

Chapter in the Springer book “Eco-innovation and the Development of Business Models: Lessons from Experience and New Frontiers in Theory and Practice”, 2014

BioTRIZ: a win-win methodology for eco-innovation

Nikolay Bogatyrev and Olga Bogatyreva

Directors of BioTRIZ Ltd Bath, UK, olga@biotriz.com

Abstract. Current attempts to resolve ecological problems by only social or technological means clearly have their insufficiencies, otherwise the ecological crisis would not be so obvious. Eco-sound innovations and nature conservation projects are not profitable, because there is no reliable methodology that allows bio- and eco- approaches to contribute to industry and the economy to the full extent. Technology and ecology are often mutually contradictory and mismatching domains: bio- and techno- worlds speak different languages. A methodology for eco-innovation called BioTRIZ is presented in this chapter. BioTRIZ is the only methodology which is fully capable of dealing with contradictions between biology and technology, because its main mechanism is based on revealing conflicting requirements and a win-win resolution. The authors’ 30 years experience in ecology, biomimetic design and theory of invention led to the formulation of basic axioms and rules for eco-innovation that are presented in this chapter. As an example of the application of these axioms and rules, a case study on eco-innovation is presented: the design of an eco-park that takes into account technological requirements, generates profit and recovers damaged ecosystems.

1. Introduction: why does knowledge of living nature help in eco-innovation?

Currently our economy globally faces social and environmental issues: public health problems, social unrest, migration, water, energy and financial crises. Because of these wrenching changes faced by contemporary society – from ecological crises and climate change to health-threatening pollution of the environment – it has appeared that conventional engineering and organization management is not necessarily working as effectively and efficiently as we would hope. These issues have started to attract the attention of governments, media, architects, designers, engineers and the general public.

Human activity at all levels – from individual behavioral patterns to the whole economic system – does not take into account the “interests” of the environment that we live in. Our shortsighted linear models of “cause-*immediate* effect” reac-

tive behavior¹ do not fit the extremely complex natural world, and they therefore exclude us from ecosystem cycles. We have huge problems with the utilization of waste, and yet there is no such thing as waste in nature. We declare an energy crisis, although energy exists everywhere in nature and ‘Life’ does not use as much energy as we do – it is at least 4 times more efficient than current technology [1]. We devote a lot of resources to producing new and diverse materials – and yet living nature has created numerous different materials with a wide range of properties (from extremely hard to soft and liquid) using only 2 basic polymers: proteins and polysaccharides. Humans use more than 350 different polymers and yet ‘we’ have still not been able to match the variety of materials that exists in living nature. And last but not least – living systems typically avoid problems, resolving them in advance before they even occur.

All the factors mentioned above make living systems the main source for ideas for self-sustainable cycles of materials, products and services. If Life is “so perfect”, why can we not take ideas from living systems and implement them straight away into macro- and micro- economic reality? Using knowledge from biology, and especially ecology, is very tempting. But apart from great interest, there is nothing for business to rely on – no procedures that guarantee success, making such projects risky and expensive. At the moment, there is no solid methodology or procedures for making biological mechanisms applicable to implement within non-biological reality such as engineering, business, economy. Inspiration from biology at present an irresponsible strategy, because there is no single proof that biological mechanisms being literally applied to the economy will not cause new economic disasters. Moreover, there are plenty of strategies in biological systems that are not acceptable for application in contemporary human society due to cultural, moral, economical and other reasons.

Before we start borrowing natural strategies from ecosystems for sustainability or manipulating them for our benefit, it would be worth answering some basic questions to make an exact definition of what we actually need. Does the strategy:

- Minimize waste?
- Increase speed of economic growth?
- Provide social stability?
- Keep living standards high?
- Reduce risk of crises?

People have already realised that if a manufacturing process is linked with consumption and recycling in a closed loop, it is desirable and favourable strategy, but if we look at natural ecosystems we will see a great variety of cycles. So we can ask ourselves – what sort of cycles do we need:

- Long or short cycles? Fast or slow?
- Reversible or irreversible?

¹ The ecological response to our activity is often sufficiently delayed: this has its own advantages, but an accumulative and postponed reaction can be unexpected and catastrophic.

- Single cycle or multiple interacting cycles?
- Interrupted or continuous “rotation”?
- Simple or complex?
- Cycles of what – material, energy, information, anything else?

We need to clearly know the result we want to achieve as we already have cycles in economy which we do not appreciate at all – the well-known cycles of crises! Thus we can say that there are some cycles that are undesirable. How do we recognize them?

