Santander X Innovation Xperts

Biomimetics:

sustainable and regenerative innovation inspired by nature

JANUARY 2023

By Santander

Table of contents

01 Introduction

The current panorama—unsustainable and degenerative by definition[1,2,3] (Figures 1 and 2)—requires every possible and feasible effort to evolve towards sustainability and regeneration. The climate emergency, biodiversity loss, global warming, biochemical fluxes of phosphorus and nitrogen, pollution, loss of fertile soil, deforestation, ocean acidification, and other dynamics that add to prevailing socioeconomic inequalities are just some of the evidence that corroborates the seriousness of the current situation. The loss of ecosystem services[4] and the consequences of this unbalanced planetary state due to human actions significantly affect not only the daily life of society and its survival, but also the international economy in a globalized world. The environmentalist cause is no longer just a matter for scientists and ecologists and is being included in the business and economic community[5,6] as a fundamental priority that requires immediate action. In this context, the development of new creative approaches has the potential to radically transform the current direction of society in order to guarantee our survival in modern culture as we have known it.

---

1. Reed, Bill (2007). Shifting from sustainability to regeneration. Building Research & Information,35:6,674 — 680.

2. Bermejo, R. (2011). Manual para una economía sostenible. Ed. Catarata.

3. IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, y col. (eds.)]. Cambridge University Press. In Press.

4. IPBES (2019), Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Brondízio, E. S., Settele, J., Díaz, S., Ngo, H. T. (eds). IPBES secretariat, Bonn, Germany.

5. World Economic Forum (2007-2020), Global Risks Reports.

6. OECD (2019), Biodiversity: Finance and the Economic and Business Case for Action, report prepared for the G7 Environment Ministers' Meeting, 5-6 May 2019.

Figure. 1

Graphical view of degenerative systems and their evolution to regenerative systems.

Trajectory of environmentally responsible design

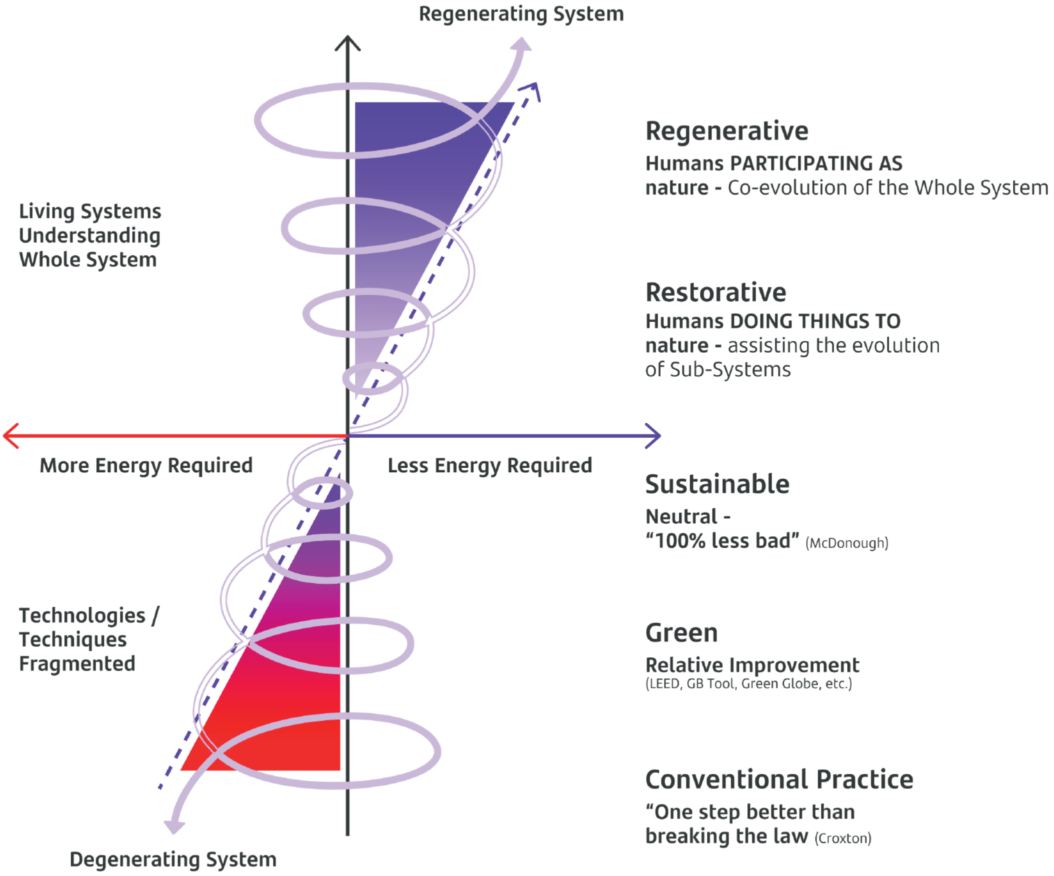


Figure. 2

Planetary limits[7].

Below boundary (safe)
In zone of uncertainty (increasing risk)
Beyond zone of uncertainty (high risk)

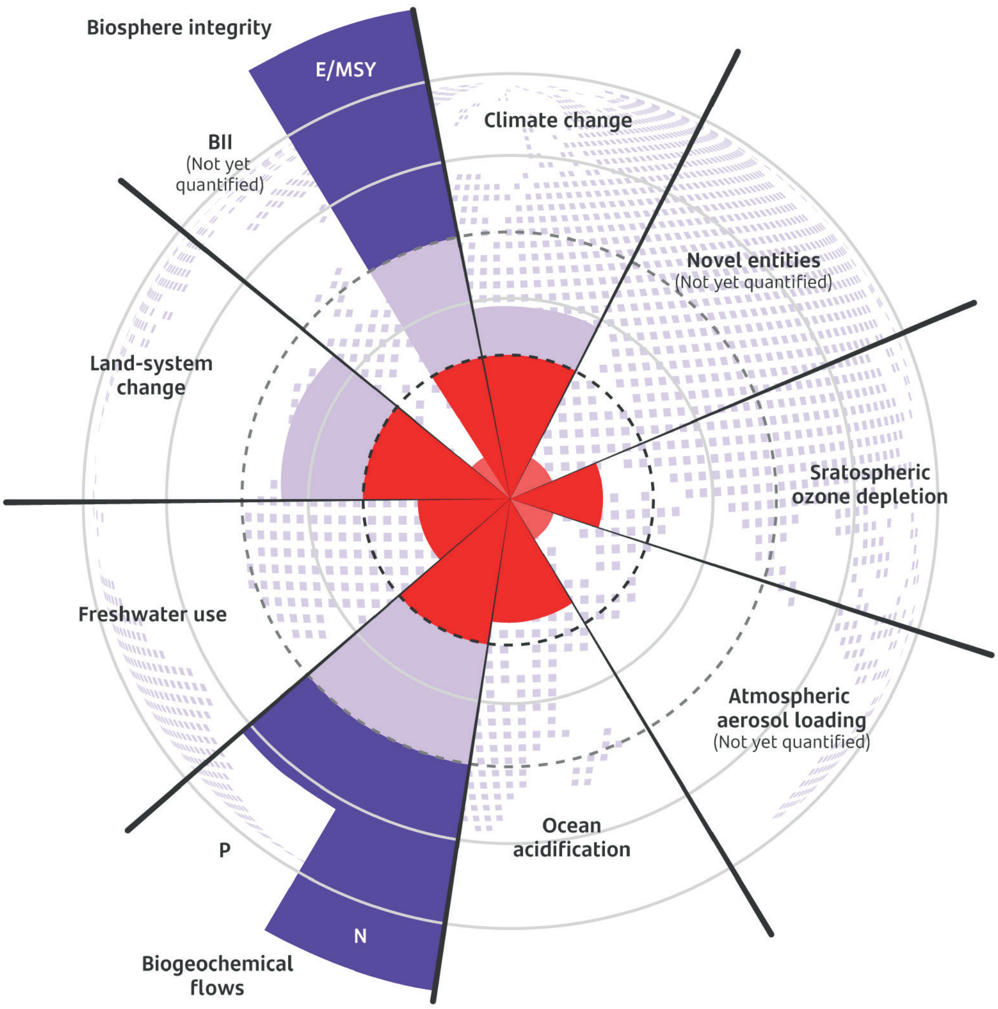


Figure 2: Designed by Azote
7. Stockholm Resilience Center, based on analysis by Persson et al. (2022) & Steffen et al. (2015).

