
**Biomimetics — Integrating problem-
and function-oriented approaches
applying the TRIZ method**

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 266, *Biomimetics*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Building on the success of the Millennium Development Goals (MDGs), the 2030 Agenda for Sustainable Development (the 2030 Agenda) is a set of international development goals to be met by 2030, adopted by the UN Sustainable Development Summit held in September 2015.

Sustainable Development Goals (SDGs) will be the impetus for change as the manufacturing and processing industries around the world are in need of new technology for the development of environmentally-friendly materials and processes. For that purpose, it is indispensable to realize low-energy and highly efficient manufacturing. Living things have a special technology for this aim.

In recent years, researchers have been expanding their work on biomimetic engineering (biomimetics), a field focused on introducing high efficiency and performance biofunctions into material design.^[2-6] Biofunction is a development in engineering technology that elucidates the processes of activities related to the functions and life phenomena of animals, plants, and microorganisms, and makes them useful in real life. More and more articles on biomimetic engineering have been reported every year, and expectations that the industry will develop practical applications for such are likewise on the rise. Numerous well-known applications of biomimetics can be cited, e.g. self-cleaning paints based on lotus leaves, easy-to-peel-off tapes inspired by the microstructures in the soles of a gecko's foot, nonreflective films structured like the compound eyes of a moth, shark skin-patterned high-speed swimwear, automobile designs that incorporate ideas taken from a boxfish's skeleton, and labels that use the structural colours of the morpho butterfly. The ranks of companies whose interest in developing materials based on biomimetic engineering principles sparked by news reports about such developments likewise has been increasing.^[2] There are more than 7,8 million species of living beings in the world, with an enormous number of distinct functions and behaviours. Whatever biofunction attracts our attention, it is unclear as to which ones will be useful toward developing innovative technologies and materials and lead to an optimal material design. In short, most engineers and researchers are challenged by their inability to focus on a single target owing to the excess of options. Thus, case-by-case material design is the mainstream in biomimetic engineering today. Only a portion of the limitless number of biofunctions are being put to use, and there are no effective means for extracting those technological elements that may be necessary. Furthermore, with ISO/TC 266 currently studying a variety of regulations regarding biomimetic engineering, there is demand for biomimetic products to be created that conform to international standards. According to ISO 18458, developing biomimetic biometric products requires they go through the following process: (1) identify issues with existing technologies and materials, (2) search for biofunctions that can resolve those issues, (3) extract and generalize the principles behind the biofunctions that have been discovered, and (4) create and optimize new technologies and materials. The question also arises of the best approach to take for identifying the functions among the 7,8 million living things said to exist and for optimizing them. This document introduces the database that will support the creation of biomimetics products according to ISO 18458.

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Biomimetics — Integrating problem- and function-oriented approaches applying the TRIZ method

1 Scope

This document describes prototypes of a database for developing biomimetic products with innovative problem-solving methods (TRIZ). The database has a mechanism to obtain the idea of technical problem-solving using the problem- and function-oriented approaches. This document focuses on the use and value of the database, but also describes its design principles.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 23845, *Biomimetics — Ontology-Enhanced Thesaurus (OET) for biomimetics*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 23845 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

TRIZ

problem-solving, analysis and forecasting method derived from the study of patterns of invention in patent literature

Note 1 to entry: The theory of inventive problem-solving was invented by Genrich Altshuller, who while president of the Inventor's Association of Russia in 1946, discovered that the evolution of technical ideas followed predictable patterns.

3.2

problem-oriented approach

approach used to search for biological functions based on 40 principles using the TRIZ (3.1) matrix method

3.3

function-oriented approach

approach used to reach biomimetic solutions from the 40 TRIZ (3.1) principles by utilizing a combination of two elements, desired function and state

4 Current status of patents for biomimetics

The Japan Patent Office's *Survey Report on Technology Trends in Patent Applications* gives us a picture of current tendencies in regard to patents focused on biofunctions.^[2] It can be inferred from a review of the data for products that are mainly related to biomimetics that at present the number of instances in

which a patent has been commoditized is limited regardless of country or region. The main products can be broken down as belonging to one the following three broad categories.