Currently, we cannot guarantee that, without appropriate adaptation, the use of knowledge from biology will bring the required result because:

- The economy is not strictly speaking a living system as it includes technology as well: laws that are applicable for ecosystems may not work there.
- The economy is a complex system that comprises social and technological components. The social component may be considered a direct analog to natural societies, but the technological component’s behavior and evolution is very much different to biology (there is only a 12% similarity in approaching challenges in biology and engineering [1] and even some trends for the directions of the evolution process in technology and biology are opposite [2]).
- Successful experience of eco-innovation in one industry may not be directly applicable to industries from completely different domains – products and consumers are very different and it is not obvious that a successful circularization model taken from one industry will work for a different industry as well.

There is certainly a demand for a reliable method that can interpret and transfer data from biology into technological procedures in a manner which would not cause harm to business and which would allow a transformation from the current linear model to an eco-friendly circular one. We are going to fill this gap with a solid methodology, called BioTRIZ [2], which is capable of working with the incompatible requirements that economy and ecology represent. Moreover, this methodology is universal; in other words, it is acceptable in all domains of human activity – from medicine and pharmacology to education, culture, engineering, science, politics and sociology.

So, in this chapter you will find:

- The answer to the questions of how, where, why and in what circumstances do we need eco-innovation.
- A brief introduction to BioTRIZ methodology.
- Axioms and rules for eco-innovation.
- A case study on eco-innovation to show how BioTRIZ rules and axioms work: the layout architecture for an eco-park that takes into account technological needs, generates profit and provides the revitalization of damaged ecosystems.

2. Ecology and the economy: defining the goals and issues of eco-innovation

Economy and ecology have a common linguistic root – “Eco”, which means “home”. Our home is our planet, so all of human society and its economy should be associated with the natural ecosystem. Economy and ecology are the most complex and sophisticated spheres. Sciences that study them suffer from the lack of formal methods and procedures that are expected to lead us to predictable outcomes. If this were not true, we would never experience any economic crises, ecological disasters or technological catastrophes. When extremely complex systems such as technology, ecology and society come to interact and interconnect, some interacting components, which may be useful and harmless within their own domain, suddenly generate long lasting disasters when they interact with other components. For example, transport development has changed our lives – people move across continents for holiday and business. Such mobility of people opens the opportunity for international cooperation in industry and cross-cultural enrichment, but it unlocks the way for local microorganisms, plants, insects and viruses to spread globally. Our transport system thus works like a mixer in the world ecosystem and we deal with its consequences every day.

A natural ecosystem is a complex system of interactions between living organisms, their groups and populations plus the abiotic environment. These interactions – relying on closed and open cycles, feedback loops, redundancies, adaptability and variability – define the ecosystems’ performances and yield biomass production, energy efficiency and resilience. On the other hand, in industrial production and consumption systems, we tend to rely on standardization and specialization, linear processes, and maximization of the performance – which leads to greater vulnerability, less resilience (capacity to recover), and poor optimization of energy and material use and re-use.

To achieve a performance similar to natural ecosystems in economy is the way to sustainability. This means that there is need for a new inter-disciplinary approach with solid methodology, which will provide for the economic prosperity of humankind, aiming beyond simple survival in the destabilized ecological conditions on our planet. This innovative approach should involve most of the scientific and social disciplines as well, as actors from private, public and political sectors. We need to go beyond isolated and singular initiatives and experiment in different areas – industry, agriculture, art, architecture, etc. – and develop *systematic tools* for eco-innovation that integrate all the most efficient methodologies and promote these methods in industry, education and the whole culture. A multidisciplinary approach makes this grand task possible, but also raises challenges. Developing a common ground methodology for such a large number of different domains is not a straightforward task. Economy and ecology, although similar in terms of complexity and involvement of animate and inanimate components, possess starkly different properties for these components.

2.1 Biology and technology: two contradictive design strategies

Biomimetics is a relatively young branch of engineering, which take ideas for design from living nature. Those who wish to trace its roots may find many historical attempts to copy living nature [1]. For example, Leonardo Da Vinci observed animals and plants and foresaw the possibility of converting biological principles into technological ones. Later, more emphasis was placed on the need to increase the functional capability of engineering devices. Today, biomimetic ideas are also driven by the concepts of sustainability and nature-friendly engineering and can be considered an eco-innovation approach. These ideas are getting popular but do not have much support from business due high project costs and lack of design methodology that can guarantee successful outcomes and reduce risk of investments.

To fill this gap, we decided to have a look at the major differences between animate nature and technology, and consider how useful it is to follow the principles of living nature [1], [4]. To compare the strategies that technology and biology follow in their development, we have analyzed more than 2500 biological phenomena, covering over 266 functions at different levels of the biological hierarchy – from cell level to ecosystem level (Fig.1). To enable us to process this huge amount of information we have established a logical framework based on the “mantra”: “things do things somewhere”. This establishes six fields of operation in which all actions with any object can be executed: “things” (substance, structure); “do things” (requiring energy and information); “somewhere” (space, time).