The Holocene, a geological period of stability, has provided a predictable climate which favored the settlement and development of cities, an agriculture designed based on annual seasons and, in short, culture as we know it. All these stable, reliable, and predictable dynamics that have created the modern world are being, for part of the scientific community, replaced by a new geological Era, known as the Anthropocene (the Age of Man). This term was coined by the American limnologist Eugene F. Stoermer and popularized in the early 2000s by the Dutch Nobel laureate Paul Crutzen. This new period encompasses the time span when human activities began to cause biological and geophysical changes on a global scale[8].

Against this backdrop, global governance has been galvanized into action, as reflected by the creation of the United Nations Sustainable Development Goals[9] (SDGs) in 2015. In addition, numerous innovations still to be developed are emerging in all sectors of society, from industry to academia, from NGOs to corporate governance and finance. There have been publicized advances in renewable and decentralized energies, in mobility (electric, hydrogen, shared, cycling, public, etc.), in agriculture (organic, regenerative, local, certified, vegan, waste-free food, etc.), in architecture (bioclimatic, vernacular, local, smart, etc.), in new materials (such as biomaterials) and even in the economic system itself (with exciting and nascent models, like the circular, collaborative or doughnut economies[10], to cite a few examples). The development and implementation of these innovations on a global scale have the potential to help humanity adapt to our new scenario.

This paper aims to inform how biomimicry can feed into this process of finding a new equilibrium, and does so in four sections that seek to answer: **what** biomimicry is in the broader framework of bioinspired innovations; **why** we think it is going to be important not only in the future, but already in the present; **where** it is making disruptive impact so far (and what findings we can take from it); and finally, **how** it might move forward in the medium-term.

---

8. Wikipedia. Anthropocene (n.d.). Retrieved August 25, 2022 from: https://en.wikipedia.org/wiki/Anthropocene.

9. United Nations. (n,d.). Sustainable Development Goals. https://www.un.org/sustainabledevelopment/es/.

10. Raworth, K. (2018). Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist. Paidos. 379.

Nature has solved most of the challenges faced by humans (and many more) and can guide, from a systemic perspective, the search for innovative solutions. The private sector and society as a whole can certainly learn from living organisms and systems thanks to the refinement of evolution, which ways to reach a high level of efficiency. In every industrial sector, nature can contribute to the improvement of processes and systems.

The private sector and society as a whole can certainly learn from living organisms and systems thanks to the refinement of evolution, which ways to reach a high level of efficiency. In every industrial sector, nature can contribute to the improvement of processes and systems.

02 Bioinspired innovation: the initial concept

Throughout the history of mankind from the 18th century to the present day, innovation shows us the way to reach some of the necessary solutions that have made it possible to adapt to new circumstances (Figure 3). In the latest wave of innovation, which began around the turn of the millennium, new concepts emerged such as sustainability, the systemic vision, and biomimicry. This final discipline, whose name comes from the Greek: βιοζ (bios, meaning life) μιμησζ (mimesis, meaning to imitate or emulate), seeks to understand how living organisms have developed over the course of evolutionary processes, as well as the structures, forms and materials adapted to their environment in order to survive and endure. Biomimicry demonstrates a way for us to create new bio-inspired technologies, while aiming to change the relationship of the human species with nature.

Figure. 3

Waves of innovation from the 18th to 21st century.

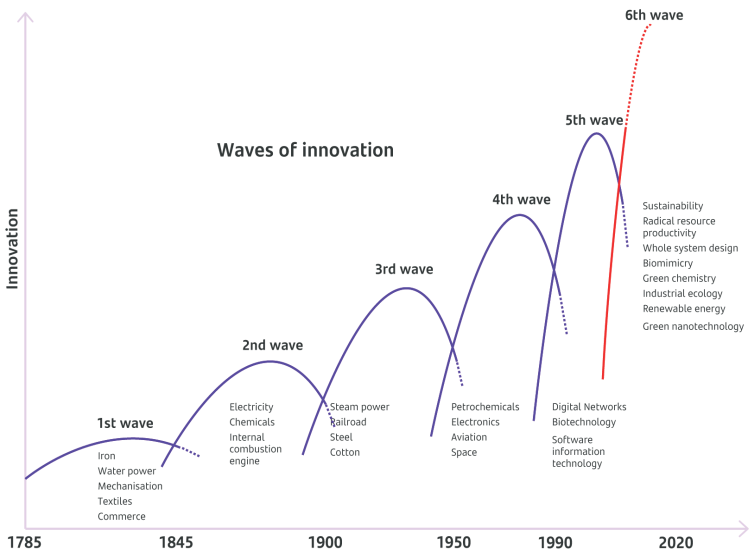


Figure 3. Hargroves K. y Smith M. (2005) The Natural Advantage of Nations: Business Opportunities, Innovation and Governance in the 21st Century. Earthscan/James and James Publishing, London.

Nature has been finding innovative, sustainable, and regenerative solutions for 3.85 billion years, and therefore we could safely say that innovation is one of the oldest processes on planet Earth. In order to search more effectively for answers to human problems, we must start increasing the attention lost towards biology, overcoming the reigning paradigm that views nature just as a provider of resources, a food storehouse or a waste repository. In doing so we will avoid the reduction of its resilience and the loss of its natural capital, which are critical aspects for planetary stability and, logically, its inhabitants.

Engineering vs. biology in the search for efficiency. Biology frequently employs a few simple materials arranged in a particular way, making use of passive methods of sensing or control. Conversely, engineering in its classical approach, tends to consume more energy and often achieves less efficient results. This is not surprising, since evolutionary forces have operated for millions of years, while engineering, from the formal perspective of using physical principles and mathematical analysis combined with functional design, is a relatively modern practice of only a few hundred years old. Today's research, measurement and imaging tools allow us to study how nature has developed solutions to the challenges it faces. These insights into mechanisms, forms, processes, and materials are already inspiring research and academia, driving innovative and new approaches to a host of design problems in more than 40 industrial sectors[11] (covering areas such as architecture, engineering, soil regeneration, circularity of materials and energy flows, solar energy harvesting, among others).

Bioinspired design is a term that is generally accepted as a catch-all category for design and engineering approaches that use biology as a resource to find solutions and that require an understanding of the natural world. However, it is relevant to mention that there are other bioinspired approaches that are merely evaluative and not regenerative[12]. **While biomimetics is a type of bioinspired design, not all bioinspired design is biomimetic.** There are three terms that are used to describe the ways in which biological systems and human designs can be related.

