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# BIOMIMETICS INSERTION IN ENGINEERING: A LITERATURE REVIEW
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**Abstract**. Biomimetics looks to nature for inspiration to find optimal solutions in various fields of knowledge. It makes it possible to transfer and insert biological principles as a source of inspiration for problem solving and new products in engineering. The present article aims to provide an overview of the engineering projects developed by the application of biomimetics. The method used was a literature review based on an extensive analysis of the international scientific production, and the Web of Science and Scopus databases were adopted as the basis of the research. The results of the research are described and also presented by tables. As the main contributions of the application of biomimetics in engineering projects, we highlight the fins of the humpback whale that have a protuberance, whose shape was applied as an aerodynamic profile in aircraft wings, the tests revealed that the air resistance decreased considerably, they were also tested in blades of industrial fans, proving a lower power consumption, greater efficiency in air circulation and noise reduction, the protuberances were also applied in wind turbines, causing a lower start-up speed and noise reduction. The characteristics of the Boxfish also served as inspiration for Mercedes-Benz engineers to design a concept car with optimized aerodynamic characteristics. In Japan, researchers analyzed the properties of the beak of the bird, called Kingfisher, and innovated bullet trains, managing to decrease air resistance and reduce energy consumption. The application on various surfaces of artificial denticles, produced based on sharks' skin, is another important application that brought innovation to the generation of products. Therefore, after analyzing the state of the art of biomimetics, we conclude that nature is a great source of inspiration for engineering projects, serving as the source for solutions to engineering problems. It is worth mentioning that there is still room for the application of biomimetics in different areas of engineering, being a field with exploration potential.

**Keywords:** biomimetics; engineering; nature; inspiration.

## 1. INTRODUCTION

The search for methods and solutions for product development has been of interest to professionals in the engineering area, in order to increasingly polish the methodology of this type of activity, with the intention of achieving better products, being able to gather several benefits, such as reducing costs, better satisfy customers, improve the performance and efficiency of products, resulting in advantage of the conquest of the active market. According to Cardoso (2012), project improvement is directly connected with the creativity of processes, regardless of the area of knowledge that they are inserted.

For a long time, humans have tried to imitate or even copy the valid characteristics of beings and systems in nature to improve the quality of life and enhance the efficiency of man-made systems. Biomimicry began with American researcher Major Jack Steele, who coined the term bionics, which can be summarized as the application of basic principles of nature in projects and studies related to biology, engineering, architecture, and design.

Benyus (1997) expanded the idea of the term bionics and created the term biomimicry, pointing out that, besides being an imitation of nature's forms, biomimicry means being inspired by biological organisms to carry out projects in different branches of knowledge.

Over billions of years, nature has been improving its systems with the intention of its members having more efficient and adaptive ways to survive, becoming a great source of knowledge and inspiration for professionals in various areas, especially in the engineering field. Biomimetics is a theme that has been standing out when related to the improvement of product development processes. This theme is characterized by the inspiration in forms and contents of nature to improve projects in multiple areas of knowledge (OGLIARI and MELO, 2015).

With these concepts as a basis, it can be defined that the resources of living organisms are excellent solutions to be applied in engineering problems as a source of innovation. According to Choi et al. (2012), for biomimicry to be applied in a convenient way, one must consider how the evolutionary process of the analyzed biological morphology occurred and determine the possible differences in the functionality of the biological system with the operational environment.

It is important to point out that the main methods of literature review are important for the expansion of information and knowledge of researchers and scientists in the field. By performing a well-reasoned literature review, it is possible for professionals to learn about and stay up-to-date with relevant developments in their fields. The application of a systematic literature review is widely used to reduce misunderstandings in the choice of documents to be studied on a given topic, interconnecting a certain methodological rigor with bibliometric indexes and statistical analyses (MARIANO; ROCHA, 2017).

Therefore, this article aims to provide an overview of the engineering projects developed by applying biomimetics, performing a literature review from database searches. Biomimetics and engineering were the terms used to carry out the search for international scientific productions.