At size levels of up to 1m, where most traditional technology (or maybe better to say – tools) is sited, the most important variable is manipulation of energy usage (up to 60% of the time), closely followed by use of material (Fig. 1). Thus, faced with an engineering problem, our tendency is to achieve a solution by changing the amount or type of the material or changing (usually increasing) the energy requirement. In contrast, in biology the most important variables for the solution of problems at these scales are information and space (Fig. 1).

This can be illustrated by comparing the functionality of biological and manmade polymers, proteins and polysaccharides. It appears that biological systems have developed relatively few synthetic processes at low size, at which the contribution of energy is significant. For biological systems, the main variety of function is achieved by manipulations of shape, or combinations of materials at larger sizes achieved by high levels of the hierarchy where energy is not an issue. This is a very subtle biomimetic lesson: instead of developing new materials each time we want new functionality, we should be adapting and combining the materials we already have. Although this is already done to some extent, it is unclear whether this is adequately recognized as a significant route. We can also realise the potential of nanotechnology, which is to escape from the nano-approach as soon as possible, and progress to the creation of larger structures, which can self-assemble in a programmed manner. This is one of the most important trends that contemporary eco-innovation should follow.

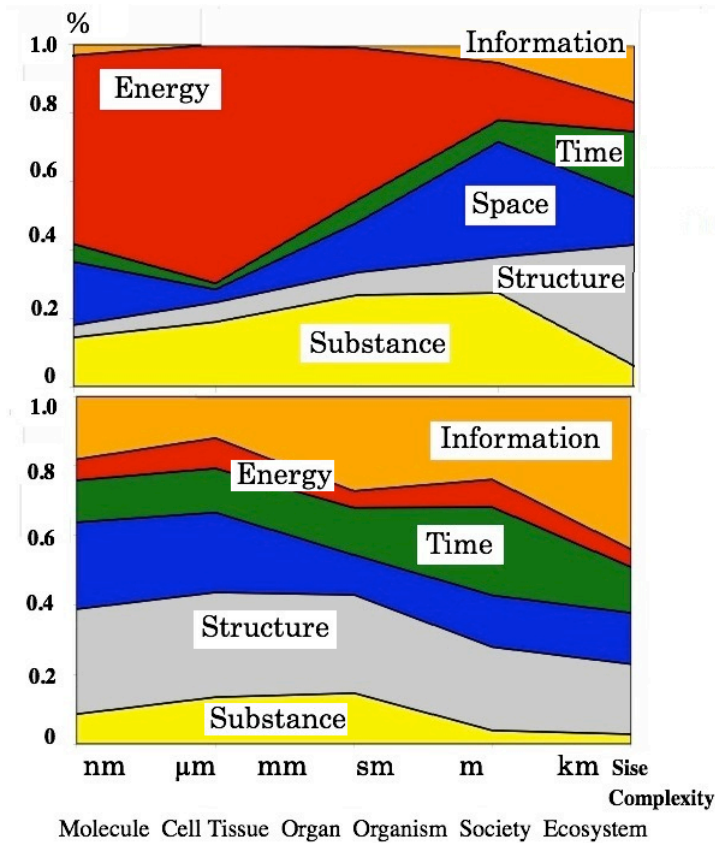


Fig. 1. How Technology (upper diagram) and Biology (lower diagram) address the challenges: “heat, beat, treat & waste” vs “ambient conditions, soft materials, problem prevention and recycling”

If we explore the graphs (Fig.1) deeper, we may notice that there are major differences at the minimum and maximum complexity scale. This means that these two extremes in complexity are largely contradictory in the way they are functioning, and therefore they are the most sensitive to any misbalance caused by human activity. This means that eco-innovation touches the most sensitive point on the largest scale of this graph, where differences in functioning can cause global problems and can potentially be a source of real disasters at all levels of our activity – from environmental pollution and people’s health problems to political conflicts and social unrest.

2.2 The ideal eco-innovation strategy: a win-win balance of biological and technological interests

Let us now focus on the similarities between ecology and economy. Many professionals hope to resolve the numerous problems of humankind by following the principles that can be found in biology. One of the most popular ideas that has emerged recently - a circular economy concept – is based on the phenomenon of cycles of matter and energy, a well known ecological mechanism [3]. In fact, this approach was manifested in the past in different countries and cultures. But now, the scale of both capabilities and problems of contemporary technology has increased enormously. The complexity and unpredictability of existing and emerging engineering systems has grown dramatically. Meanwhile extremely complex systems do exist in nature – natural ecosystems. Their adaptability, sustainability, self-perpetuating properties, and the long life span of some of them can serve as a model for arranging human mechanisms (social, economic, political and cultural) in a win-win fashion, and allowing us to get rid of undesirable, dangerous and harmful practices.