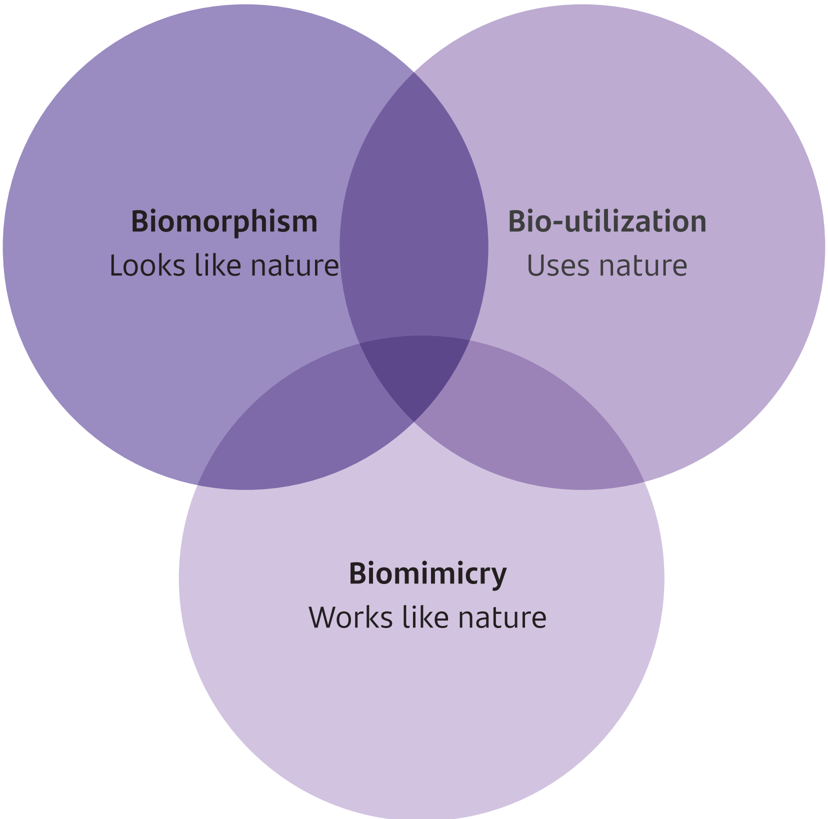
---

11. Smith, C y col. (2015). Tapping into nature. The future of energy, innovation and business. Terrapin Bright Green LCC, NY. Recuperado el 20 de julio de 2022 en: www.terrapinbg.com/publications.

12. Vallet, F., y col. (2013). Using eco-design tools: An overview of experts' practices. Design Studies 34(3): 345–377. Retrieved August 30th, 2022 at: https://www.webofscience.com/wos/woscc/full-record/WOS:000318261500004?SID=EUW1ED0E734Mtk2fanAKFNb6cmO3I.

Figure. 4

Forms of bioinspiration.



- **Biomorphism.**

Within bio-inspired design, this refers to **designs that visually resemble elements of nature** (as we find in fish-shaped buildings, clothes with butterfly shapes or prints, or cars painted with camouflage). Biomorphic designs can be very beautiful and beneficial, in part because humans have a natural affinity for nature and its forms. However, **it is important to understand that looking like nature is not a reliable indicator of biomimetic design,** since a **biomimetic design may or may not look anything like the organisms that inspired it.**

Figure 4: Manuel Quirós

- **Bioutilization.**

This refers to the use of biological material or living organisms for a particular design or technology, such as using bacteria to produce bricks[13], using fungal mycelium to make vegan leather[14], bamboo as a bicycle frame, or a living wall of plants to help clean the air in an office. The use of living organisms or parts of it can be very useful, and so biomimetic designs sometimes incorporate bioutilization. Nonetheless, **just because a design employs a living organism or uses a natural material does not mean that the it is biomimetic.**

- **Biomimicry.**

The distinguishing feature of biomimicry is the study and emulation of functional strategies to create sustainable and regenerative solutions. In addition, a determining factor that differentiates biomimicry from other bio-inspired design approaches is the emphasis on learning and emulating the regenerative solutions that living systems have for specific functional challenges.

13. https://biomason.com
14. https://biomason.com

03 The rise of bioinspiration for business

More than a decade ago, the Financial Times published a special report[15] stating that many companies outside the agriculture, food and pharmaceuticals sectors seemed to have few links with the natural world. As we move towards sustainable development, many large corporations and public agencies have implemented "green" programs, but the conservationist approach is far from entrenched. However, this perception may be changing, as many companies are realizing the financial benefits that preserving natural ecosystems can provide, joining existing efforts to protect and conserve the environment. Since then, studies, analyses and position papers have continued to be published, which have only confirmed and expanded on that reference work of 2010, whether in the realms of academia[16], business[17], design in Western countries[18] or innovation policies for middle-income nations[19].

One of the maxims in living systems is that they optimize rather than maximize as we humans do[20], thus showing us a sustainable and regenerative model. Here, biomimicry can provide a critical bridge between the private sector and nature. By increasing efficiency and reducing costs, bio-inspired solutions can enable us to improve productivity and efficiency, and ultimately the standard of living, all while preserving biodiversity.

---

15. Special Report: Sustainable Business Financial Times (London): 4 Oct. 2010: 1-4.

16. Biomimetics in 2019: Academic Progress Report. 2020. Available at: https://www.isbe-online.org/?ui=english&mod=info&act=view&id=4046.

17. Bonime, W (2020). Biomimicry: Using Nature's Perfect Innovation Systems to Design the Future. Forbes.

18. The State of Nature-Inspired Innovation in the UK. Systematic Insights into The State of Nature-Inspired-Innovation in the UK – New Report Launch from Biomimicry Innovation Lab in collaboration with the Nadathur Group. 2021. Available at: https://bootcamp.uxdesign.cc/the-state-of-nature-inspired-innovation-in-the-uk-186e10379ad3.

19. Nature-inspired innovation policy: Biomimicry as a pathway to leverage biodiversity for economic development. Lebdioui, A. (2022). Ecological Economics, Volume 202, December 2022.

20. Exploring the way life Works. The Science of Biology. Hoaland, M.B., Dodson, B. & Hauck, J. (2001). Jones & Barlett Publ. Intnal, Canada. 376 pp.

This statement is reflected in the evolution of the number of patents containing the terms biomimicry, bionics and biologically inspired (Figure 5), a trend similar to that observed in the analysis of the number of scientific publications, where an intense and sustained growth is observed (Table 1). This evident upward trend illustrates that the discipline and related bioinspired approaches are clearly maturing.

Figure. 5

Evolution of the number of patents containing the terms "bionic", "biomimetic" or "biologically inspired"

