-se com experiências de base, como as da cultura maker, em resposta à condição de fragilidade e emergência que caracteriza a sociedade atual (Rawsthorn & Antonelli, 2022). Nesse sentido, a presente contribuição visa fortalecer a discussão sobre o papel crucial desempenhado pela bioinspiração no processo de design, destacando a necessidade de espaços de experimentação e inovação. Através de uma análise de projetos que vão desde a composição de materiais inovadores para tecnologias de manufatura aditiva (Tang, M., Zhong, Z., & Ke, C., 2023) até o design especulativo, seguido de algumas experiências de design e uso de inteligência artificial, o documento convida à exploração contínua das riquezas do mundo natural como uma fonte inesgotável de inspiração e orientação para um futuro do design mais sustentável, resiliente e ambientalmente harmonioso.

Palavras-chave: Design Bioinspirado - Metodologia - Sustentabilidade - Emulação da Natureza - Aplicações Digitais - Inteligência Artificial - Materiais Inovadores - Processos de Produção - Interação Social - Economia Circular