- a) Products related to molecules and materials. Examples include hydrophilic and hydrophobic materials (e.g. water-repellent paints, tile-related building materials, and water-repellent glass); structural coloration materials (e.g. chemical fibers); optical materials (e.g. antireflective film and displays); adhesive and gummed materials (e.g. adhesive tape, carpet tile, and cyclone vacuum cleaners); medical and biocompatible materials (e.g. injection needles and cosmetics); low-value resistance and low-friction materials (e.g. competition swimwear, fuselage paint for airplanes, and ship-coating materials); and antifouling materials (e.g. antifouling coating for ship bottoms).
- b) Products meant to reduce the resistivity of a structure (e.g. cooling fans, washing machines, mixers, and the shape of the noses on bullet trains) or save weight (e.g. automobile wheels).
- c) Products related to robots (e.g. robots patterned after dragonflies, elephant noses) or machine controls (e.g. sensors and software for controlling smart grids).

In Japan, numerous products related to the molecular and materials fields exist, e.g. hydrophilic and hydrophobic materials, optical materials, and adhesive and gummed materials. In the US and Europe, in contrast, more products in the machine field are encountered. Much work was once being done in Japan in the areas of biomimetic chemistry and robotics, and it was a leader in molecular scale biomimetics. However, researchers and engineers have not been able to keep pace with the new currents that emerged in material-related biomimetics in this century. Broadly speaking, this is because in Japan collaborations between different fields such as biology and engineering never took place owing to preconceptions in Japanese research and academic settings about interdisciplinary interactions. R. Kosaka et al. reviewed and analysed the latest trends related to biomimetics and innovations. It is followed by the comparative analysis of biomimetics-related patents versus the number of related scientific articles in Japan, the USA and European contexts. From the analysis, it is pointed out that the trends of research and patents are predominantly correlated in the USA and Europe. Japan has a relatively small number of patents and articles but has comparatively more activity in patent applications than in article publications.^[8,9] Additionally, it is believed that the materials field will become the primary destination for application of biomimetics. If more products are to be brought to market in these areas, it will be necessary to develop even more technologies in the area of microstructure fabrication techniques in order to reduce manufacturing costs and improve durability. Furthermore, if the biomimetics market is to expand, would-be producers will need to adopt a "biomimetic" way of thinking in the control and processing fields. In particular, observers have highlighted the importance of autonomous distributed control systems, and the expectations of people involved in the field for advances in the development and practical application of such systems are high.

These reports concluded that biomimetics is applied to technical fields completely different from molecules/materials, structures, machines, and processes, and its application industry is extremely wide. In order to match with applied industries, it is necessary to overcome existing technical and industrial barriers. Therefore, it can be said that a biomimetics database that links knowledge from different technical fields and applied industries is essential.

5 Theory of database

5.1 TRIZ

There are a variety of approaches to solving engineering problems. Researchers and engineers have found success in wielding such approaches as a strengths, weaknesses, opportunities, and threats (SWOT) analysis, which applies a business framework to the problem; "logic" (or "issue") trees; Osborn's checklist; mind maps; quality control methodology; and the Taguchi method. Among these methods is one that has been applied in a variety of fields since 1990 as a means for generating ideas for material design in mechanical engineering. This is the Theory of Inventive Problem Solving, usually known by its Russian acronym TRIZ (Teoriya Resheniya Izobreatatelskikh Zadach, Теория решения изобретательских задач). TRIZ was developed by Genrikh Saulovich Altshuller (1926-1998), who worked as a clerk in a Russian patent office.^[10-14] Altshuller came up with TRIZ as a set of "principles for performing

creative problem solving" that applied a system to the regularities he uncovered in his examinations of some 1,5 million patents. The distinguishing feature of this method is that it presents a set of rules and principles for solving issues in engineering technology. The main feature of the TRIZ method is that its principles and the principles for solving engineering technology are presented, and by patterning the problem that needs to be solved, hints for problem solving are obtained regardless of research field. There are several usages such as (1) principle, (2) prediction, and (3) effects.