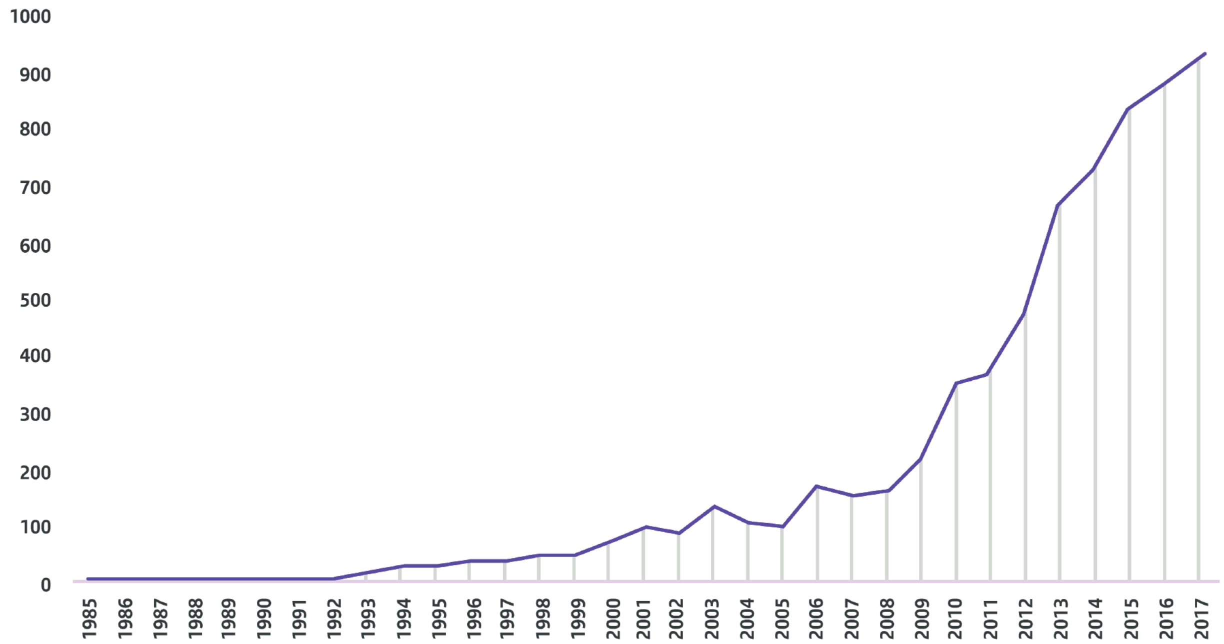


Figure 5: Helms, M. (2018). Deep Biologically Inspired Design: Overcoming Skepticism and Driving IP Creation. Available at: https://patternfoxconsulting.com/bio-inspired-design-overcoming-skepticism/.

Table. 1

Number of biomimetic research articles retrieved in WOS (Web of Science).

	2017	2018	2019
Biomimicry	161	142	198
Biomimetic	3179	3554	3609
Biomimetics	1704	1771	1354
Biomimic	18	45	28
Bio-inspired	1483	1511	1616
Bioinspired	1081	1199	1414
Bionic	542	605	696
Nature-inspired	392	461	516
Biologically inspired	442	401	368
Bioinspiration	51	59	74
Bio-inspiration	36	33	35
Biomimicking	35	41	52
Subtotal	9124	9822	9960
Final number	**6990**	**7504**	**7915**

Note: The final number is lower than the subtotal due to duplicate articles tracked with different keywords.

An interesting study by the Fermanian Business & Economic Institute (FBEI) of Point Loma Nazarene University[21] states that the influence of biomimicry and bioinspiration in some large industries could generate a considerable impact on GDP and employment in the United States: approximately $425 billion over the next two decades (Figure 6). In addition, the reduction in economic losses from natural, energy, mineral and forest resource depletion and CO2 pollution would also be significant.

Table 1: Biomimetics in 2019: Academic Progress Report. 2020. Available at: https://www.isbe-online.org/?ui=english&mod=info&act=view&id=4046.

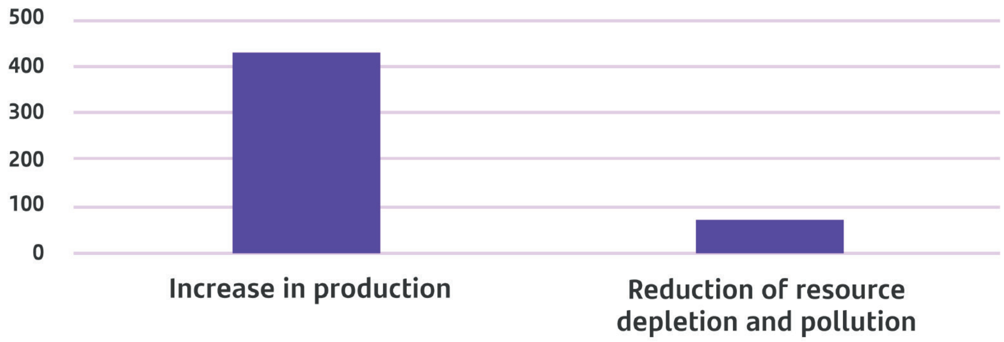
21. Bioinspiration: an economic progress report (2013). The San Diego Zoological Society, the Fermanian Business & Economic Institute, Point Loma Nazarene University. 44 pp.

According to a recent Swiss Re study published in April 2021[22], global GDP could stop growing by between 4% (if all the goals set by the Paris Agreements are met and the temperature increase is less than 2°C) and 18% (with 3.2°C or more) between now and 2050 due to climate change. Assuming a capacity of biomimicry to reduce these costs by a modest 10%, the added value for the whole world would be in the hundreds of billions of dollars. The number of jobs linked to the discipline could be substantial, reaching 1.6 million workers, according to the same FBEI report, which in some cases would correspond to replacements of jobs linked to older products and technologies, but in many cases would correspond to completely new markets.

The report also points out that this impact could rapidly spread on a global scale, as numerous companies in the UK, continental Europe, Africa, and Australia are already active in the field. Assuming a GDP share of 1% (lower than the 1.4% calculated for the U.S. and with lower proportions for less technologically advanced nations) biomimicry could add around $1.6 trillion to total global output by 2030[23].

Figure. 6

Estimated impact of biomimicry on the U.S. GDP by 2030 according to FBEI (in billions of USD)



22. Swiss Re Group. World economy set to lose up to 18% GDP from climate change if no action taken, reveals Swiss Re Institute's stress-test aalysis. 2021. Available at: https://www.swissre.com/media/press-release/nr-20210422-economics-of-climate-change-risks.html.

23. Bioinspiration: an economic progress report (2013). The San Diego Zoological Society, the Fermanian Business & Economic Institute, Point Loma Nazarene University. 44 pp.

Figure 6: FBEI

Table. 7

Estimated impact on sales of biomimetic products and services in the North American market by industry sector according to FBEI.

Bioinspiration to Influence Many Industries by 2030 Project percent of industry sales