## 2. RELATIONSHIP OF BIOMIMETICS WITH ENGINEERING

As the world population has grown, the consumption of products and services has also increased. An increasing amount of consumers of natural resources is worrying researchers because it is important to ratify that there are limits on our planet. The nature, when it reaches its limits, demands changes in our attitudes. With these statements as a basis, this section seeks to bring a study on some solutions developed through biomimetics and innovations inspired by nature.

Biomimetics has been present in the generation of innovative products since the time of the first recorded flights. According to Primrose (2020), a German aviation pioneer, after becoming an engineer and starting to study the flight of birds and describing the aerodynamics of the animals' wings, managed to develop a glider that could change the center of gravity by displacing its body at a certain height. However, after some time of study, in 1893, he managed to achieve flight distances of approximately 250 meters. According to Detanico (2010), it is interesting to highlight the invention of Velcro, in 1941, when the engineer George de Mestral observed how ticks stuck to clothes and dog hair, thus creating Velcro.

Aiming at improving the aerodynamic performance in low Reynolds number regime, a study on the wavy leading edge airfoil is being developed as a flow control mechanism. When preying, humpback whales (Megaptera Novaeangliae) have the ability to perform turning maneuvers, resulting from the protuberances or tubercles existing across the leading edge of their large fins (PIMENTEL; PAULA; SANTOS, 2018).

In one of their papers on whale fin tubercles, researchers Fish and Phil found that airfoils with front edges made from aerodynamic tubercle profiles decreased air resistance by approximately 40%. Another study of whales' fin profiles applied to fan blades proved to decrease energy consumption by 20 percent, improve air circulation, and make less noise. When the whales' fins were applied to wind turbines, the equipment achieved a lower start-up speed and considerable noise reduction (PRIMROSE 2020). “Figure 1" shows a humpback sperm whale with tubercles at the ends of its fins.

Figure 1. Humpback whales with tuberous fins. Source: Reproduced courtesy of Ed Lyman, Hawaiian Islands Humpback Whale National Marine Sanctuary

For the construction of a concept car, Mercedes-Benz relied on a fish called the boxfish. This study began when the research team visited the museum in Stuttgart, Germany, and observed the boxfish. Therefore, it was found that this fish moved with great efficiency and a low drag coefficient, besides its shape representing a vehicle of great comfort and space (OGLIARI and MELO 2015). Based on these characteristics, a prototype called Bionic Car was created, which was tested in wind tunnels and water tanks, obtaining good results regarding consumption and structural rigidity (MERCEDES-BENZ, 2015).

According to Primrose (2020), in Japan, researchers analyzed the beak properties of the bird called Kingfisher to apply to trains. They determined the ratios of transverse section and beak length to the overall size of the bird. From this study, several "beaks" of different shapes were developed for the bullet trains and tested in wind tunnels. The tests confirmed that the Kingfisher bird was the most efficient among those studied, achieving a decrease in air resistance and a reduction in energy consumption. “Figure 2" below shows the train inspired by the Kingfisher bird.

Figure 2. Train inspired by the bird Kingfisher. Source: https://www.flickr.com/ photos/48975388@N07/42189044932

After a long time of work, studies and tests, together with the support of the Natural Science Museum of London and NASA, the latest competitive swimwear model, called LZR Racer, was launched in 2008. Again biomimicry is present in product development, i.e. the clothes were inspired by shark skins, resulting in a product line made of very light polyurethane, manufactured by fabrics trapped by supersonic waves. Other competition clothes were manufactured with inspiration in sharks' denticles, which reduce the drag and turbulence of the body in the water (COUTO, 2009).

## 3. METHOD OF WORK

To perform the literature review on the insertion of biomimetics in engineering, two databases, Web of Science and Scopus, were selected to perform the literature search and apply the parameters. The searches and data collection in the two databases were performed between 06/10/2021 and 06/13/2021. The search in the two international databases was performed using two descriptors "biomimetics" and "engineering", with the temporal scope selected for the period 1990 to 2020.