Contemporary technology does not have many of the necessary features that we find in living systems (Tables 1 and 2), but then again living nature is not totally useful for us – complexity, high unpredictability and vulnerability are not features we would like to transfer to our economy and society. Now we can clearly see the challenge for eco-innovation: to merge the advantages from both domains and get rid of the disadvantages. For Tables 1 and 2, we would like to capture the leftmost features, while casting off the rightmost ones.

In eco-innovation products, we would like to jointly capture all the advantages of technology and living systems, even if they are apparently contradictory. Some possible contradictory requirements to an eco-innovation product (machine, process) are:

- Limited functionality, but reliable and self-repairing.
- Adapted and adaptable.
- Fast changes and development, but precisely adapted to functioning conditions.
- Functionality beyond the limits of living systems, but should be recyclable – operating within the limits of an ecosystem.
- Complex and easy manageable.
- Recyclable (mortal) and everlasting.

Table 1. Living Systems: desirable and harmful features for engineering

Features of living systems which are useful for engineering:	Features of living systems which are not useful for engineering:
Reliable	Complex
Adaptable	Slowly evolving
Self-repairing	High uncertainty in behaviour

Self-regulating	Adapted to narrow specific conditions
Self-reproducing	Mortal
Recyclable	

Table 2. Technology: advantages & shortcomings

Technology: useful features	Technology: undesirable features
Limited functionality	Limited functionality
Fast changes and development	Complexity
Deterministic and automatic	Slow or limited adaptation
Functionality beyond the limits of living creatures	Require maintenance
	Short range of efficiency (“here, now and at any price”)

We suggest that our future ideal eco-innovation product or process should possess all the advantages of animate nature together with our current traditional technological achievements [5]. To merge the contradicting requirements, we use the BioTRIZ methodology described in the next section.

3. Methodology: brief description of tools and capabilities

Hundreds and thousands of years of technological development was driven by trial-and-error methodology, insight, serendipity and random discoveries. Eventually this approach proved that it couldn't provide predictable, reliable, and safe results – especially when technological systems become so complex that they start demonstrating dangerous and unexpected emergent effects. Only radically novel systematic methodology can provide the pathways for an inventive process with a guaranteed result. Such systematic methodology started to emerge in the twentieth century, and one of the most effective appeared to be TRIZ (known by the Russian acronym for Theory of Inventive Problem Solving) [6]. The following features make TRIZ a powerful analytical technique suitable as the basis for eco-innovation [2]:

- *Novelty*: TRIZ derives its strength from a set of inventive principles that have been defined through the analysis of more than 30,000 successful patents [4]. Its solutions are never average but radically innovative, by aiming higher than other creative approaches because it searches and deals with contradicting requirements on a win-win basis.
- *Reliability*: TRIZ leads us towards a solution systematically, therefore the result is guaranteed.
- *Capability*: TRIZ has been successfully applied to solve not only complex problems, but also problems perceived as otherwise “unsolvable”, where con-

flicting requirements are extreme (for example, an object should be both long and short, be present and absent at the same time, etc.).

- *Breadth*: Its problem-solving capabilities are superior, since its embedded innovative principles mirror a range of approaches to creative thinking. Moreover, its underlying process takes the user all the way from problem analysis to solution.
- *Depth*: As a creative methodology, TRIZ helps ‘imagine the unimaginable’ by going beyond perceived limitations and widening the horizon by probing deeper into a topic. Thus, TRIZ helps prepare for as yet unexpected successful solutions and also helps identify and mitigate unconventional threats.
- *Flexibility*: TRIZ has been shown to be adaptable to many different domains beyond its original remit in mechanical engineering. Its basic truths are transferable and applicable to any problem-solving domain. The content of the TRIZ online journal clearly supports this statement [7].

The vast sphere of innovation that deals with the consequences of negative effects from technology on the environment uses “pre-systematic” (or “pre-TRIZ” if you like) methodology – trial-and-error, inspiration and random search for the solution. These cure symptoms – not causes. The direct application of TRIZ to biosystems, according to issues described above in this chapter, is not always relevant [5], in spite of the seemingly “obvious” similarity of the domains involved. We have resolved the contradictive requirements from biology and technology (economy) described in Section 2.1 using TRIZ tools [2], and created a method to operate with systems that comprise living and non-living interfaces, and natural and artificial parts (e.g., agriculture, forestry, medicine, etc.). We develop and use the BioTRIZ method in various projects with industry and teach this method at our workshops. For example, one construction company in the UK successfully applied the BioTRIZ method to solve a problem in building construction. There was a need for free cooling without losing the insulation properties of houses in extremely continental climates where days are hot, but nights are cold. The BioTRIZ method led to the development of two new environmental building technologies: an infrared transparent insulation and a concrete formwork, made from biodegradable starch foam to achieve a much better end-of-life profile compared to other materials [7].