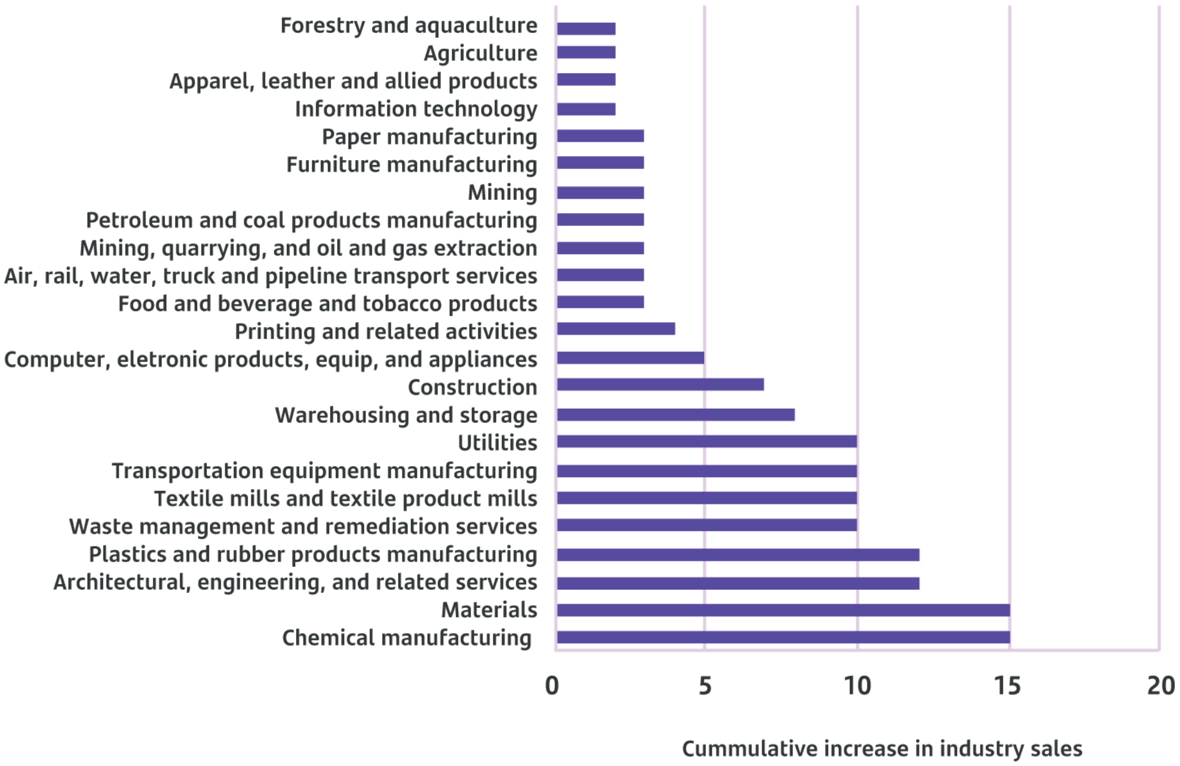


Table 7: FBEI.

04 Success stories and future opportunities

It would be practically impossible to attempt to address all or even a significant number of success stories already operating in the biomimetic/bio-inspired solutions market. The number of designs is growing at a dizzying pace, with examples ranging from the most essential applicability in transportation, energy, construction, or education itself, to more sophisticated and complex examples such as robotics, sensorization, innovation in materials, optics, structural rearrangement, color physics or computation itself.

In order to guide our attention and open the field to new innovations, we mention here some innovations already in the market which are particularly useful to extract: (1) key sights and (2) noted opportunities for the advancement of this approach (Table 2).

Bullet Train

The redesign of the Japan Railway's 500-series Shinkansen bullet train[24,25,26] —used in both outreach and teaching—is a good example of biomimetics with a whole scientific basis behind it, as well as a bit of luck. Before it was redesigned, the movement of the train, at speeds of up to 321 km per hour, caused air pressure to build up in the tunnels, generating a sonic boom every time the train left one. This phenomenon affected people living up to 25 km away, and for a time the project was not allowed by the Japanese authorities.

---

24. Zygote Quarterly Journal. Issue 2 (Spanish edition). Pag. 10-35. Retrieved August 30th, 2022 at: https://zqjournal.org/editions/zq02ES.html.

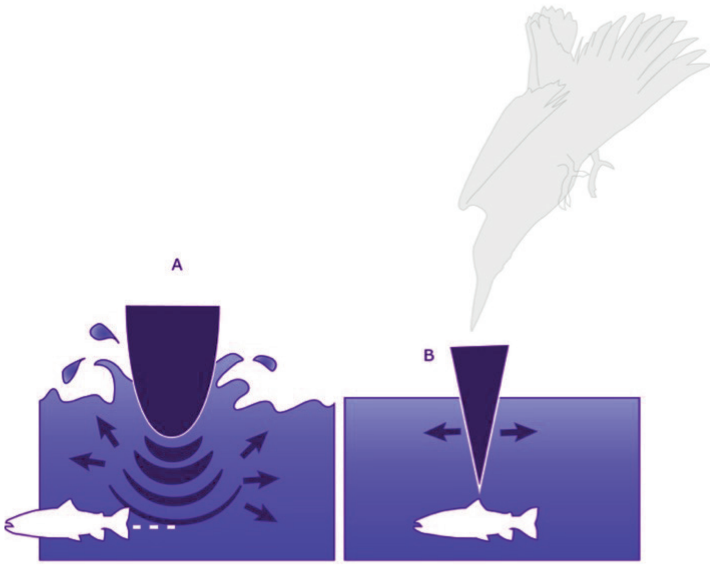
25. Benyus, J. M. 2009. Biomimicry in action. TEDGlobal, Oxford, England. Retrieved August 30th, 2022 at: https://www.ted.com/talks/janine_benyus_biomimicry_in_action?language=en.

26. Quirós, M (2014). La velocidad, el ruido y las aves. Retrieved August 30th, 2022: https://natureinspireus.wordpress.com/2014/01/29/la-velocidad-el-ruido-y-las-aves/.

The engineers in charge of redesigning the train head could not find a solution until Eiji Nakatsu, chief engineer and amateur ornithologist, was inspired by the beak of the kingfisher (Alcedo atthis), a bird that dives headfirst into water, a medium denser than air, without splashing, allowing it to hunt successfully (Figure 8). After redesign, the result was not only quieter than the original model, meeting the project's objective, but also 10% faster, saving 15% in electricity. Today all "misnamed" high-speed duckbill trains follow this inspiration dating back to the 1960s.

Table. 8

Effect of airborne to aquatic entrance and its impacts based on input design. Ask Nature.



Gecko

The gecko sticks almost effortlessly to any natural surface such as rocks and overhanging branches (and even to oiled glass when scientists tested them).

Table 8: Asknature. (n.d.). https://asknature.org.

Although Aristotle already wondered about this curious ability more than 2,000 years ago, it was only two decades ago when researcher Kellar Autumn[27,28,29] started his experiments, which resulted in hundreds of published papers, many millions of dollars in research and more than 100 patents for products and services. Studies and analyses of the nanostructures of different species of geckos and other insects revealed a simple but unexpected solution: the adhesive strength of their legs is proportional to the linear dimension of contact. By splitting the tiny, hair-like setae on its toes, the gecko manages to maximize the surface area of its feet, allowing it to cling to almost any surface thanks to Van der Waals force, short-range intermolecular attraction. This principle has revolutionized the design and manufacture of not only industrial adhesives, but also surgical glues used in the medical industry.

In nature, there are other interesting cases of adhesives used by marine animals (octopuses, limpets, lampreys) or in the plant world. Velcro is a famous example as well, inspired by the seeds of the thistle that remained attached to the fur of its creator's dog. Or more recently Purebond®, an adhesive for the lumber industry without volatile components, inspired by molecules from the byssus of the mussel (Mytilus edulis).

Biomimetic surfaces

This field, which has not yet received much attention, has recently become more relevant in research[30], and has application to a broad spectrum of technologies. The concept refers to the nanometric surface architectures of various organisms, which have remarkable functionalities and whose design is already being used in industry.

To name a few, this includes structural coloration, the Lotus effect, super-hydrophobicity or slipperiness, all of which have multiple applications.

---

27. Autumn, K. et al (2000). Adhesive force of a single gecko foot-hair. Nature, 405(6787), 681-685.

28. ZQ Issue 17 Vol. 3. (2016). Retrieved September 1st, 2022 at: https://issuu.com/eggermont/docs/zqissue17.

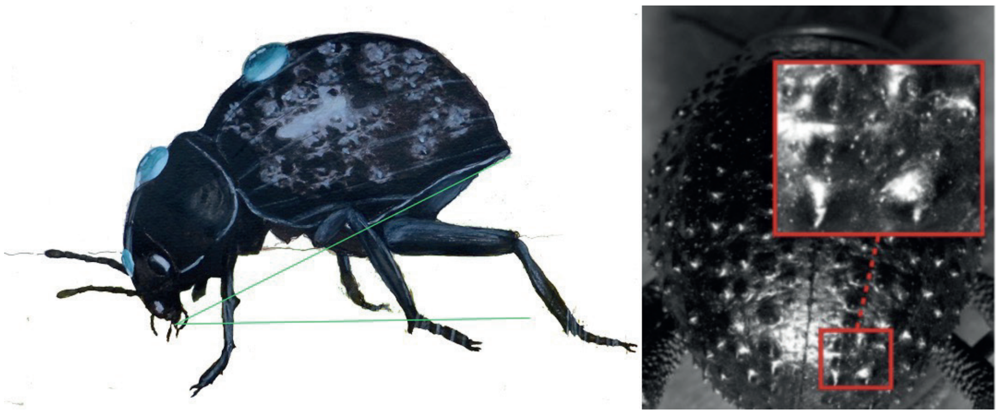
29. Quirós, M (2014). Magia en los dedos del Gecko. Retrieved September 1st, 2022 at: https://natureinspireus.wordpress.com/2014/07/16/magia-en-los-dedos-del-gecko/.