40 principles for problem-solving is one of the methods in category (1) principle in TRIZ, a technique to settle a problem from an invention principle of 40 by an inconsistent matrix way. The merit of the TRIZ method is that it presents a set of rules and principles for solving issues in engineering technology. It does this by looking for the patterns in the problems for which solutions are being sought, thus making it possible to get ideas about how to solve those problems regardless of the field of research. There is any number of ways to apply it based for example on principles, predictions, or effects. Here, we will focus on problem solving methods that make effective use of the 40 problem-solving principles the theory proposes. The principle-based approach entails taking the physical characteristics spanning the 39 parameters shown below and using them to create a 39-by-39 matrix comprising "parameters wish to improve" and "problems that will arise when improvement is made". The goal is to resolve the technological contradictions represented by the intersections between those parameters an inventor seeks to improve and those parameters that will change for the worse.

The 39 features of Altshuller's contradiction matrix:

(1) Weight of moving object (2) Weight of stationary object (3) Length of moving object (4) Length of stationary object (5) Area of moving object (6) Area of stationary object (7) Volume of moving object (8) Volume of stationary object (9) Speed (10) Force (11) Tension or pressure (12) Shape (13) Stability of composition (14) Strength (15) Time of action by a moving object (16) Time of action by a stationary object (17) Temperature (18) Brightness (19) Energy spent by a moving object (20) Energy by a stationary object (21) Power (22) Loss of Energy (23) Loss of substance (24) Loss of Information (25) Loss of Time (26) amount of substance (27) Reliability (28) Measurement accuracy (29) Manufacturing precision (30) Harmful factors acting on an object from outside (31) Harmful factors developed by an object (32) Manufacturability (33) Convenience of use (34) Repairability (35) Adaptability (36) Complexity of device (37) Complexity of control (38) Level of automation (39) Capacity / Productivity.

The 40 problem-solving principles of TRIZ:

(1) Segmentation (2) Extraction (3) Local Quality (4) Asymmetry (5) Consolidation (6) Universality (7) Nesting (8) Counterweight (9) Prior Counteraction (10) Prior Action (11) Cushion in Advance (12) Equipotentiality (13) Do It in Reverse (14) Spheroidality (15) Dynamicity (16) Partial or Excessive Action (17) Transition Into a New Dimension (18) Mechanical Vibration (19) Periodic Action (20) Continuity of Useful Action (21) Rushing Through (22) Convert Harm Into Benefit (23) Feedback (24) Mediator (25) Self-service (26) Copying (27) Dispose (28) Replacement of Mechanical System (29) Pneumatic or Hydraulic Constructions (30) Flexible Membranes or Thin Films (31) Porous Material (32) Changing the Color (33) Homogeneity (34) Rejecting and Regenerating Parts (35) Transformation of Properties (36) Phase Transition (37) Thermal Expansion (38) Accelerated Oxidation (39) Inert Environment (40) Composite Materials.

This Russian technology has been systematized by researchers around the world, including Dr. Darrel Mann and Dr. Nakagawa,^[15] and has been developed using engineers, and many databases and software have been developed in each country. In addition, at present, TRIZ data collections from all over the world are linked, and an environment is in place where TRIZ industrial patents can be created from various sites. In Japan, Mitsubishi Research Institute spread TRIZ software to the world in 1997, and many companies are using TRIZ for engineering purposes. The Japan TRIZ Council was established in 2005, and the Japan TRIZ Association was established in 2007 (<http://www.triz-japan.org/>). At the TRIZ annual symposium of this association, development examples at many Japanese companies were reported.

5.2 Bio-TRIZ method

Engineers would like to add the functions in case of materials design for superior performance, but living creatures keep the principle to sacrifice something to get new functions as evolution. This optimization concept is called trade-off. Trade-off is a situational decision that involves diminishing or losing one quality, quantity or property of a set or design in return for gains in other aspects. The TRIZ method is a category of problem-solving using trade-off. Organisms evolve in response to changes in the environment by repeating trade-offs and acquiring new functions. By incorporating this mechanism into TRIZ, we can expect the development of products that incorporate a highly functional and highly efficient biological mechanism.^[15] Bio-TRIZ is a new concept developed by Olga and Nikolaj Bogatyrev, designed to solve technical problems to bring high efficiency bio-functions found in nature into TRIZ's 40 problem-solving principles.^[16] For example, in metallurgical and mechanical engineering, to open pores in a material means reducing its strength. However, living things create sophisticated structures that prevent cracks from forming when they open pores. This maintains the strength of a material while simultaneously saving weight. Biofunctions in this way are a significant source for patentable new technologies. They imply ideas for the development of next generation materials and can also be expected to do much in the area of education in new engineering design. Developing next-generation materials demands that their creators consider such factors as harmonizing with nature, environmental friendliness, and the use of biomass.

