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Permaculture and TRIZ – methodologies for cross-pollination between biology and engineering

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Abstract

Theory of Inventive Problem Solving (TRIZ) was developed due to analysis and mostly for dealing with artificial engineering systems in 1950[th] of the twentieth century. Permaculture was developed as a method of engineering of artificial natural living systems in 1970[th] of last century. Permaculture (which is portmanteau word – PERMAnent + agriCULTURE) is ecologically balanced agriculture or ecological engineering and architecture of artificial super- productive ecosystem, which requires minimum of human interference and create minimum of negative environmental impact. Permaculture designs living eco-systems like engineers design and operate machines made of inanimate materials. Both methodologies were developed independently, but have a lot in common. In our paper we are going to compare these methodologies and show the points of mutual enrichment. We argue that both processes of knowledge transfer "from biology into engineering" and "from engineering to biology" can be done via TRIZ – Theory of Inventive Problem Solving.
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Keywords: TRIZ; permaculture; eco-innovation;

1. Introduction

People always dreamed about fantastic machines and devices. Fairy tales all over the world give us numerous examples. Humans always relate attributes of man-made devices with the natural prototypes: swim like a fish, fly like a bird, everlasting like oak, strong like a bear, beautiful like a flower, etc. And natural prototypes were considered much better than the man-made machines, because typically living natural systems ares reliable, adaptable and

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sustainable. This has been proven by millions of years of biological evolution. In our days we start taking ideas from biology and implement them in technology. This approach is called biomimetics [1].

But the contemporary technologies created the unique situation: now machines are often better than natural prototypes and we would like to see the features of the machines in natural systems. Especially this trends is explicit in industries that rely on biological productivity of agro- or wild eco-systems, environmental design, parks, recreation areas, etc. In such case we need the opposite trend – we need to introduce the engineering features to ecosystem we live in. At the beginning of the seventies, a holistic and constructive attempt to follow this trend was done by *permaculture* (*perm*anent + agri*culture*) – the conscious design of artificial ecosystems, which should possess the productivity and benefit of the conventional agricultural systems combined with the self-dependedness, elasticity and self-serving features of the natural ecosystems [2]. We may call this eco-engineering.

In the first case when we take ideas from biology into technology we make life-like technology, prescribe it features that used to belong only to living creatures [1, 3]. We are going to discuss potential shortcomings of the direct copying of natural living systems and suggest the win-win strategy for using biology in engineering design.

In the second case, where we want to embed technological features into living systems, the win-win strategy for such kind of marriage can be achieved by similar procedures that we suggest to biomimetic design. We argue that both processes of knowledge transfer "from biology into engineering" and "from engineering to biology" can be done via TRIZ – Theory of Inventive Problem Solving as the best knowledge-transfer technique [4]. TRIZ has its origin in technology and engineering, thus it needs careful and thoughtful professional adaptation to be relevant and workable in the biological domain.

1.1. What can TRIZ contribute to permaculture?

Engineering in ecology is the most difficult challenge due to high complexity and uncertainty of an ecosystem's reaction to a change we make (intentionally or not). TRIZ deals with complexity really well. On the other hand permaculture is very good at an acquiring multi-domain experience joining into a comprehensive system biology, agriculture, engineering and architecture of artificial super-productive ecosystem.

The importance of non-destructive, sustainable and highly productive agriculture is the imperative of our time. Win-win targets of permaculture are beneficial results both to humans and the whole biosphere. These "commandments" are stated at a very high level of abstraction, just like Ideal Final Result concept in TRIZ. Highly abstract principles of permaculture [1] can be turned into precise instructions using TRIZ in case precise problem definition is done and contradictions are revealed. In our paper we show this on the example of the universal bumblebee domicile's design.

1.2. What can permaculture contribute to TRIZ?

Permaculture has accumulated large number of well-validated empirical data – successful case studies. The main issue for permacultural designers (when they start to create a new system in the new conditions/environment) is HOW to transit from that high theory to practical solutions and decisions? In other words, there is a deep gap between theory and practice in Permaculture. Every permaculturist overcomes this obstacle intuitively with the help of his/her experience or by trial-and-error method. That means that permaculture with solid methodology of step-wise transition from those theoretical "dictums" to practical level will make this challenge predictable, reliable and repeatable. We have already tried and successfully applied TRIZ for permacultural challenges of various levels – from organism to ecosystem [5]. Permaculture contributes to TRIZ with its very well developed methods and examples of providing self-functioning in the engineering systems that include living component (TRIZ does not have much experience in operation with living systems).