The topics analyzed in both surveys were research areas, year of publication, types of documents published, organizations responsible for the records, and countries. Another analysis made was in relation to the papers with the highest number of citations, highlighting the number of citations, authors, and main contributions. From these bibliographic surveys it is possible to identify the core of authorship, lines of research, and references. After extracting the information, we started the analysis of the papers.

## 4. RESULTS

As highlighted in the previous section, the bibliographic information was taken from two databases, Web of Science and Scopus.

The first search was conducted on the Web of Science database with the descriptors "biomimetics" and "engineering", aiming to identify all publications with a search time-space of 1990 to 2020, obtaining 745 records in this database.

Among the Web of Science categories, materials science multidisciplinary with 161 records, material science biomaterials with 132, biomedical engineering with 98, nanoscience nanotechnology with 89, chemistry multidisciplinary with 82, applied physics with 78, engineering multidisciplinary with 63, and robotics with 62 records stand out. The first record in this database was in 1995, and 2019 was the year with the highest number of papers found in the database.

There were 441 papers in article format, 166 papers in proceeding paper format, 148 papers in review format, 11 papers in editorial material format, 5 papers in book chapter format, 5 papers in meeting abstract format, and 1 paper in correction format. The papers were written by researchers and scientists from several organizations, especially the University of Washington with 40 papers, University of Washington Seattle with 40, University of California System with 27 and Chinese Academy of Sciences with 20 written papers. The countries that stand out in this area of research are the United States with 247 entries, China with 93, England and Germany with 79.

The areas with the largest number of publications covering the topics "biomimetics" and "engineering" are from the branch of materials scince with 302 publications, engineering with 295, science technology other topics 143 and chemistry with 122 publications. It is important to highlight the main contributions of the papers with the highest number of citations. Table 1 below specifies these publications, highlighting the number of citations, authors and the main contributions.

Chart 1 - Most cited papers and their main contributions (Web of Science).

| Citations | Work | Authors | Contributions |
|---|---|---|---|
| 1266 | Molecular biomimetics: nanotechnology through biology | Sarikaya; Tamerler; Jen; Schulten; Baneyx | Presents applications of molecular biomimetics in hybrid technologies using tools from molecular biology and nanotechnology. Discusses combinatorial biological protocols, bacterial cell surface technologies that have affinities to metals. |
| 1053 | Biomedical applications of layer-by-layer assembly: From biomimetics to tissue engineering | Tang; Wang; Podsiadlo; Kotov | Displays an investigation into biomedical applications of layer-by-layer assembly. Addresses applications of layer-by-layer assembly in biomimetics, biosensors, drug delivery, protein and cell adhesion, mediation of cellular functions, and implantable materials. |

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|---|---|---|---|
| 727 | Recent developments in bio-inspired special wettability | Liu; Yao; Jiang | It highlights the application of biomimicry in special wettability, i.e. bio-inspired wettability, with a focus on self-cleaning surfaces inspired by lotus leaves, plants and insects inspired by anisotropic superhydrophobic surfaces. |
| 705 | Catalytically active nanomaterials: A promising candidate for artificial enzymes | Lin; Ren; Qu | Highlights the important role of catalytic nanomaterials in the fields of biomimetics. Describes novel applications of enzymes in biomedical diagnostics, environmental monitoring, and therapeutics. Identifies biomimetic catalysts as colorimetric probes for detection of cancer cells, nucleic acids, proteins, and other small molecules. |
| 515 | Development of nanocomposites for boné grafting | Murugan; Ramakrishna | It presents an overview of the strategy of using bone nanocomposites, bone exerts, synthetics to bone structure and development of nanocomposites from conventional monolithic biomaterials. In addition, it reports on the state of the art of nanocomposites, providing suggestions for research and new developments |

Source: the author, 2021.