5.3 Biomimetics-integrating problem- and function-oriented approaches applying TRIZ

The database comprises carefully selected information, stored in files categorized into the 40 TRIZ problem-solving principles, about living things that can be used for establishing patents according to ISO 18458. The user can get ideas for efficiently developing biomimetic products in a short period of time, therefore, by optimizing the biofunctions the base presents by the problem-oriented approach and function-oriented approach. Furthermore, the data contained can also contribute to product development based on existing work since the user can also view an inventory of biomimetic products related to the SDGs.

6 Structure of biomimetics-integrating problem-and function-oriented approaches applying TRIZ

6.1 Problem-oriented approach — Search from technical contradiction matrix

There is demand for biomimetic products to be created that conform to international standards. According to ISO 18458, this database can provide novel idea to develop biomimetic products according (see Figure 1).

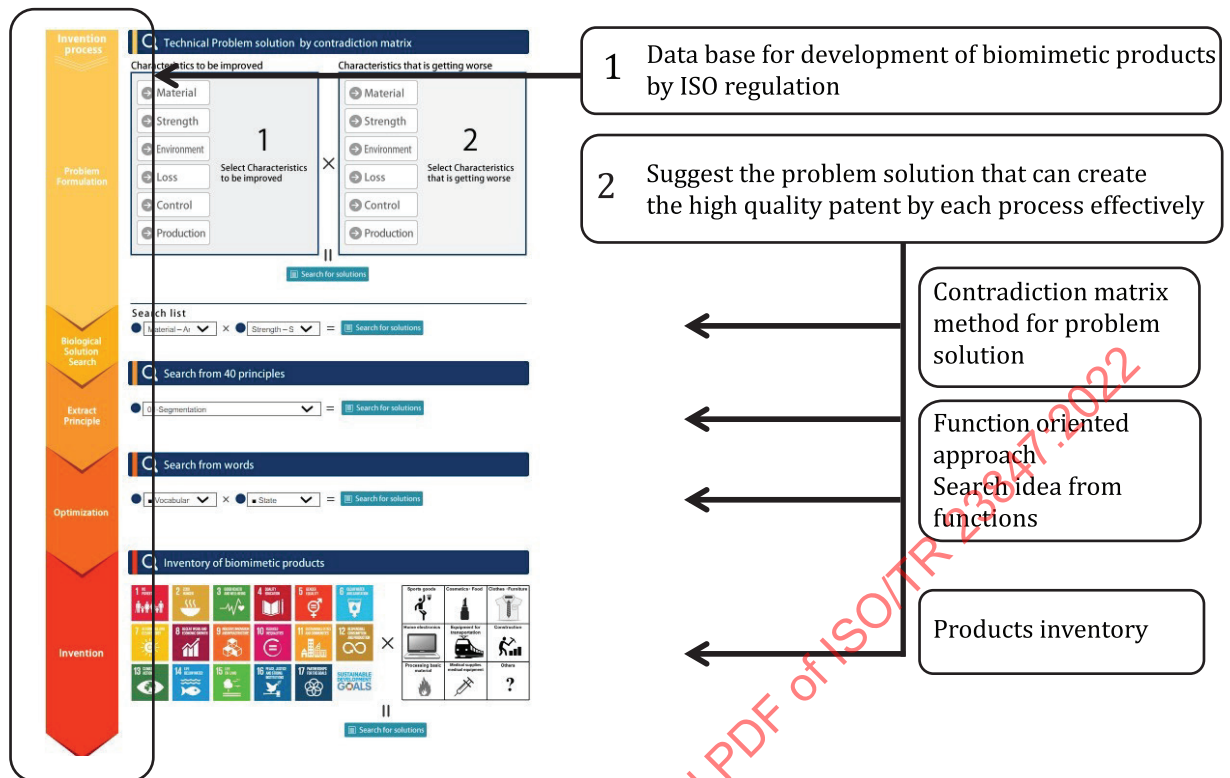


Figure 1 — Outline of database

The strength of this database lies in the fact that when the user queries it over technological contradictions, i.e. the problem of improving one parameter having a negative impact on another, it has the framework in place to automatically display any number of bio-functions that can suggest a solution as it runs through the four processes shown earlier (Figure 2 and Figure 3). The database comprises carefully selected information stored in files categorized into the 40 TRIZ problem-solving principles about living things that can be used for creating patents. This database can contribute to decision-making in the creation of biomimetic products. By merely condensing the technological problems which engineers face and putting them into a contradictions matrix, our database can supply the problem-solving principles that would seem appropriate for resolving those issues and furthermore will search out bio-functions for the user. The user can get ideas for efficiently developing biomimetic products in a short period of time by optimizing the bio-functions from this database. Furthermore, the data contained can also contribute to product development based on existing work since the user can also view an inventory of biomimetic products.