30. Bulletproof feathers. How science uses nature´s secrets to design cutting-edge technologies. (2010). Robert Allen Ed. The University of Chicago Press. 192 pp.

A few years ago, German engineers discovered that the water-repellent capacity of leaves derived from its surface being rough and covered with bumps. This phenomenon, known as the "Lotus effect", is already used as a dirt repellent in buildings and textiles, achieving significant savings in water and cleaning products. Super-hydrophobicity is also common in the plumage and hair of various animals and insects, such as the Namibian beetle (Stenocara gracilipes, Figure 9), which manages to live in one of the planet's driest areas and has inspired the Sahara Forest Project[31], which aims to provide fresh water to desert environments.

Table. 9

Stenocara gracilipes in an inclined position to drink water from desert dew thanks to its superhydrophobic and superhydrophilic exostructures.



Numerous insects, birds and other organisms show bright and vivid colors with unique optical effects achieved through sophisticated surface nanostructures that interact with visible light: a phenomenon known as structural coloration[32]. This concept could revolutionize the coloring of vehicles, textiles and even the security of coins and banknotes. This innovation could be significant in the textile industry, considering the major negative impact that textile dyeing has on aquatic ecosystems.

31. Biomimetic Science Institute. The Sahara Forest Project, an arid ecosystem. Retrieved December 19th, 2019 at: https://www.biomimeticsciences.org/es/en/2019/12/19/el-sahara-forest-project-un-ecosistema-arido/.

Table 9: Drawing by Luisa Nunes and photo by Thomas NØrgaard. Layout by M. Quirós.

32. Engineered Biomimicry. (2013). Lakhtakia, A. y Martín-Palma, R.J.Eds. Elsevier Publ. 465 pp.

Replacing paints and dyes currently based on highly polluting fluids with nanometric structures still requires imagination and, most importantly, a boost in research funding, however the future remains promising.

To conclude this section, a final innovation inspired by shark scales, which have extraordinary hydrodynamic properties and play a fundamental role in sharks' feeding and protection against predation or abrasion. *Sharklet Technologies*[33] has patented a solution to stop the proliferation of antibiotic-resistant bacterial strains by emulating the characteristics observed in the skin of sharks, which lack the growth of crustaceans or barnacles that are found in other marine animals. By mimicking these structures at a scale of 2-3 microns, and without the use of chemical agents, the surface of medical devices has been found to be free of pathogens.

Pax

Spirals and vortices, their three-dimensional form, are structures repeatedly found in nature. Ranging from the pores of our skin, the antlers of animals or seashells to galactic spirals or the shapes of cyclones, they all emulate these forms, and not by chance. Leonardo da Vinci in the 15th century already wondered why water swirls in rivers. *PAX Scientific*[34] is an innovative research and development company that aims to create better products by optimizing fluid mechanics, with multiple designs for devices and systems, including fans, mixers, water purifiers and more. Their most cutting-edge product is the *Lily impeller*[35] water mixer, inspired by seaweed that takes the shape of a spiral to manage the force of flowing water.

This mixer uses 300 watts of energy (barely enough for a couple of light bulbs) to keep water moving in storage tanks of up to 40 million liters. The energy savings and consequent reduction of greenhouse gas emissions is colossal, based on the observation and research into how natural flow geometries operate.

---

33. Pax Scientific. (n.d.). https://www.paxscientific.com

34. Ibid

35. Treehugger. The Lily Impeller: Nature-Based Design Inspires Game-Changing Efficiencies. (2021). Retrieved in September 2022 at: https://www.treehugger.com/the-lily-impeller-nature-based-design-inspires-game-changing-efficiencies-4863361

Interface floor

In 2000, Interface, a leading carpet manufacturer, introduced its first bio-inspired product known as Entropy®, which is already a case study for academics and researchers[36]. This product revolutionized the way they manufactured carpets by using tiles that mimic the randomization of colors and patterns that occurs naturally on a forest floor. In parallel, TacTiles®, inspired by the aforementioned minute hairs on the legs of geckos, was introduced as an alternative to conventional glue adhesives for bonding tiles, reducing the use of volatile organic compounds. Savings in materials, production and maintenance, the elimination of toxic substances and the transition from a product model to a service model are just some of the steps the company has taken from focusing on the common good, being a clear and inspiring example of how business and nature conservation are compatible.

Biomimetic architecture

As the urban environment evolves and we seek to build in a more efficient and automated way, architecture and urbanism must also be transformed. There are already some well-known and fantastic examples of biomimetic architecture[37] such as the Bullit Center or the Harare, inspired by termite mounds. Recently a new building in the American Arizona desert has gone further by improving performance and efficiency on a limited budget. The new Pinal County District Attorney's Office[38] imitates the vertical walls of saguaro cactus (Carnegiea gigantea), which provide continuous self-shading and heat redistribution, thereby preventing overheating.

Ribbed panels divide sunlight into changing areas, redistributing the heat load and generating self-shading. Although the metal panel absorbs heat, the façade system "breathes", allowing air to circulate and cool the structure as a whole.

---

36. Biomimicry Institute. Biomimicry Case Study: Entropy®: Non-directional Carpet Tiles. Retrieved in March 2016 at: http://toolbox.biomimicry.org/wp-content/uploads/2016/03/CS_Interface_TBI_Toolbox-2.pdf.

37. Biomimicry: an inspired way to regenerative design in cities based on nature. Quirós, M. (2019). Multifunctional Urban Green Infrastructure. Pp 79-92. Chapter 5. Retrieved at: https://natureinspireus.com/wp-content/uploads/2019/03/aa.pdf.

38. Urbanland. Using Biomimicry to Design Smart Buildings. (2022). Retrieved August 22, 2022 at: https://urbanland.uli.org/planning-design/using-biomimicry-to-design-smart-buildings/.

In connection with architectural façades, it is also worth mentioning the existence of a type of glass bio-inspired by spider webs, the structure of which allows them to be seen by birds to prevent them from being destroyed. It is commercially known as Ornilux, of which there is also a case study[39].

Table. 2

Key learnings and opportunities derived from the analyzed examples

Sucess Story	Key insights	Future Opportunities
Bullet Train	A multidisciplinary approach is a necessary prerequisite for a bioinspired innovation.	The framing of specific problems from the negative externalities of existing products/services can give way to disruptive and unexpected solutions.
Gecko	Before coming to solutions, the analogy between the challenges faced by the animal kingdom and the challenges faced by humans (in this case, the need to use adhesives) is the first necessary step in identifying possible bio-inspired solutions.	The development of measurement and imaging tools (which allow for the study of nanometric structures) has a unique potential for innovation.

39. Biomimicry Institute. Biomimicry Case Study: Ornilux®: Bird Protection Glass. Retrieved March 2016 at: http://toolbox.biomimicry.org/wp-content/uploads/2016/03/CS_Ornilux_TBI_Toolbox-2.pdf.