3.1 BioTRIZ axioms for eco-innovation: a win-win resolution of conflicts between the economy and ecology

At the beginning of the seventies, a holistic and constructive approach was undertaken with the appearance of *permaculture* (*permanent* + *agriculture*) – the conscious design of artificial ecosystems, which should possess the productivity and benefit of conventional agricultural systems combined with the self-dependence, elasticity and self-serving features of natural ecosystems [8], [9].

Achievements of permaculture are impressive, and it appeared that this approach can be applied not only in agriculture (the initial realm of application), but also in forestry, fishery, architecture and construction, energy supply, transport and even to economy, education and culture.

As any methodology starts with axioms and theorems, we can consider BioTRIZ axioms for eco-innovation. The means of introducing biology into engineering is indicated in the left column of Table 3, showing the difference approaches to innovation in biomimetic engineering.

Table 3. BioTRIZ axioms for eco-innovation

Biology – to engineering: biomimetics	Engineering – to biology: eco-engineering
Axiom of simplification: reduce the functionality of a biological prototype for an engineering design.	Axiom of maximization of useful function: add as many beneficial functions as possible to the ecosystem.
Axiom of interpretation: instead of copying, interpret the essence of a biological mechanism/structure/function or strategy into engineering language.	Axiom of interpretation: engineering functions and strategies that we would like to see in the ecosystem need to be interpreted into biological language.
Axiom of ideal result: if you still want to copy, do not copy the means of providing a function, copy the result of the function.	Axiom of ideal result: maximum benefit/profit for humans should be achieved only with super-optimal functioning of the ecosystem.
Axiom of contradictions: translation of “What?” (engineering target) into “How?” (answers from biology) should be done via aggravated statement of conflicting requirements.	Axiom of contradictions: eco- and human-requirements are usually contradictive. Any engineering manipulation may cause damage if interests of the ecosystem are not taken into account.

The introduction of technological features into biological systems (forestry, parks, agriculture, etc) requires a different approach than biomimetic engineering, and is shown in the right column in Table 3. The BioTRIZ axioms make the two directions of the knowledge-transfer process mutually compatible and less contradictory. Biomimetics and eco-engineering can be considered as two parts of the eco-innovation strategy as they both target to get maximum benefit for economy knowledge about living nature (Table 3).

3.2 BioTRIZ rules for eco-innovation from ecology

To develop BioTRIZ rules for eco-innovation we used the very basic concept from ecology: r- and K- development strategies of survival of organisms/species or ecological systems [10]. These strategies relate to cycles, energy and matter resource management and even indicate system readiness for change [8].

The r-strategy is characterized by fast-reproducing, short-lived and ‘cheap’ (in terms of resources spent on raising an offspring) individuals. The r-strategy is also characterized by fast adaptation and is therefore more common in unstable environments with abundant resources. This strategy is common for the initial stages of ecological succession – the beginning of the cycle of an ecosystem life. The K-strategy is characterized by successfully competing for scarce resources, a constant size of population/system and being constantly close to the carrying capacity of the environment. Slower reproduction and long life expectancy are also traits of the K-strategy. Both the K- and r-strategy strike a balance between opposite trends in productivity and production: the beginning of the cycle ecosystem consists of highly productive species with a cheap brood, but with low biomass production (for example annual plants, grass meadow, microscopic algae). Closer to the climax of an ecosystem cycle it consists of K-strategy species with high biomass production, but lower productivity (trees, large predators – such bears, tigers, whales, etc.) [10]. Knowledge of these phenomena can be used in designing new systems or revitalizing existing ones and should be the main guide for eco-innovation.

Following the maximum profit ideology of our economy, we need both types of strategies: maximum production and maximum productivity; durability and easy recycling; cheap production and high demand - produced with minimum resources, but is a valuable resource itself. All these contradicting requirements are resolved by the following BioTRIZ rules for eco-innovation:

1. Everything is a resource, if and only if it is there at the right time, in the right place, in the right dose, in the right mode, for the right consumer. If any of these compulsory conditions are not fulfilled, a valuable resource turns into pollution, waste, direct damage or potential harm. So, the rule for waste management is – find the right time, place, dose, mode or user so that any waste becomes a valuable resource.
2. Manufacture a product in minimum number of steps, but use it in maximum number of steps.
3. Any product should be either inert/everlasting (K-strategy) or easily degradable (r-strategy). Analyse the properties of a product, classify them into K- and r- categories, and modify the product or process properties to follow the rule above.
4. Products of degradation should not be harmful for the ecosystem (see resource definition in rule 1) and should be included as natural ingredients in natural cycles.
5. To avoid a misbalance in the ecosystem, use only local resources that are already present or available within the given ecosystem.

What we should avoid:

- Over-exploitation of a resource, system or process;
- Under-exploitation of the resource, system or process;
- Blind mechanistic imitation of successful models in living Nature;

- Maintaining the same state of a system in a changeable environment;
- A new system should not aggravate the existing ecological *status quo*.