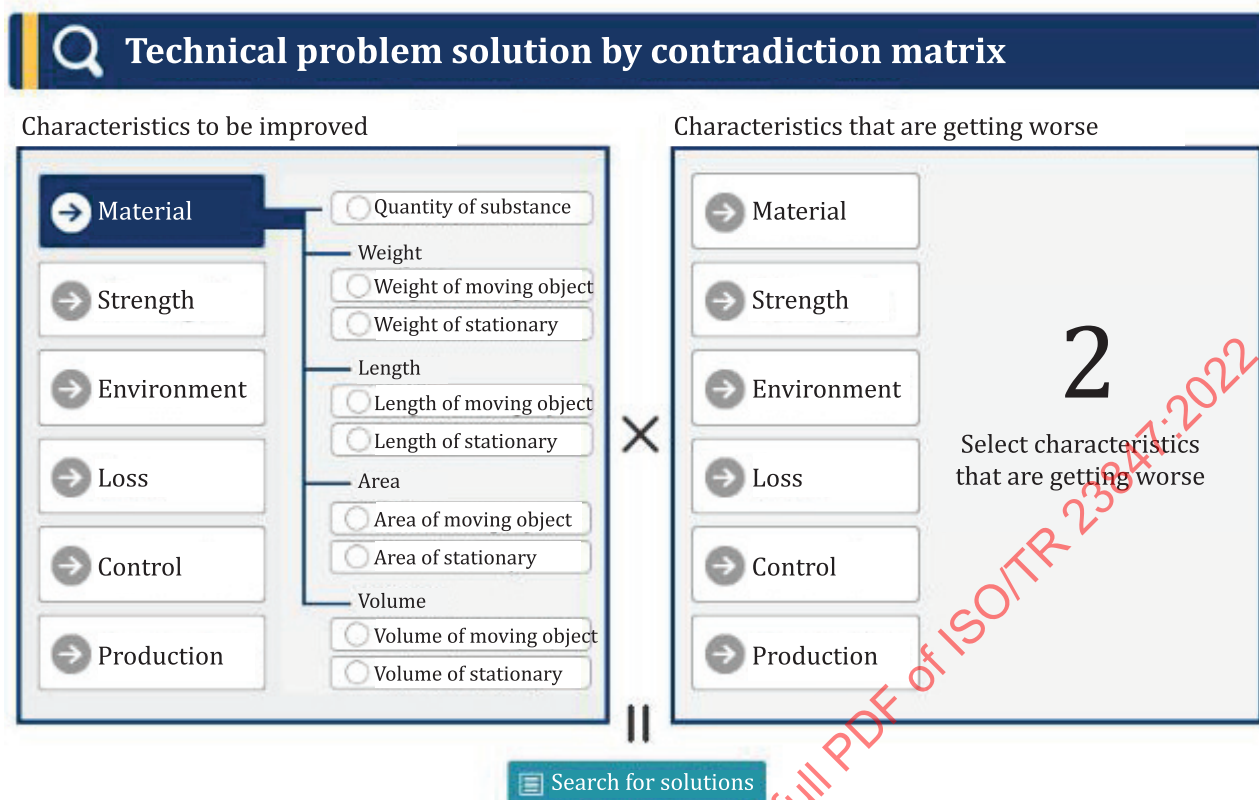


Figure 2 — Using the contradictions matrix in the database

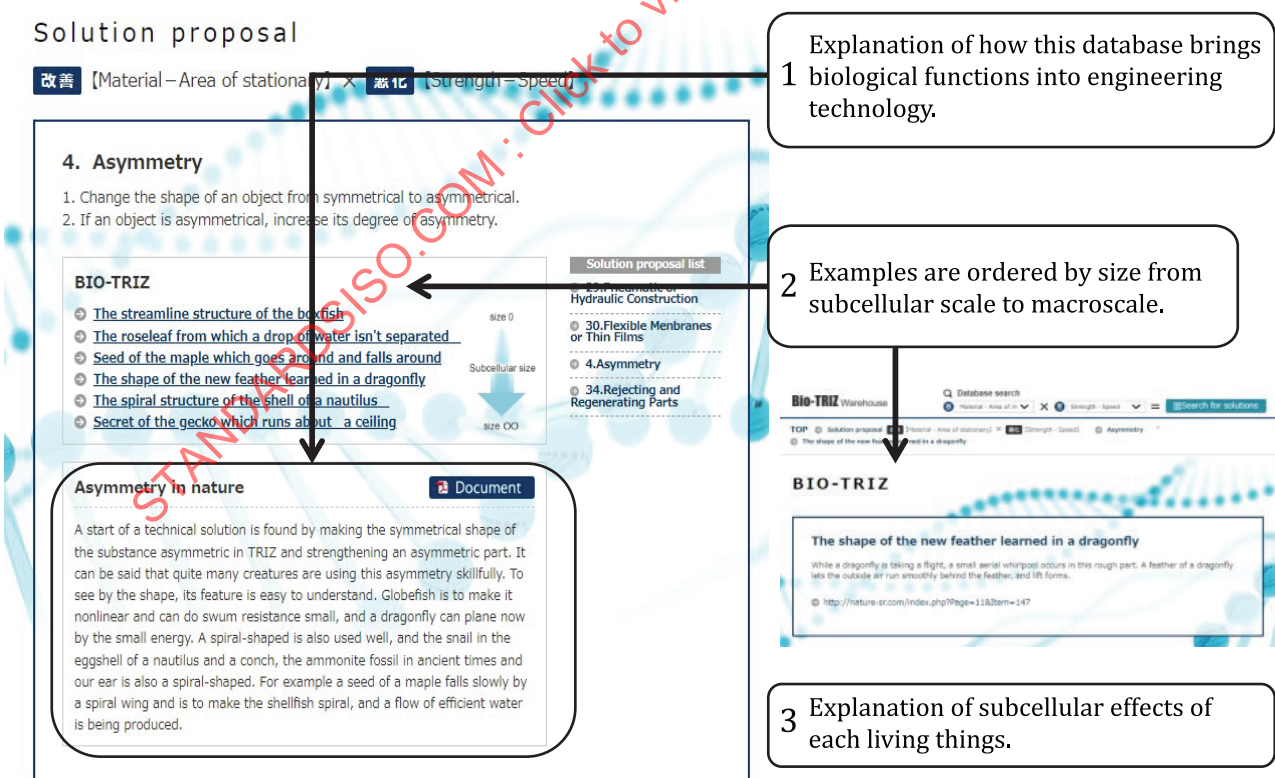


Figure 3 — Example of problem- oriented approach in the database

6.2 Function-oriented approach — Search from function

Biomimetic information obtained from a function parameter was transformed by a Resource Description Framework (RDF) utilizing a problem-oriented approach. This method can search natural principles extracted from natural phenomenon and develop it to search a biomimetic solution from 40 principles in TRIZ. Users can get ideas for problem solving with the function parameter thorough natural phenomenon and information on biomimetic-TRIZ by a different viewpoint (see [Figure 4](#)). Biomimetic information can be extracted by connecting key words of functions by RDF. This constructs a two-way research process consisting firstly of a “problem-oriented approach” from a 39-by-39 matrix and secondly a “function-oriented approach” which can get biomimetic information from the function in [Figure 1](#).^[17-19] The function is chosen as well as the state of the solid, liquid and gas. As shown in [Figure 5](#), a search for a mechanism of a similar creature can be made as well as the natural principle to improve its function by choosing moving and solid. A new wing shape can be learned by studying the characteristics of dragon flies.