Biomimetic surfaces	Tangibly implementing the array of potential applications that come from the use of the biomimicry lens requires not only funding but also the creation of much closer collaborations between scientists, entrepreneurs, engineers, and designers.	Beyond the concrete problem-solution scheme, there is a prior field of major potential in technological research: improvement and innovation in materials and surfaces for applications not yet specified.
PAX	Patterns repeated in nature may point to applicable technological solutions that can entail significant gains in efficiency.	Energy savings derived from the use of forms repeated in nature have a great potential to contribute to addressing the energy transition and the consequent reduction of Greenhouse Gases (GHG).
Interface Floor	Biomimicry can be a key ally in reconciling economic and environmental objectives.	Innovation not only in products or services, but also in the business model itself has enormous potential to contribute to the creation of shared advantages.
Biomimetic architecture	Shapes in nature fulfill a specific function that solves a challenge faced by the organism in its environment. Therefore, using natural models found in similar surroundings as a guide can lead to effective designs.	Bioinspiration is a considerable building block for the most symbiotic and sustainable relationship between a built environment and naturally pre-existing one.

Finally, we should not close this section without mentioning those innovations that, despite being exciting or dazzling, have not succeeded on the market for numerous complex reasons.

For example, the Mirasol Qualcomm e-reader[40,41], which made it possible to read an electronic device in broad daylight, inspired by the structural coloration already mentioned in this publication. The second case, often cited popularization and academia, is WhalePower[42], a company that, inspired by whale fins, improved the efficiency of wind turbines by reducing the volume of wind required, as well as the resulting accumulated energy.

40. Retrieved March 2011 at: https://asknature.org/mirasol-e-reader/.

41. Retrieved November 2011 at: https://www.zdnet.com/article/qa-how-biomimicry-succeeds-and-fails-according-to-chris-garvin-terrapin-bright-green/.

42. https://whalepowercorp.wordpress.com.

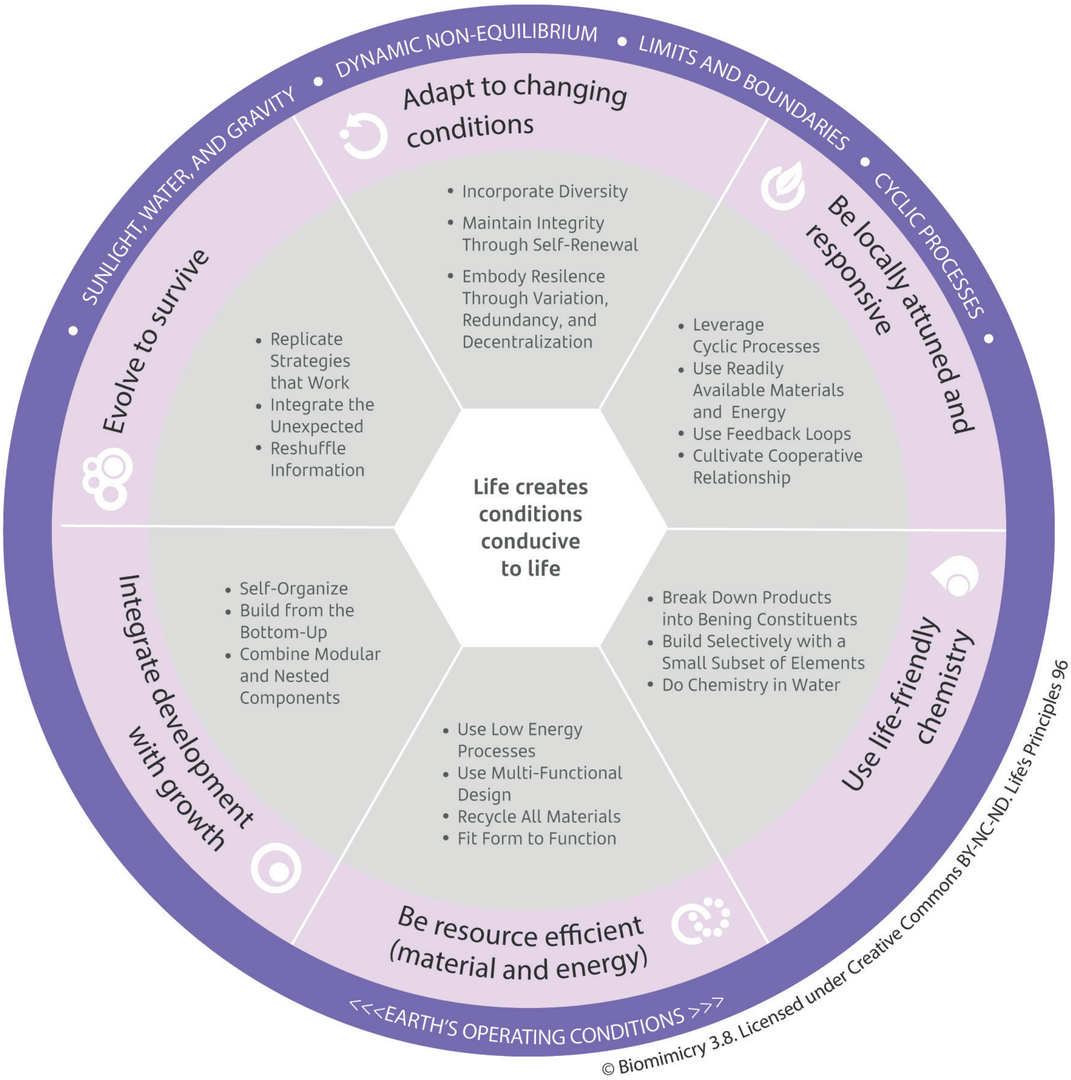
05 Spotlight on: areas with the greatest potential in this decade

How can we build more efficient structures using non-toxic materials in architecture? How can we produce with zero waste? How will water treatment and natural catchments be managed? How can energy be produced, stored, and distributed from a city? How can buildings interact with its surrounding city? One of the most interesting aspects of biomimicry is that it allows us to learn from nature and its strategies for survival and prosperity. Nature has solved most of the questions above (as well as many more) and can certainly guide, from a systemic perspective, the search for innovative solutions to these and other challenges.

Living organisms are the true engineers, architects, technicians, and teachers who show what works and what endures. Their strategies have been compiled and summarized under various terminologies according to the institutions that propose them, such as Biomimicry 3.8 by the Biomimicry Institute or Delft University. Biomimicry 3.8 designed the following table designed to illustrate Life's Principles (Figure 10), most of which are applicable to any industrial sector. The diagram represents the strategies of nearly 30 million species that have evolved over 3.8 billion years.

Figure. 10

Life's Principles[43] according to the Biomimicry Institute of USA.



