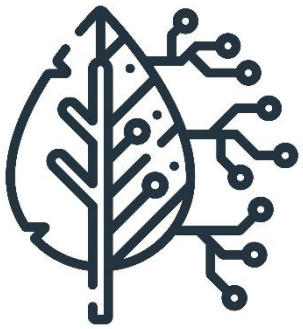
SCIENCE AND TECHNOLOGY BRIEFINGS
PARLIAMENTARY OFFICE FOR SCIENTIFIC AND TECHNOLOGICAL ASSESSMENT

Briefing 27

December 2021

N° 4762 ASSEMBLÉE NATIONALE – N° 258 SENATE

Biomimicry



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Summary

- *Throughout history, mankind has intuitively relied on nature for its innovations, drawing particular inspiration from flora and fauna. Living organisms are an inexhaustible source of inspiration at any scale, including that of an ecosystem.*
- *From aerospace to agriculture to engineering materials, biomimicry can be integrated into the innovation strategy of any industrial sector. After 3.8 billion years of evolution, natural processes have proven to be both economical and resilient.*
- *France has an exceptional biodiversity heritage. This is particularly thanks to its overseas territories and the collections of its natural history museums. Developing biomimicry will enable it to make the most of this unique pool of resources. Biomimicry is therefore also a powerful incentive for preserving biodiversity.*

Ms. Huguette Tiegna, Member of Parliament

The term "biomimicry" is derived from the Greek *bios*, meaning life, and *mimetis*, meaning imitation. Biomimetics is more than just a discipline; it is a multidisciplinary scientific approach that draws on the properties and strategies of nature and living organisms to meet engineering and innovation needs.

Throughout history, and probably even since prehistoric times, mankind has often drawn inspiration from nature and its environment to innovate. One of the best-known examples is Leonardo da Vinci drawing inspiration from birds for his famous flying machines in the 15th-century.[1]

The American inventor and engineer Otto Schmitt was the first to use the term biomimetics back in 1963. In 1997, the American biologist *Janine* Benyus took up the term and made it popular with her book entitled "*Biomimicry: Innovation Inspired by Nature*". She was the first to establish biomimicry not just as an engineering method, but as a potential strategy for sustainable, nature-friendly innovation.[2]

This approach distinguishes three levels of biomimicry depending on the source of inspiration:

1. The Organism Level, where forms, shapes, or patterns are inspired by organisms or natural elements. In this case, the aim is aerodynamics or hydrodynamics, weight reduction, strength of the final product, and so on;
2. The Behaviour Level, where functions and processes are inspired by the way an organism interacts with its environment. This is the case, for example, in areas such as chemical synthesis and designing innovative materials.
3. The Ecosystem Level, where ecosystems are used as inspiration to create more integrated technical systems.

There is also a distinction between biomimicry, which is inspired by living organisms without necessarily incorporating them into the finished product, and the approach that uses such organisms as a biological indicator or as an integral part of the technical process.[3]

Life on Earth has adapted to a wide range of physical and chemical conditions (temperature, pH, light, chemical composition, etc.) over the past 3.8 billion years. The processes and organizational patterns found in today's living organisms are resilient, economical and they result from an evolutionary balance between the survival of the species and the pressure of different environmental constraints.

It is estimated that there are between 8 and 12 million species on Earth,[4] only 2 million of which are known to date. **Thanks to its overseas territories and its exclusive economic zone (EEZ), which is the second**

largest in the world, France has a wealth of natural resources and is home to around 10% of the biodiversity described around the world.[5] In addition to this immense reservoir of open-air natural resources, France's various natural history museums also possess a wealth of knowledge with great potential. The largest collection is that of the French Museum of Natural History, which contains nearly 67 million specimens[6] and documentary archives.

The different terms of biomimicry

There are a number of terms for concepts related to biomimicry. All have the prefix *bio-* but they vary depending on the area of application. These definitions are regulated by ISO 18458:2015*. The most common terms are:

bio-inspiration: a creative approach based on observing biological systems;

biomimetics: interdisciplinary cooperation between biology and technology, or other fields of innovation, with the purpose of solving practical problems through the functional analysis of biological systems, how they are abstracted into models, and how these models are transferred and applied to provide solutions;

bionics: a technical discipline that seeks to reproduce, improve or replace biological functions with their electronic or mechanical equivalents;

nature-based solutions: actions to protect, manage sustainably and restore natural or modified ecosystems to directly address societal challenges in an efficient and adaptive manner, while ensuring human well-being and producing benefits for biodiversity.