2. Taking biology into engineering: challenges and advantages

Biomimetics is a relatively young branch of engineering, but 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 as we face the issue of the destruction of our planet's biosphere. Growing popularity of biomimetics in our days happens due to the wrenching changes, which contemporary society faces: ecological crisis, climate change and health-threatening pollution of the environment. It has appeared that the conventional engineering approaches do not necessarily work as effectively and efficiently, as we had expected. This is especially apparent if we take into account their global impact on our life. These issues have started to attract the attention of governments, media, architects, designers, engineers and the general public. No doubt that science fiction books, films, Internet discussion forums, computer games, and other media have warmed the public's interest in copying living Nature and seem to have turned it into a kind of fashion.

To make biomimetic procedure successful, the search for the most relevant biological prototype requires not only inspiration, but also highly professional biologists of broad profile on board working together with engineers. This encounters cross-cultural obstacle – engineers and biologists speak different "languages" and employ different methodologies [6]. The most successful projects include an engineer with biological education or biologist with engineering education. That is why there should be the third person in a team – a professional interpreter from biology into engineering. To interpret from the biological "language" into engineering procedures and means is not a trivial challenge. This looks similar to translation from one human natural language to another. So, the result of biomimetic design process often does not look like the prototype, but BEHAVES like it [6]. Engineers are getting the desired functionality of their artifacts from biology; therefore biomimetic translation procedure is structured aiming towards engineering interests and goals.

3. Taking engineering to biology: what changes are required in the conventional TRIZ to target ecologically-sound innovation?

Are there any empirical achievements in engineering approach within the contemporary ecology? Currently this pool of successful permacultural achievements is very impressive, because it appeared that this approach can be applied not only in agronomy (the initial realm of application), but also throughout the whole agriculture, forestry, fishery, architecture and construction, energy supply, transport and even in economical and cultural sphere as well. Permaculture can be considered as eco-engineering, because it claims to achieve maximum functionality useful for humans from natural eco-systems with minimum of human labour and ideally – totally self-dependent. Similar to biomimetics it needs solid methodology to reduce high risks of such projects. There are common assumptions that all conservation projects are not profitable and biomimetic engineering is extremely expensive. This happens because there are no methods and procedures designed for such challenges. Therefore the simplest way to protect an environment – is not to touch it at all. This is not a good strategy for seriously damaged eco-systems that appeared below the threshold of possibility to be able to recover themselves (without human help). Moreover, there are no methods to keep natural eco-systems above this threshold. We do not know how to help; we do not have a method of doing this. Eco-engineering results are aiming towards the biology rather than technology and therefore its methods should be different.

4. Taking biology into technology and *vice versa*.

Due to sufficient differences of biological and technological domains we need to deal with different issues while merging biology with technology and embedding engineering features into living systems. These two processes require different approaches and methods. To address this difference we suggest Axioms for translation from biology into engineering and backwards.

The interpretation technique for biomimetics is based on TRIZ (Theory of Inventive Problem Solving) with sufficient improvements and adjustments to the biological peculiarities (BioTRIZ) [1,3]. This algorithm for biomimetic design is described in our paper [6]. Here we only state the very general principles on which we build the process and procedure of knowledge transfer. We call these methodological statements axioms (the left column of the table 1). Interpretation and transfer from technology into biology requires different approach and mechanism, which just started to emerge in permaculture (table 1, right column). Adding TRIZ to the permaculture design principles makes these two opposite direction of knowledge-transfer process less contradictive and mutually compatible.

Table 1. Axioms for merging biology and technology

Biology – to engineering: biomimetics	Engineering – to biology: eco-engineering
• Axiom of simplification: reduce the functionality of a biological prototype for the engineering design.	• Axiom of maximisation of useful function: add as many new beneficial functions, as possible to the eco-system.
• Axiom of interpretation: instead of copying interpret the essence of a biological mechanism, structure, function or strategy.	• Axiom of interpretation: engineering functions and strategies that we would like to see in eco-system 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 eco-system part of eco-machine.
• Axiom of contradictions: translation of "What?" (engineering target/question) 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 eco-system are not taken into the account.

The reliability, adaptability and sustainability of biological solutions were proved by millions of years of biological evolution on our planet. We bring together the use of classical TRIZ and Biomimetics by adapting TRIZ problem-solving algorithm to serve as a framework for interpretation procedures from biology to engineering [7].