4. The eco-innovation project BOMBORETUM as an illustrative example of BioTRIZ axioms in action.

We have developed BOMBORETUM, which is the layout architecture for an eco-park that takes into account technological needs, generates profit and provides the revitalization of damaged ecosystems. The origin of the name BOMBORETUM is in two words: “Bombus” is the Latin name for a bumblebee and “arboretum” is a nursery for trees, bushes and shrubs. This case study is an example of eco-innovation in the context of introducing technological, engineering features to living nature.

Eco-parks can play an important role in aiding the sustainability of ecosystems that bear the load of an urban environment. Any terrestrial ecosystem is based on plants, which provide the primary organic resource for the whole ecosystem as the result of photosynthesis. (By the way, at this stage CO₂ is excluded from the atmosphere, and it is essential in the contemporary global climate situation). And to make maximum yield possible and provide for the well-being of flowering plants, it is necessary to guarantee the pollination process. One of the most essential elements of terrestrial ecosystems is a wild pollinator. These beneficial insects can be called “flowers’ legs” or “love messengers” that allow plants – which are far away from each other and cannot move to “mate” with each other – to transfer pollen from one flower to another. Thanks to pollination, we get seeds and fruits.

When agricultural fields are surrounded by a healthy natural ecosystem that consists of all the compulsory elements (including its “reproductive system” – wild pollinators) we take for granted that these crop fields bloom and give yields. Wild pollinators do their invisible job and also help agriculture by pollinating fruit trees, bushes, vegetables and herbs. When the population of pollinators decreases, crop yields inevitably drop. This happens due to the uncontrollable pressure of human activities (chemical application in agriculture, constant tillage, grass mowing and/or kettle grazing, various types of pollution, etc.). In most cases “reversing” the scenario is difficult: natural ecosystems are never restored from agricultural landscapes to the initial wild form. But it is possible to compensate for the distorted systems with relatively simple measures by maintaining and facilitating the crucially important parts of ecosystems – its “reproductive organs”, or wild pollinators.

The simplest way to protect an environment is to not touch it at all. However, this is not a good strategy for damaged ecosystems that have already appeared below the threshold of possibility of being able to recover without our help. Moreover, there are no methods of keeping natural ecosystems above this threshold.

BOMBORETUM is the first working model for the active recovery of a damaged ecosystem with added value for the economy.

The best pollinators in the world are insects. Bees are among the most adapted for this function (there are 20 thousand different species of bees!). Common honeybee apiaries are valuable, but are not able to provide pollination for all plants due to natural limits of these insects (short proboscis, nectar and pollen preferences, climate and weather restrictions – bees do not like rain and extreme temperatures, etc.). That is why we need specially reared wild pollinators for getting seeds and fruit from crops (e.g., the solitary bee *Megachile rotundata* for alfalfa crops, and bumblebees for vegetables and berries in green-houses – cucumbers, peppers, tomatoes, egg-plants, raspberries, straw-berries, etc.). Industrial companies which grow pollinators yield multi-million profits in the Netherlands, Belgium, Canada, Israel, Japan, etc. The less expensive strategy of obtaining pollinators is to provide them with artificial domiciles in the required numbers and nectar- and pollen-plants as food sources. This approach was successfully practiced in Canada, Australia, New Zealand, Russia, Poland, France, etc.

To rear wild pollinators in an artificial environment and to then introduce them into the wild is not a good idea – it is too expensive and does not guarantee successful naturalization. To resolve these issues, we decided to create a sustainable and self-reproducing, self-perpetuating eco-mechanism that will work by itself and give the maximum effect [11], [12], [13]. Different parts of this park were implemented, tested and proved in the Central Siberian Botanical Garden of the Russian Academy of Sciences (Novosibirsk, Russia) [12].

Let us follow the BioTRIZ axioms for eco-innovation to design this eco-park.

- Axiom of maximization of useful function: add as many beneficial functions as possible to the ecosystem.

We need to provide a super-optimal environment not only for pollinators and plants, but also for people – the users of the park, who get an immediate profit (from the fruit and seeds of the crops) plus a nice and educational recreation area. We are going to design a meadow with an additional unnatural functionality – everlasting blooming, unlimited access for pollinators to food and nesting zones, high yield of beneficial crops (berries, fruit, herbs, seeds, etc. with efficient technology of harvesting and service). In addition, BOMBORETUM is a recreation area and should possess functionalities to support this aim.

- Axiom of interpretation: engineering functions that we would like to see in the ecosystem need to be interpreted into biological language (Table 4).

Table 4. Biological interpretation of engineering functions

Requirements from machinery and management	Engineering function interpreted into ecosystem design
Machinery is designed to process large uniform areas.	Minimal outer borderlines to minimize the outer impacts on the inner environment.