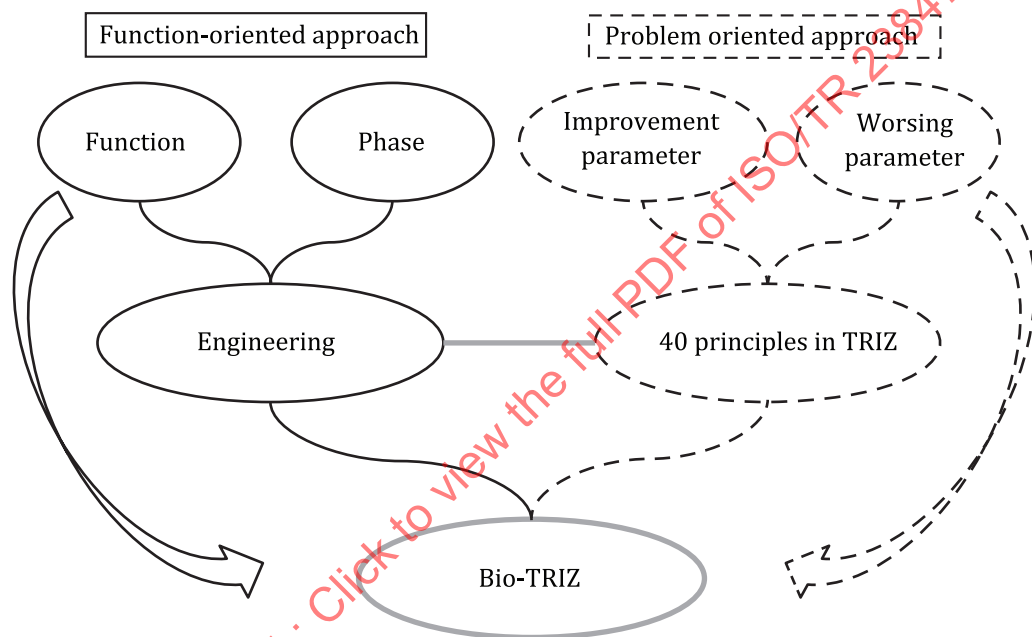


Figure 4 — Two types of search system in the database



Search from words

•(move) × •(solid) = (Search for solutions)

Engineering	Biomimetics	TRIZ principal
friction	The dog which is easy even if I run through a slippery snowy road	4. Asymmetry
brush	If wild burdocks touch, they don't get away!	3. Local Conditions
hyperboloid	Seed of the maple which goes around and falls around	4. Asymmetry
desorption	The ceiling, secret of the gecko which runs about	3. Local Conditions
vibration	A human heart is the pump which are multiple functions.	1. Segmentation
resonance	Secret of 6 legs walking of a cockroach	19. Periodic Action
inertia	The wild goose how isn't which crashed even if it gathers	15. Dynamics
light electrophoresis	Vegetable MARANTA which moves by light	11. Cushon in advance
spiral	The bacterial flagellum motor equipped with a clutch	14. Spheroidality
condensation	Nectar of the aphis which falls by wax	30. Phase Transition
explosion	Jet of octopus	29. Pneumatic or hydraulic Construction
beak effect	Even if it's stuck into a mosquito, it isn't painful.	3. Local Conditions
fluidization	The new wing of the form to learn to dragonfly	15. Dynamics
shape memory effect	Both tree bugs and insect bites "Miura fold"	7. Nesting

Figure 5 — Example of function- oriented approach in this database

6.3 Inventory of biomimetic products

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 SDGs, which are an urgent call for action by all countries, developed and developing, in a global partnership. A successful sustainable development agenda requires partnerships between governments, the private sector and civil society. Biomimetics is a concept that uses ideas from nature to further technology, and it can contribute to realize the SDGs because nature gives us solutions for engineering problems. This database includes biomimetics product information in various sectors related to the SDGs such as materials science, electronics, cosmetics, transformation, sports, construction, lifestyle^[20].