TRIZ initially was created for the conventional (i.e. non-living) engineering systems, so it requires adaptation and adjustments to the living parts of complex agricultural systems. This adaptation resulted in emerging of a set of tools and procedures that we have called BioTRIZ. The BioTRIZ method was tested and successfully applied not only to permaculture [6], but also for biomimetics, management, psychology and even conventional engineering problem-solving process. Often our customers preferred BioTRIZ approach to target "Bio-", "Eco-" and "Green-" strategies in technology development, as they are important in our days.

5. Example of application of the BioTRIZ axioms in agriculture.

Axioms for putting biology into technology were presented by us at ETRIA 2012 symposium and published in the proceedings [5, 6]. Now we are going to illustrate the opposite process – implementing engineering approach in management of biological systems.

It is well known that wild pollinators are essential part of any terrestrial ecosystem. 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 in the contemporary world fauna!). 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 that 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.

Bumblebees are among the best of these beneficial insects, because they perform their pollinating function sufficiently more effective and efficient than honeybees. But the point is that bumblebees establish their nest wherever they want, and farmers need them close to their crops. One of the natural and cheap methods is attracting bumblebees into the artificial domiciles (nest-boxes), which are placed around the agricultural fields [8]. A typical nest-box look like a bird-box (20x20x20 cm) and attached to a pole or a tree (Fig.1, a). Some bumblebees species prefer it under the ground (Fig 1, b). Boxes are provided with some nesting material (dry moss, wool, grass) for thermo-insulation of the comb. Bumblebees occupy these boxes, establish colonies and perform their beneficial function as crop pollinators.

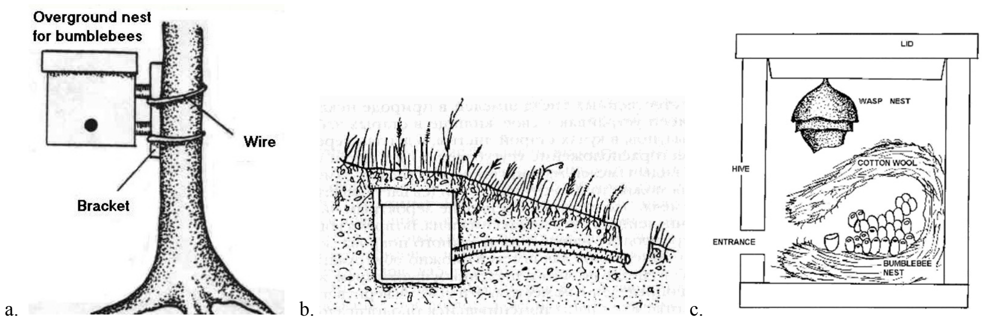

Fig. 1. Artificial domicile for bumblebees: (a) above the ground position; (b) Underground position of the artificial bumblebee domicile; (c) Nest-box occupied with wasps and bumblebees (cross-section).

Super-optimal environment for nesting causes a serious problem: in spite of the surplus places of nesting we provided for bumblebees, the cases of co-habitation or attempts of co-occupation of the same nesting box were regularly registered. This results in long and exhausting hostile competition, which may end up either wasps or bumblebees victory. But winners are so weakened that often die soon also.

In other words we can formulate the main contradiction – we need to get rid of wasps AND at the same time we need to accommodate them as close as possible.

To combine these two opposite trends, obtaining benefit and eliminate harm, the doubled nest-box was designed with the help of axioms described above (fig 2).

Axiom of maximization of useful function: add as many new functions, as possible to the eco-system, which is beneficial for us. – We eliminated negative effect of close co-habitation of bumblebees and wasps, but created maximum of useful action of this interaction – mutual stimulation, which resulted also with the maximum benefit for humans – pollination of crops (mainly by bumblebees and partly by wasps) and pest-control (by wasps). Surely we could install two conventional (single-compartment) nest-boxes close to each other. But it is obvious that the double one is better, because it economizes material (timber and screws), labour to manufacture and it also has better thermo-insulation properties.

The upper compartment is provided with cotton wool, moss, dry grass or other fiber nesting material (ideally taken from rodents' nests). It is to be chosen by the bumblebees. And the lower compartment is left empty. That is why bumblebees are unable to inhabit the lower chamber, because there is no soft debris (dry grass, moss, leaves, wool). On the other hand, wasps prefer empty cavities without any debris. The lower compartment is left empty (which is more attractive for wasps) and is inhabited by wasps. To prevent wasps completely from occupying the upper compartment we covered its ceiling (the internal surface of the lid) with paraffin or polyethylene film – such surface does not allow wasps to attach their comb.