Less plant diversity is preferable; all the agricultural machinery is adapted to monocultures.	Continuously blooming plants during the summer provide colonies with pollen and nectar.
Single harvesting process, after which there are no blooming plants on the field.	Plants with different flower depths simultaneously blooming to prevent competition among different bumblebees' species, because different species of bumblebees have different length of proboscis.
Park should be a busy place to make a profit.	Diverse environment due to segmentation of the foraging area as bumblebees keep to their own territories.
Parks are never quiet due to visitors and noisy play-areas.	Nesting zones should be separated from foraging zones by 20-25 metres, because bumblebees do not forage near their nests.

- Axiom of ideal result: maximum profit for humans should be achieved only with super-optimal functioning of the ecosystem part of an eco-machine.

Let's define what is an ideal eco-machine:

- Sustainable: provide the conditions for a self-regenerating ecosystem – plants and their pollinators.
- Cost-efficient maintenance – allowing a “mass-production” strategy with use of existing machinery.
- Simple and regular layout that allows safe crowd management and health and safety, as well as convenient operating with the existing agricultural machinery.
- Attractive place for human recreation and for nesting and foraging of wild pollinators.

Desirable features can be achieved if we replace the natural reserve of these beneficial insects with laboratory rearing, but it is still very expensive: even under industrial breeding, one bumblebee colony's price is \$70-150 (USD). This solution does not match the ideal result axiom formulated for humans/engineers. So, this means that bumblebees should stay “self-serving”, i.e. sustainable mode of existence. This can be achieved by the following measures:

- Decreasing the contrast of the environmental conditions inside and outside of the reserve. This is a typical compromise and is not perfect. It is not a win-win solution at all.
- Creating a network of small nature reserves instead of one.
- Creating a “nomadic reserve” – alternating reserves of small territories for 1-2 years each.

All these options do not suggest a radical win-win decision, as they do not match both the technical and natural ideal result's requirements. We therefore need to apply the next axiom – the resolution of contradictive requirements – to strike a win-win balance.

- Axiom of contradictions: eco- and human-requirements are usually contradictory. Any engineering manipulation may cause damage if the interests of the ecosystem are not taken into account.

To protect the natural populations of bumblebees, small nature reserves (from 1 to 5 hectares) were established throughout the agricultural landscapes. However, unexpectedly, the number of bumblebees decreased rather than increased. This happened because the accumulation of parasites, natural enemies, and diseases were activated at full strength, and there was a high rate of mortality due to competition and other population growth regulative mechanisms. Thus the micro-reserve worked as a huge “meat-grinder” which was draining the surrounding territories of bumblebees and destroying them constantly. In other words, the small-sized nature reserves brought harm and damage instead of the expected benefit. Following the axiom of ideal result, we can create a crucial requirement: the natural reserve must exist and at the same time must not exist, plus some more contradictions presented in Table 5. This is a contradiction that the BioTRIZ method is looking for! Now it should be resolved by win-win strategies – inventive principles. Let’s first consider the different possibilities.

Table 5. Ideality in ecological and engineering contexts

Ecosystem requirements (from the position of bumblebees and plants)	Requirements from machinery and management
Individual foraging patches should not be larger than 100 square meters.	Machinery is designed to process large uniform areas.
To be suitable for different species of pollinators, the variety of plants should provide different lengths of nectar tubes.	Less plant diversity is preferable, all the agricultural machinery is adapted to monocultures.
Bees require blooming plants during all seasons.	Single harvesting process, after which there are no blooming plants on the field.
Nesting zones for wild pollinators should be isolated.	The park should be a busy place in order to make a profit.
Bees should not be disturbed.	Parks are never quiet due to visitors and noisy play-areas.

Now we can start to design “the ideal reserve” layout. To minimize the borderline of the reserve, it should be circular. To minimize the borderline of the nesting zone, it should be circular. To provide the necessary distance from foraging spots, a nesting zone should be in the center of the circle. Thus, the foraging zone with blooming plants should be the wide ring (Fig 2). The foraging zone can be frag-

mented in the two ways (Fig.2 A, B) to provide more plant diversity: bumblebees, bees and other wild pollinators prefer flowers with different length of nectar tubes