* https://www.iso.org/obp/ui/#iso:std:iso:18458:ed-1:v1:fr

■ Biomimicry in France today

In France, the Center for Studies and Expertise in Biomimicry (Centre d'études et d'expertises en biomimétisme – Ceebios)[7] plays a central role. Situated at the interface between the industrial, academic and institutional worlds, it aims to promote a bio-inspired approach based on sustainable development, while creating methodological tools and research and development platforms. The aim is to make biomimicry a *"tool for ecological transition"* combining biodiversity, innovation and economics.[8]

Today, when a French industrial company carries out a bio-inspired project, it is most often with its own R&D teams and the scientific support of private players, generally Ceebios, or scientists under partnership, because unlike Germany, **there are almost no biomimetic engineers in France**. However, large generalist structures such as Capgemini Engineering and Akka Technologies offer bio-inspired solutions, and there are also smaller specialised companies, such as Myceco, which serves the defense sector and Operators of Vital Importance (opérateurs d'importance vitale – OIV). Other firms such as Bioxegy[9] also offer scientific support and methodology, or even project management, with access to a network of multidisciplinary researchers, ranging from biologists to engineers and designers.

Training in biomimicry is limited to that provided by the University of Pau and Pays de l'Adour (UPPA)[10] and the ENCSI Les Ateliers design school.[11] The former is a master's degree in materials science designed to train future researchers. The second, which is open to people with 4 or more years of higher education, is an institutional diploma for those in continuing education from all walks of life (and from different countries) who want to learn about bio-inspiration to enhance their professional profile and make it fit in with sustainable development.

A number of engineering schools offer introductions to biomimicry in the form of a lecture or a short series of lectures, such as the biometrics module provided by the École Polytechnique as part of its engineering degree.[12] The same goes for the École Nationale Supérieure d'Architecture de La Villette.

While it may not be necessary to offer a longer training course on biomimicry (more than one year), more training and awareness-raising activities could be beneficial. Engineers who are familiar with the bio-inspired approach would be better able to develop multidisciplinary working groups and partnerships between basic research (biology, ecology, etc.) and the R&D departments of certain industries.

■ Examples of biomimicry innovations

The rise of biomimicry in industrial society is largely attributable to military innovation. Camouflage techniques inspired by the environment and nature were developed during the First World War.[13] During the Second World War, the US Air Force based the formation of fighter planes on the flight pattern of migratory birds (the "V-shaped" flight pattern). The first bird is positioned at the front and the others in its wake benefit from free lift, which enables them to stay aloft and expend a lot less energy – this type of formation allows the aircraft to save fuel.

Airbus recently initiated a project called *fello'fly*, which seeks to apply this principle to airliners,[14] which would fly in pairs. This could reduce fuel consumption by 5-10% with an equivalent reduction in greenhouse gas emissions.[15] Airbus is working on a number of projects inspired by nature, all aimed at improving energy

efficiency during the flight phase, such as improving the wing structure or the choice of fuselage skin material.

Bionics is also an important part of bio-inspired applications and reflects this legacy of early military developments. In France, the Institute of Movement Sciences (Institut des sciences du mouvement – ISM) biorobotics team in Marseille[16] observes human and animal movements to create innovative optical sensors. This work is mainly inspired by the desert ant *(Cataglyphis bicolour),*[17] which uses the pattern of polarized light in the sky as a compass. This work is strongly reflected in the field of navigation, where the aim is to overcome the dependence on the North Magnetic Pole or the sometimes poor quality of a GPS signal. Current systems will be rendered obsolete in the coming years as the North Magnetic Pole undergoes abrupt changes due to the Earth's internal activity and becomes increasingly unstable.[18]

Biomimetics can be applied to a wide range of sectors. In the field of cosmetics, L'Oréal[19] draws inspiration from nature to address specific issues (e.g. protecting the skin against UV radiation) or internal sustainability objectives, such as optimising water resources.

The agricultural sector is exploring plant bio-control using pheromones to avoid the use of pesticides. The French group M2i reproduces pheromones in the laboratory to create "sexual confusion" that disrupts communication between males and females of invasive species and prevents them from reproducing without the need for biocides. These pheromones can also be used to repel unwanted species, or to attract them to another location.

The processes used in anaerobic digesters aim to reproduce the principle of animal digestion. Since termites and cows have the best digestive "efficiency", the INRAE/LBE teams are studying their respective intestinal microbiota to improve the efficiency of methanizers.

On the borderline between biomimicry and biotooling, nature provides non-invasive biological indicators. The electricity transmission system operator RTE is seeking to monitor how submarine cables connected to offshore platforms impact the marine ecosystem. The OASICE project (*cOquilles Saint-jAcques outil de Surveillance de l'Impact des Câbles Electriques*)[20] uses scallops to monitor the impact of electrical cables by observing the striation pattern on their shells to see if they are under stress – potentially caused by the presence of the installation.