7 Example using a fan

7.1 Problem-oriented approach for fans

The following example is demonstrated by developing a new fan. Increasing the surface area of the blades used on the tiny fans creates a large rotational torque, which allows for obtaining greater energy. However, increasing the surface area makes the rotation slower. This is a contradiction. The database is used to search for inventive principles that would resolve the conflict of surface area versus speed, and the four principles are found. These four principles are based on the TRIZ. An explanation is offered in the following list:

29. Pneumatics or hydraulics:

(1) Using expansion, fluid-filling, air cushions, and other liquid/gas phenomena not found

in solids

30. Flexible membranes or thin film:

- (1) Using flexible shell and membrane coatings in lieu of three-dimensional shapes
- (2) Isolating objects from the outside environment through use of shells and membranes

4. Asymmetry:

- (1) Turning the symmetry of a substance asymmetrical
- (2) Strengthening asymmetrical components

34. Rejection and regeneration, discarding and recovering:

- (1) Exclude elements of an object that have completed their function
- (2) Revitalize the consumable elements of an object

A further data search on this database gives information concerning a new wing form devised from that of dragonflies, corresponding to principle 4. Asymmetry. Specifically, a cross-section of the wings of dragonflies reveals that, unlike those of hawks and kites, they are not a streamlined form; instead, they have a corrugated structure, creating small eddies of air at their tips and conveying air on the exterior smoothly towards the back of the wings, allowing the dragonfly to achieve lift even amidst minor gusts of wind. The proposed solution of using a wing design inspired by dragonflies makes use of the above structure. This database is being used to provide a high quality of potential solutions. The database also contains different biological data within principle 4. Asymmetry (see below), so the researcher can make reference to these varying data points and use their technological prowess to develop and patent new biomimetic technologies. The following are examples:

EXAMPLE 1 “Hovering movements of hummingbird wings”

Birds obtain lift by pushing their wings downward and use this to fly. Insects gain lift commensurate to the degree to which they flap their wings. Hummingbirds are somewhere between insects and birds. They obtain 75 % of their aerodynamic lift by beating their wings down and 25 % when they draw them up.

EXAMPLE 2 “Twirling maple seeds”

When maple seeds rotate, small vortices at their tips allow air pressure near the top of the blades to decrease and pump the blades up, causing them to remain in flight.

7.2 Function-oriented approach for fans

In a function-oriented approach, most existing wind turbines are identified to have stream-lined blades that resemble those of hawks and kites, with the physical size of the blade increasing and a search for a combination of “move X solid” is made. As seen below, there were fourteen hits for natural principles that can be used to resolve this issue (see [Figure 5](#)): friction, brush, hyperbolic-conchoid, attaching-detaching, vibration, resonance, inertia, photophoresis, spiral, condensation, explosion, beak effect, fluidization, shape memory effect. “Dynamics” is a crucial element in controlling the flow of wind. If we filter for that, “wings inspired by dragonflies” a hit tied to the principle 4. Asymmetry is returned. What is interesting is that both approaches allow us to arrive at the biomimetic data corresponding to dragonflies. If we turn to another natural principle of “inertia”, we get a hit for “new morphing wings.” We can get an idea of developing morphing wings, which have the following elements: the way in which birds spread their wings wide when in flight and flap them when landing and taking off the way they quickly descend to catch prey, and the way they can fold their wings tight to curb wind resistance. In this way, both approaches allow for arriving at a substantive method of problem-solving, and different knowledge can be obtained from the biological world for the production of new patents as this technique supports a unique thought process.

7.3 Inventory of biomimetic products for fans

The domestic and foreign patent examples about the field of various sectors such as materials science, electronics, cosmetics, transformation, sports, are recruited for this database. For example, biomimetic product patents can be searched for the optimization of this new idea. Information about fans can be found in electronics. An aerial gap is set up to the aspect of the wing, aerial resistance is suppressed and a smooth aerial flow is invented like a wing of a dragonfly. SHARP Corporation has also adopted new technology derived from dragonfly wings to make fans for air conditioners as well as slim ion fans. The circulating air was found to flow smoothly without resistance as shown in [Table 1](#).

Table 1 — Information for development of new fans from this database

ISO TC 266 specifications approach	Problem-oriented approach	Function-oriented
(1) Identify issues with existing technologies and materials	Surface area vs Speed	Move X Solid
(2) Search for biofunctions that can resolve those issues	Dragonfly	Dragonfly
(3) Extract and generalize the principles behind the biofunctions that have been discovered	Assymmetry	Fluidization
(4) Create and optimize new technologies and materials	A wing of a dragonfly for a fan of an air conditioner	