The second search was conducted in the Scopus database with the same descriptors "biomimetics" and "engineering", identifying publications from 1990 to 2020, obtaining 6931 records in this database.

In Scopus, five areas stand out in relation to the publication of papers in this area, being the engineering area with 4095 publications, materials science with 3330, biochemistry, genetics and molecular biology with 1980, chemical engineering with 1693 and chemistry with 1056. The three first records in this database were published in 1992, and 2020 was the year with the highest number of papers found in the database, with 899 publications.

Regarding the type of document published, there were 4069 articles, 166 papers in conference paper format, 961 reviews, 11 book chapters, 5 editorials, 34 books, 32 papers in short survey format, among others. As for the countries with the largest number of publications, we identified the United States with 2242 papers, China with 1556, the United Kingdom with 512, and Germany with 408 publications. Regarding the affiliation of the publications, the Ministry of Education China has 227 records, the Chinese Academy of Sciences has 166, Massachusetts Institute of Technology with 144, Harvard Medical School with 107 and the National University of Singapore with 102 publications.

Similarly to what was done in the Web of Science database, during the bibliographic search in Scopus the most cited works and their contributions were also identified. Chart 2 below presents this information.

Chart 2 - Most cited papers and their main contributions (Scopus).

| **Citations** | **Work** | **Authors** | **Contributions** |
|---|---|---|---|
| 2604 | Fabrication of novel biomaterials through molecular self-assembly | Zhang | It presents the achieved advances of substances at the interface of nanomaterials and biology, including the fabrication of nanofibers for application in three-dimensional cells, in tissue engineering in the assembly of peptide nanotubes, in the assembly of electronic materials by bacterial phage selection, etc. |
| 2161 | Functional supramolecular polymers | Aida; Meijer; Stupp | It develops a study on supramolecular polymers, which have mechanical properties similar to plastics and elastomers, with great processing, recycling, and self-curing capabilities due |

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|---|---|---|---|
| | | | to their reversible monomer-to-polymer transitions. |
| 2053 | Design, fabrication and control of soft robots | Rus; Tolley | It discusses the development of robots inspired by natural systems, combining the performance of robotic systems with deformable bodies. |
| 1412 | The conflicts between strength and toughness | Ritchie | Conducts an analysis of the conflict between hardness and ductility from test examples in metallized glass, natural and biological materials, and structural ceramics. Analyzes the latest strategies to circumvent the conflict of hardness and ductility using new biologically inspired materials. |
| 1306 | Training and operation of an integrated neuromorphic network based on metal-oxide memristors | Prezioso; Merrikh-Bayat; Hoskins; Adam; Likharev; Strukov | It presents the development of circuit-based networks combining CMOS (metal-oxide-semiconductors) with adjustable terminal resistive devices for neurological analysis. |

Source: the author, 2021.

## 5. FINAL CONSIDERATIONS OF THE STUDY

Nature is one of the greatest sources of inspiration. With thousands of years of evolution, it has developed materials, structures, and mechanisms that work and that last. This evolution caused the emergence of important efficient biological mechanisms that can be linked to the most diverse areas of knowledge. The evolution of these principles led to the creation of the term biomimetics, which according to Ogliari and Melo (2015), can be used to improve projects in various segments based on nature.

Biomimetics is beneficial for numerous applications and areas, with emphasis on functionalities in engineering, materials science, chemistry, physics, biochemistry, robots, biomaterials, and others. In addition to providing models for many man-made devices, processes, and mechanisms, nature can serve as a source of inspiration and guidance for determining the feasibility of new innovations in terms of durability, efficiency, performance, and compatibility.

Based on the literature review performed in the Web of Science and Scopus databases, it is concluded that the largest number of publications is related to the area of engineering, materials science and biotechnology. The countries that stand out in relation to the publication of biomimetics related to engineering are the United States and China, and most of the documents written are in article formats. It was identified a large number of citations of works regarding the application of biomimetics for solutions and development of biomaterials.

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