Germany, a European leader in biomimicry

Despite recent progress, France is considered to be lagging behind other countries when it comes to biomimicry.

In Europe, Germany is leading the way with its Biokon network, which brings together biomimicry experts from all over the country. This network encourages the development of multidisciplinary projects and strengthens the links between basic research and applied research. Support from the Federal Government, in particular the BMBF (the German Federal Ministry of Education and Research), facilitates the development of strategies and the securing of medium-term funding, particularly in the field of materials and bionics. Biomimicry projects can benefit from the federal *High-Tech Strategy 2025 (HTS 2025)* plan, which provides €1 billion in funding over 10 years, alongside funding from the national laboratories' own funds.

Sustainable biomimicry for businesses and biodiversity

Today, a great deal of companies are turning to biomimicry and using it to improve their Corporate Social Responsibility (CSR)[21] practices and to achieve their sustainability targets. **Clear criteria should be put in place to validate this type of approach**, in accordance with ISO 18458:2015 and its sustainability criteria. A bio-inspired technology should meet a high standard of Life Cycle Assessment (LCA) and be part of a strong biodiversity protection policy. **Working with living organisms means placing ethics at the heart of the process.**

For example, architecture is often inspired by nature to reproduce forms or structures for aesthetic purposes but rarely for sustainable development purposes. Yet the building sector has great ecological potential, and nature can be used to help design more energy efficient and resilient buildings. The sector needs to move further in this direction.

Also, according to Emmanuel Delannoy, Associate Senior Advisor at Pikaia, biomimicry is a way of *"explaining biodiversity to companies"*. Considering flora and fauna as strategic resources as well as a common good to be preserved is in line with the permaculture approach.[22] Inspired by the principles of permaculture,[23] it uses so-called "ecosystem" biomimicry to rethink the economy.

At the same time, some scientists, such as Yvon Le Maho,[24] are campaigning for biomimicry to be used as a means of opening up research to the diversity of living organisms and their potential applications. The issues of animal experimentation must also be taken into account in this respect.

Thus, by showing that living organisms are a major source of ideas and innovations, biomimicry plays a major role in the fight against the collapse of biodiversity. For the past several decades, scientists have been warning that biodiversity, both terrestrial and marine, is collapsing at an "unprecedented and accelerating" rate.[25] It is now estimated that one in eight birds and one in four mammals are threatened with extinction. It is also estimated that the biomass of flying insects[26] and arthropods[27] has decreased by around 70% in the last few years.

In 2019, the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) estimated that "*approximately 1 million animal and plant species are now threatened with extinction, and many of these are likely to become extinct in the coming decades, a level never before seen in human history.*"

The main cause is human activity - including climate change. There is still room for action, especially in terms of raising awareness among the population and economic actors. By making any species or ecosystem a potential part of the solution to our problems, biomimicry can make a significant contribution to this collective awareness. In any case, it is a powerful incentive to work together to protect biodiversity.

The Office's websites:
http://www.assemblee-nationale.fr/commissions/opecst-index.asp
http://www.senat.fr/opecst/

Recommendations

1. In order to give a decisive impetus, **organise a Biomimicry Conference** under the joint supervision of the Ministries for Ecological Transition, the Sea, Agriculture and Food, Higher Education, Research and Innovation and the Economy, Finance and Recovery.
2. **Organize this Conference during the French Presidency of the European Union**, making biomimicry a focus for the development of marine, polar and overseas biodiversity.
3. At the end of this Conference, **establish an action plan for the biomimicry sector** in order to define the means and elaborate the actions to be carried out in the short and medium term.
4. **Appoint a Biomimicry contact person** within **each innovation department of the ministries concerned**.
5. **Establish a biomimicry charter** together with the main players in biomimicry to ensure that all projects are part of **an overall ethical approach that respects the principles of protecting nature**.
6. This charter will be used to **establish a label recognising companies** that are committed to ethical biomimicry.
7. **Support basic research** in biology and ecology, both in the laboratory and in the field, and **preserve and make better use of natural history museum collections** to provide a catalogue of resources that can be used in engineering.
8. **Encourage multidisciplinary training** for engineers, architects, designers and biologists, including developing certification for continuing education.
9. **Specifically reference bio-inspired projects in calls for proposals.** This will provide a better record of the industry's activities in France.
10. **Strengthen French-German partnerships** as part of the French Presidency of the European Union in 2022. It may be necessary to consider creating a European biomimicry structure in order to pool resources and actions.