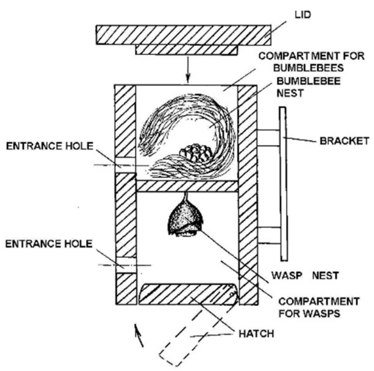

Fig. 2. Double-decker artificial domicile for bumblebees.

This design decreases the tension of competition and excludes conflicts between wasps and bumblebees completely. On the other hand getting rid of negative side of competition, we preserved the stimulating effect of close co-habitation of wasps and bumblebees. Our field tests showed that it works, also saving timber and improving insulation of nests, comparing with two traditional singular detached domiciles (fig. 1).

Let us follow the BioTRIZ axioms for eco-innovation to resolve this challenge: merge dangerous co-habitation phenomenon with useful social facilitation phenomenon on win-win balance. This simple, efficient and effective solution was based on the axioms that we formulated:

Axiom of interpretation: engineering functions and strategies that we would like to see in eco-system need to be interpreted into biological language. We have not applied any repressive measures to get rid of negative effects, but used positive strategy and only biological stimuli – we offered for both conflicting parties the required nesting cavities.

Axiom of ideal result: maximum benefit/profit for humans should be achieved only with super-optimal functioning of eco-system part of eco-machine. This means – no competition and maximum population growth: we are maximizing value, creating "unnatural" natural environment that works both for our benefit and supports ecosystem reproduction. We offered to bumblebees and wasps not only artificial domiciles, but the most desirable (super-optimal) conditions – the life of insects in the double nest-box excludes competition and provides the super-optimal conditions (mutual stimulation of bumblebees and wasps, better thermo-insulation of both compartments).

Axiom of contradictions: eco-system and human-requirements are usually contradictive. Any engineering manipulation may cause damage if interests of eco-system are not taken into the account. In our case the initial situation contained contradiction not only between insects' conflict and agricultural (human) interests, but there was conflict between bumblebees and wasps. When the new double nest-box was introduced – all the conflicts and contradictions were resolved on the win-win basis.

In fact the double nest-box resolved physical contradiction (wasps should be present *and* absent in the artificial domicile at the same time) with the help of separation in space (the internal cavity of the nest-box is separated into two compartments).

The resolving of the conflicting requirements between wasps and bumblebees was achieved also with the help of the following inventive principles: "Segmentation" (1) – the box is segmented into two halves; "Another dimension" (17) – the nest-box is designed as "a double-decker" system. "The other way round" (13) – instead of elimination of wasps – they are attracted to the nest-box; "Blessing in disguise" – turn harm into benefit (22) – competition between bumblebees and wasps turned into mutual stimulation, which increases the rate of successful occupation of domiciles. "Feedback" (23) – mutual stimulation of the previously competing parties is the example of the positive feedback. "Self-service" – bumblebees and wasps self-serve in the process of establishing their colonies as well, as self-regulate their relationships without human intruding.

According to philosophy of permaculture: if something is made correct, the consequences of it could be even more positive than you initially expected. Indeed this novel domicile for beneficial insects possesses extended positive effects not only for insects, but also for the whole ecosystem, agriculture, manufacturing process, maintenance, etc.

6. Conclusions.

Human technology is evolving very fast, giving people more and more power to change many aspects of living: industry, lifestyle, health, culture, society, economy and, finally - the ecosystem itself. We 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. Green technology as an innovation strategy 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 opens the opportunity for using Nature to our benefit without causing damage, misbalance or ecological catastrophe to it.

A tremendous difference in the way that human economy and living nature causes a lot of problems and is the main obstacle for making biomimetics profitable and attractive for business. We need to honestly face the conflicts between Nature and technology and address these contradictions using adapted TRIZ – BioTRIZ methodology. The processes of knowledge transfer both "from biology into engineering" and "from engineering to biology" can be done via careful and thoughtful adaptation of TRIZ. BioTRIZ axioms are only a small but important part of the whole theoretical background for the method we developed after ten years of research and experience in TRIZ. An illustration of the above mentioned axioms is presented on the example of the bumblebee domicile design. It shows a win-win strategy, when local positive effects proliferate to broad positive consequences. This is what we call sustainability – local action with global positive outcome and this is exactly what all “green” initiative aims for.

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