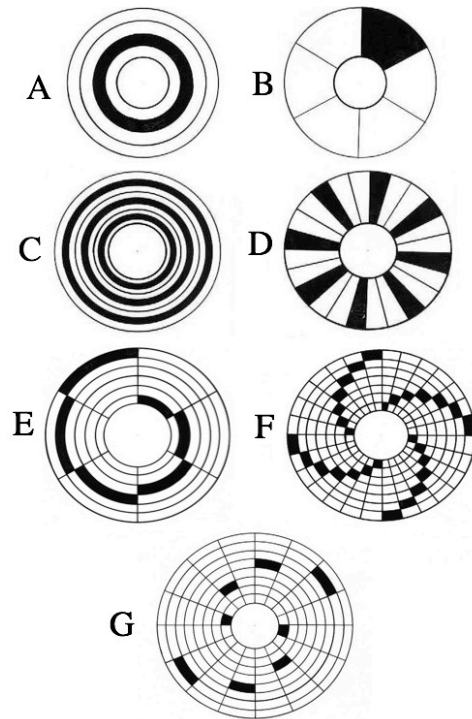


Fig. 2 Step by step process of the design of a park/recreation area that restores surrounding damaged ecosystems

Black zones - areas with blooming plants, central circle – nesting zone isolated from public; A, B - wide ring foraging zone: concentric or radial. C, D - large fields subdivided into more radial beams or concentric rings; E - single-spiral layout as a result of merging radial and concentric fragmentation; F - plain four-spiral layout; G. Two-spiral layout with the interruption of spirals along "parallel and meridian"

But bumblebees like small foraging patches! Radial patches or numerous rings are the possible answers to these requirements (Fig. 2 C, D). A radial highly segmented layout is not good, because bumblebees avoid foraging along lines – according to our observations spots for individual or group feeding zones have equilateral shape. A concentric highly segmented layout is even worse, because bees will concentrate within the nearest rings and will not use the whole territory evenly, which is detrimental to pollination and crop productivity.

The solution to these contradictions can be achieved if we superpose radial and concentric designs; divide the foraging zone into spots suitable for individual use

for bumblebees; make standard the optimal spot size for bees all over the blooming foraging area to reduce competition for nectar.

Following these ideas, a fragmented spiral appears “automatically”. If a park area and therefore foraging zone for bees is large enough, the spots of the fragmented spiral can exceed the optimal size (optimal size for different species of bumblebees is similar [12]). In a single-spiral layout, the rear blooming spot happen to be too large and bees may ignore it (Fig 2, E). To avoid this, it is possible to increase the number of spirals (Fig. 2, F). The larger the park is, the more spirals with different blooming plants we can introduce as well as the variants of their fragmentation – along the meridians or parallels (Fig. 2, G). The regular network of radial and concentric lines represent paved paths/roads, which is convenient for agricultural machinery to move along, as well as for visitors of the park.

So, BOMBORETUM has become technological system – “invisible rearing machine for natural eco-system” – while remaining a park and recreation area. Is it simple to operate and control? Is it sustainable (self-repairing, adaptive, self-regulated)? Does it need minimum resources and does it produce minimum waste? The answer to all these questions is “Yes” – this is an ideal eco-innovation product that comprises features and follows the “interests” of nature and technology. This makes BOMBORETUM manageable and profitable.

5. Conclusions

Technology is evolving very fast, giving people more and more power to change many aspects of living: lifestyle, health, culture, society, industry, economy and, finally, the ecosystem itself. We still are only a part of the whole biosphere and taking everyday decisions we should also consider its “interests” – this is the aim of eco-innovation initiatives. Eco-innovation manifests itself in two contexts: introducing biological principles into technology makes it more life-like and therefore eco-friendly, and adding technological features to ecosystems opening the opportunity for using nature to our benefit without causing it damage, misbalance or ecological catastrophe.

A tremendous difference in the way that human economy and living nature function causes a lot of problems in our days and is the main obstacle for spreading ideas of eco-innovation, making them profitable and attractive for business. We need to honestly face the conflicts between nature and technology and not just proclaim them and at the same time postpone action, leaving aggravated problems for our children to resolve. This happens because there were no methodologies to deal with contradictive requirements that are capable of merging incompatible things. The BioTRIZ methodology of facing and resolving contradictions in management and engineering contributes to eco-innovation initiatives by replacing a passive approach with elements of inspiration and irresponsible belief that nature is always perfect (perfect for whom?) by solid methodology. The BioTRIZ method described in this chapter is not only capable of facing and resolving contradic-

tions to strike a win-win balance, but also has tools for searching and revealing hidden conflicts and obstacles for eco-innovation.

The BioTRIZ rules and axioms for eco-innovation were presented, and the practical implementation of BioTRIZ axioms was explained in the case study of an eco-park. The design of the eco-park restores damaged natural ecosystems and produces extra value for agriculture, education and recreation – essential parts of any economy. This is a valid example of a win-win strategy, when local positive effects proliferate to global constructive consequences. This is what we call sustainability – local action with global positive outcome and this is exactly what the eco-innovation initiative aims for.

So, if this chapter makes you think first, then act in the following way, our aim has been achieved: do not avoid or dodge conflicting requirements and sidestep seemingly unsolvable problems, face (and even search for!) contradictions and resolve them on a win-win basis.

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