Persons consulted

Ms. Kalina Raskin, CEO and co-founder of the cooperative society Ceebios

Ms. Chrystelle Roger, CEO of Myceco

Mr. Stéphane Viollet, Research Director and head of the Biorobotics team at the Institut des Sciences du Mouvement Etienne-Jules Marey (Etienne-Jules Marey Institute of Movement Sciences) (CNRS/Aix-Marseille University)

Mr. Jérôme Casas, honorary member of the Institut Universitaire de France (Academic Institute of France) and Professor at the Institut de Recherche sur la Biologie de l'Insecte (Insect Biology Research Institute) (CNRS/University of Tours)

Mr. Emmanuel Delannoy, Associate Senior Advisor at Pikaia

Mr. Yvon Le Maho, member of the French Academy of Sciences and Emeritus Research Director at the Institut Pluridisciplinaire Hubert Curien (Hubert Curien Pluridisciplinary Institute) (CNRS/University of Strasbourg)

Ms. Annabelle Aish, Head of the Bioinspire-Muséum project at the French Museum of Natural History

Mr. Jian-Sheng Sun, Professor and Director of the Department of Living Adaptation at the French Museum of Natural History

Mr. Yves Bréchet, member of the French Academy of Sciences, Professor at the Institut Polytechnique de Grenoble (Grenoble Polytechnic Institute) and Scientific Director of Saint-Gobain

Mrs. Florence Dufrasnes, Head of Space Systems Technical Strategy, R&D/T, IP & Spectrum Management at Airbus

Ms. Delphine Bouvier, International Director of Green Sciences Transition at L'Oréal

Mr. Pierre Meyer, Director of Industrial Partnerships in the European Industrial Affairs Department at RTE

Mr. Sidney Rostan, Founder & CEO of Bioxegy

Ms. Geneviève Sengissen, Head of Continuing Education at the École Nationale Supérieure de Création Industrielle – Les Ateliers (National School of Industrial Design)

Mr. Emmanuel Chiva, Director of the Agence de l'Innovation de Défense (Defense Innovation Agency)

Colonel de Peyret, Director of the *Battle Lab Terre project* at the Ministère des Armées (Ministry for Armed Forces)

Ms. Natasha Heil, researcher at the Laboratoire de Modélisation pour l'Assistance à l'Activité Cognitive de la Conception (Modelling Laboratory for the Assistance of Cognitive Design Activity) at the Unité Mixte de Recherche Modèles et Simulations pour l'Architecture et le Patrimoine (Joint Research Unit Models and Simulations for Architecture and Heritage) (CNRS/Ministry for Culture)

Mr Olivier Guerret, Co-Founder of M2I Life Sciences

Mr. Jean-Philippe Steyer and Mr. Jean-Jacques Godon, Research Directors at the Environmental Biotechnology Laboratory of the French National Research Institute for Agriculture, Food and the Environment (INRAE – Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement)

Interviews with German actors:

Mr Olivier Schwarz, Professor at the University of Siegen, Head of the Biomimetics in Medical Engineering Department at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA

Mr. Peter Fratzl, Professor and Director of the Biomaterials Department at the Max Planck Institute

Members of the BMBF (German Federal Ministry for Education and Research):

Ms. Simone Flach (Referat 224 – "Cooperation with Europe and Israel" Department)

Ms. Christine Ernst and Mr. Tom Wünsche (Referat 521 – "Future of Work and Value Creation; Industry 4.0" Department)

Ms. Silvia Ebert and Mr. Olaf Rotthaus (Project Operator for PTJ-*Projektträger Jülich*)

Ms. Rosita Cottone (Referat 523 – "Innovative Materials – Batteries" Department)

Références

[1] *In 2019, an exhibition on "Biomimicry – from Leonardo da Vinci to the present day" was organised with the support of the CNRS:* https://cesr.cnrs.fr/actualites/actualites-scientifiques/exposition-sinspirer-du-vivant-le-biomim%C3%A9tisme-de-l%C3%A9onard-de

[2] *In her famous Ted Talk video (viewed over 1.5 million times to date), Janine Benyus encourages the audience to "imagine designing spring" and to consider all the processes involved in highlighting the organisation and efficiency of Nature in action:* https://www.ted.com/talks/janine_benyus_biomimicry_in_action?language=fr#t-84002 .