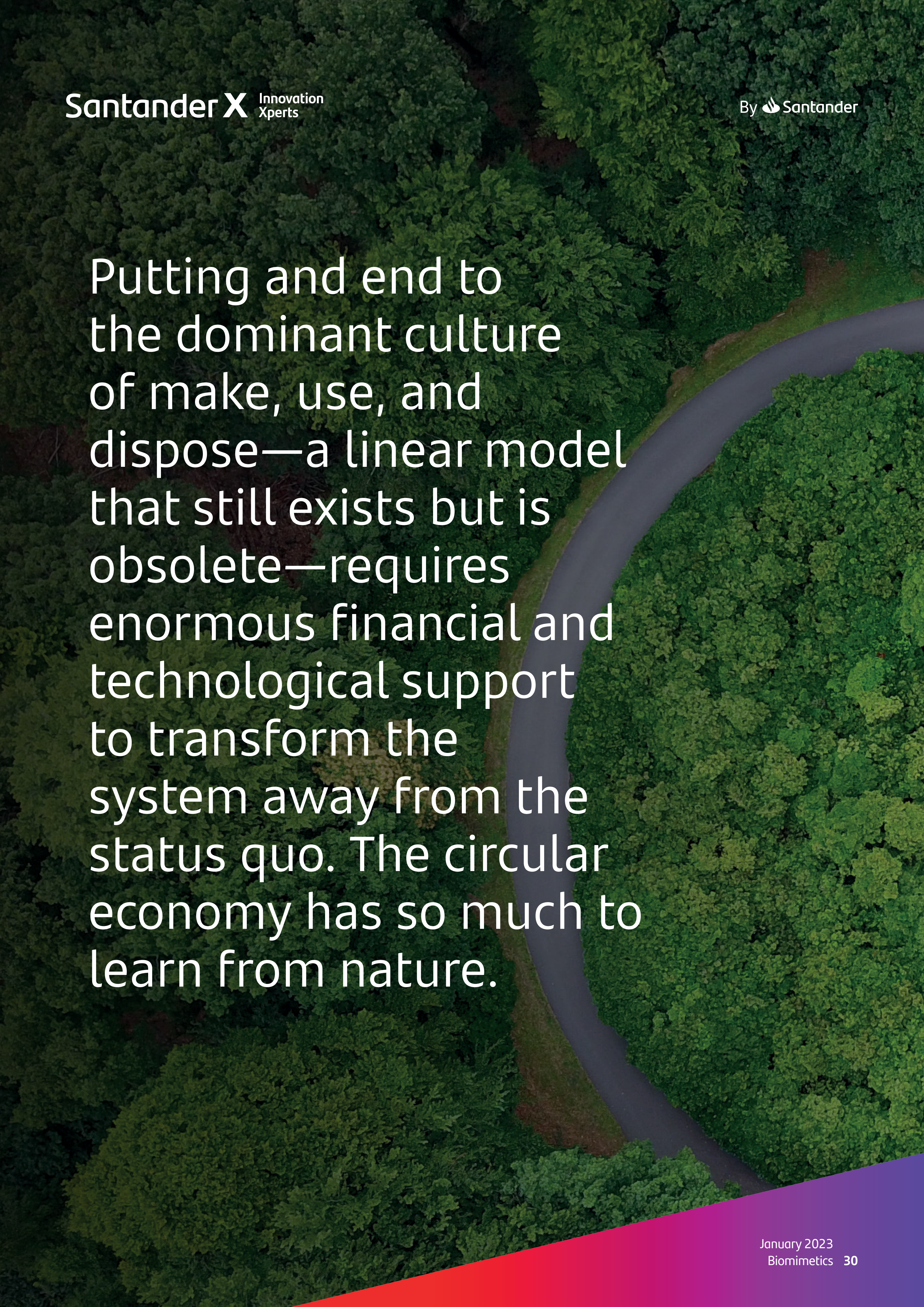
43. Baumeister, D. et al. (2012). Biomimicry Resource Handbook: A Seed Bank of Best Practices. Missoula, Biomimicry 3.8. p. 326.

Biomaterials: the next revolution. Biology, like technology, requires materials to develop its structures, where cost-effectiveness and reliability are shared values. The design of biomaterials is already a reality, with products that are water-based or manufactured with abundant local resources, and that have biodegradability characteristics and functionalities beyond the protection of products in industries that use packaging (fashion, food, packaging-transport, etc.). However, their use is relatively still minuscule, and continues to have an enormous potential.

Robotics in service of people. There is nothing more biomimetic than a robot. Bio-inspired assistive robotics in an aging world, which also suffers from frequent natural disasters due to climate change, will represent a change in health and humanitarian care models. Advances in computer technology, materials and sensorization will be of great help. For example, artificial muscles or electroactive polymers, artificial intelligence, real-time imaging, speech recognition or all-terrain mobility, among others, are some of the fields with enormous potential.

The circular economy working towards efficiency. Putting and end to the dominant culture of make, use, and dispose—a linear model that still exists but is obsolete—requires enormous financial and technological support to transform the system away from the status quo. The circular economy has so much to learn from nature.

Collaboration for social innovation. The collaborative behavior found in many social insects, birds, fish and mammals is often a sign of success in responding to serious challenges. For example, distributed sensing and swarm intelligence in control systems in flights of birds/insects or in schools of fish, as well as the management of information flows in forests between roots and fungal mycelium can be directly related to social innovation, where the concept of dominance is eliminated, and the intelligence of the group prevails over the individual. These decentralized but interdependent relationships demand an evolution in the project leadership in the face of global challenges that will require multidisciplinary teams.



Putting and end to the dominant culture of make, use, and dispose—a linear model that still exists but is obsolete—requires enormous financial and technological support to transform the system away from the status quo. The circular economy has so much to learn from nature.

In focus

The importance of funding

For all of the above to be possible, the transformation of the financial sector will be instrumental for biomimetic innovation, as a shift in investment flows can actively contribute to the transition towards a regenerative economy[44]. In this regard, the nascent Ethical Biomimicry Finance[45] proposes a methodology to place nature at the heart of investment decisions. In the same vein, the prestigious Cambridge Institute for Sustainability Leadership[46] has published the Planetary Boundaries conceptual framework, whose integration into business decision-making aims to help companies understand the consequences of their environmental impact while providing a new critical perspective on how to address that impact. The Natural Capital Finance Alliance[47], the working group on nature-related financial reporting[48] and the Coalition for Private Investment in Conservation[49] are also spearheading this shift in investment.

44. Henderson, H. (2014). Mapping the global transition to the solar age. ICAEW. Tomorrow's Company Available at: https://www.icaew.com/-/edia/corporate/files/technical/sustainability/tecpln12453-solarage-web.ashx.

45. Ethical Biomimicry Finance. (n.d.). Available at: http://www.ethicalbiomimicryfinance.com/index.html.

46. CISL (2019). Linking planetary boundaries to business: Part of Kering's series on planetary boundaries for business. Available at: https://www.cisl.cam.ac.uk/resources/natural-resource-security-publications/linking-planetary-boundaries-to-business-part-of-kerings-series-on-planetary-boundaries-for-business.

47. Natural Capital Finance Alliance. Available at: https://naturalcapital.finance/.

48. Taskforce on Nature-Related Financial Disclosures. Available at: https://tnfd.global/

49. The Coalition for Private Investment in Conservation. Available at: http://cpicfinance.com/

06 Conclusion

The private sector and society as a whole can undoubtedly learn from living organisms and systems thanks to the refinement of evolution, which shows the way towards a high level of efficiency. Sectors such as energy, materials, architecture, agricultural management, medicine, mobility, robotics and education will be the focus of interest in innovative biomimetic investment in the coming years. Arguably, nature can contribute to the improvement of processes and systems in every industrial niche. How can we accelerate this transformation? By stimulating innovation and recognizing that we are surrounded by nature, yet to be explored. The future is waiting for surprising design solutions pointing towards optimism.

Author

Manuel Quirós

Holds a PhD in Biology, is a part-time professor at the Instituto de Empresa, University of the Basque Country, University of Navarra and ESIC University

He teaches on biomimicry, sustainability and regeneration, biodiversity and conservation, bioinspired disruptive innovation and CSR/ESG. He is co-founder of the Biomimicry Iberia Association and the International Network of Biomimicry Studies.

esade

Santander X Innovation Xperts

www.santander.com/santander-x-innovation-xperts-en

By Santander