[3] *Biomimicry can be inspired by both flora and fauna, and the latter has long been a source of inspiration, particularly for the pharmaceutical sector. It is estimated that more than half of today's medicines are inspired by or derived from natural compounds, mainly plants.*

[4] https://inpn.mnhn.fr/docs/communication/livretInpn/Livret-INPN-especes-2021.pdf

[5] *Some additional figures: France is home to 10% of the world's 2 million known species, i.e. approximately 200,000 species. Half of these are found in mainland France and the other half overseas. 80% of these species are said to be "continental" (terrestrial or freshwater species), despite the fact that France has the world's 2nd largest EEZ. However, there is a bias here, as collecting information on marine biodiversity is much more complicated than terrestrial or freshwater biodiversity, with many species still to be discovered. Finally, 11% of these species are endemic, which means that they only exist on French territory (particularly in the Overseas Territories). Therefore, we, as French citizens, are the only people who can guarantee their survival and conservation.*

[6] https://www.mnhn.fr/fr/collections *With 400 years of history, the collections at the National Museum of Natural History in Paris are among the most unique in the world. They contain fossilised and natural specimens of flora and fauna, as well as documentary archives, which make them a rich source of information.*

[7] https://ceebios.com/

[8] https://ceebios.com/wp-content/uploads/2021/11/Ademe-Myceco-Ceebios-Externalites_Positives_Biomimetisme-SyntheseComplete-web3.pdf

[9] https://www.bioxegy.com/

[10] https://www.technopolepaysbasque.fr/fr/4-sites-technopolitains/id-ocean/actualite/biomimetisme-luppa-creee-un-master-en-materiaux-bio-inspires.html

[11] https://formation-continue.ensci.com/developpement-durable/nature-inspired-design

[12] https://synapses.polytechnique.fr/catalogue/2021-2022/ue/478/MEC574-biomimetisme?from=D1

[13] *More recently, the continuous track system of tanks (also known as caterpillar tracks) is inspired by the way a caterpillar moves, and drone swarms mimic the collective intelligence of wasp or hornet swarms.*

[14] https://www.airbus.com/innovation/future-concepts/biomimicry/fellofly.html *The lead aircraft's engines produce a vortex in their wake. The follower aircraft then flies in the air upwash of the lead aircraft's wake and benefits from a lift effect known as wake-energy retrieval, and this limits the thrust of its own engines. For fello'fly operations, the two aircraft should be about 3 km apart to reap the full benefits of wake-energy retrieval while maintaining a safe distance between them.*

[15] *According to Airbus, saving one tonne of fuel is equivalent to saving 3 tonnes of* CO_2 *emissions (*https://www.lefigaro.fr/societes/comment-airbus-s-inspire-des-oiseaux-migrateurs-pour-economiser-du-carburant-20200103*).*

[16] *The biorobotics team is headed by Stéphane Viollet, Research Director at the CNRS. His work aims to understand how natural sensorimotor mechanisms work and then to implement them in robotics. When confronted with a real environment, they are able to support or disprove what we believe to have understood in animals. This will allow us to improve our understanding of these sensorimotor mechanisms through iteration (https://ism.univ-amu.fr/fr/biorob).*

[17] https://www.science.org/doi/10.1126/scirobotics.aau0307

[18] *The North Magnetic Pole – which is not to be confused with the Geographic North Pole (or Terrestrial North Pole) - depends on the currents induced by the movements of the Earth's core, which is composed of liquid iron. Historically located in Canada, it has been moving towards Siberia at a rate of 40 km/year since the 1990s. Being a natural element, the magnetic field cannot be scrambled, which is why a large part of the world's navigation systems, including those of NATO for example, rely on the World Magnetic Model, which is becoming increasingly inaccurate and needs to be updated regularly to reflect these movements.*

[19] *The only cosmetic company to be interviewed for this briefing.*

[20] https://www.rte-france.com/nos-engagements/la-mer-quand-lavenir-passe-par-le-dialogue

[21] *According to the French Ministry of the Economy, this is "the contribution of companies to the challenges of sustainable development" and according to the European Commission "the voluntary integration by companies of social and environmental concerns into their business activities and their relations with stakeholders".*

[22] https://www.pikaia.fr/vos-enjeux/permaeconomie/

[23] *Permaculture is an agricultural concept based on three main principles: care for the planet, care for people and fair share.*

[24] *Yvon Le Maho is a member of the French Academy of Sciences and was one of the first researchers to observe penguins in Antarctica in their natural environment. This technique led him to discover antimicrobial proteins, which allow penguins to keep fish in their stomachs at 37°C without decomposing or deteriorating.*

[25] https://ipbes.net/news/Media-Release-Global-Assessment-Fr

[26] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0185809

[27] https://www.nature.com/articles/s41586-019-1684-3