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INTRODUCTION OF THE IDEALITY TOOL FOR SUSTAINABLE DESIGN

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Abstract

Sustainability strategies in nature are studied, translated to design principles and used as a base for bio-inspired sustainability tools such as the life principles and the ideality design tools. While the life principles tool reflects a holistic view, the ideality tool is derived from a technical view that might be more inherent and applicable for engineers, observing biological systems as if they were technical systems.

In this paper we demonstrate how to use the ideality tool by two case studies. The first one demonstrates the tool in a sustainable design context and the second one demonstrates the tool in a biomimetic design context. In addition, we describe an experiment that compares the ideality tool and the life principles tool. Both tools have a major value as sustainability tools and there is no difference between them in terms of users' perceptions regarding the tool. However, the ideality tool has an advantage in terms of the tool validity. Students who used the life principle tool significantly missed more sustainability criteria identified by experts compared to students who used the ideality tool.

Keywords: Bio-inspired design and biomimetics, Conceptual design, Sustainability

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1 INTRODUCTION

1.1 Sustainability tools

Sustainability, a present need and one of the major challenges of humanity today, should be addressed during the design stages that determine most of the environmental impact (Fitzgerald et al., 2005). Sustainability design tools are used to implement sustainability during the design process or to assess sustainability levels of a given system. They may be classified into one or more of three basic categories according to their function (Faludi, 2012): (i) Suggesting specific design ideas (strategies) – guide the designer in what to do. (ii) Setting priorities / focusing attention (objectives) – clarify what are the design objectives and where to focus the attention and budget. (iii) Keeping score (metrics) – help to measure whether the objectives are met. All the three are needed for an effective sustainable design process.

1.2 Bio-inspired sustainability tools

Seeking nature guidance for sustainable models and measures is reasonable and has expanded in the last years as part of bio-inspired or biomimetic design. Biological systems are a source of inspiration for sustainable solutions as they operate within restricted living constraints without creating waste or irreversible damage to the ecosystem. On the contrary, they enrich and sustain the ecosystems. Nature forms and structures provide a wide range of properties with the minimal use of material or energy. Nature manufacturing processes are conducted within life and therefore avoid high temperature, strong pressures or toxic materials (Benyus, 1997). Nature systems demonstrate efficient flows of energy and material and nature products are recyclable.

Most of current bio-inspired sustainability tools are pattern based. Patterns are abstractions of design solutions; they build analogies between observed solutions and problems, and are used to transfer knowledge across domains (Hoeller et al., 2007), (Goel et al., 2011). In the context of sustainability, patterns are design strategies and principles that repeat in nature and promote sustainability of biological systems.

This pattern based approach makes a bio-inspired sustainability tool an appropriate tool for the design concept stage. Early design stages lack detailed information that is usually required for sustainability assessment such as material and energy consumption. *Life Cycle Analysis* for example is a design tool that requires such detailed information (Tukker, 2000). Bio-inspired design tools do not require a detailed list of energy and material consumption, but an implementation of certain patterns, design strategies or principles.

The pattern based approach yields lists of design patterns, strategies or principles that can be used as checklists tools, providing criteria, issues, aspects, guidelines or principles to be integrated and assessed during the design stages. Such checklists are intended to ensure that potentially significant environmental issues are identified and considered as a basis for judgmental decisions. Checklists are relatively easy to use, but they not necessarily cover all the requirements, and may require time to check each item separately. Next we describe two major bio-inspired sustainability tools.

1.2.1 The life principles tool

Life principles are considered sustainability strategies that nature follows in order to survive, subject to earth operating conditions, limits and boundaries . Various attempts have been done to define the life principles (Benyus, 1997), (Hoeller, 2007), (Zari, 2007). The core knowledge is summarized in the *life principles* framework of Biomimicry 3.8.[1] The tool is rich and includes six major strategies and twenty design principles. A designer who implements these strategies and principles during the design stages may foster sustainability. However, some of the life principles are general and their application in engineering is neither clear nor straightforward. There is not much evidence for their practical use in the academic literature. In addition, it is unclear how they were revealed and how to search for new ones.

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[1] http://biomimicry.net/about/biomimicry/biomimicry-designlens/lifes-principles/ [Accessed 24.01 2013].

1.2.2 The ideality tool

The *ideality* sustainability tool was developed to address the limitations of the *life principles*. The *ideality* tool is derived from TRIZ, the theory of inventive problem solving (Altshuller, 1999). According to TRIZ, ideality is defined as the qualitative ratio of system useful functions to its harmful functions. Useful functions are the benefits that the system provides and harmful functions are the undesired costs or the system operation, such as recourses, noise, waste, pollution, etc.

The relation between the terms sustainability and ideality is clear and previously discussed (Helfman et al., 2014b). Due to a competition on resources, biological systems must demonstrate ideal architecture, structures and processes in order to "achieve more with less" and sustain. Ideality was already a base for the development of practical eco-guidelines for product innovation and sustainability (Chen and Yang, 2011, Russo et al., 2011). Here, we offer a new sustainability tool, a list of ideality strategies in nature, representing sustainability strategies and design principles in nature, formulated with TRIZ technical view. This tool, presented in Table 1, provides also a framework to lead a search for more sustainability strategies in nature, based on the TRIZ ideality framework. An analysis of biological systems by the *ideality* framework led to identification of repeated ideality strategies and design principles in nature. The analysis rational and results including selected examples are presented elsewhere (Helfman et al., 2014b).

In this paper we move one step forward and introduce how to use the *ideality* tool as a sustainability tool in general and for biomimetic design in particular. We provide two case studies demonstrating how to use the tool and describe an experiment to assess the *ideality* tool vs. the *life principle* tool.

Table 1. Nature Ideality strategies & design principles

	General Strategy	Design Principle
Increase Benefits	More Functions	1) Multifunctional Design - Increase the number of functions that are related to one structure by unification of system parts.
	Stronger effect of one function	2) Intensify the interaction with the environment to achieve extended or stronger effect of one function by: ✓ Repetition of elements ✓ Increased surface area
Reduce Costs	Defensive Strategy- Preventing disturbances and harmful effects. Saving the costs of disturbances	3) Reduction of disturbances such as friction, loads, turbulence and more by structures
		4) Decrease of surface area when it has harmful effect
	Opportunist Strategy - Usage of available resources to save costs	5) Usage of physical, chemical, geometrical and other effects and gradients as energy resources- saving energy costs
		6) Adjustment of structure to function: structure provides the function- saving material costs
		7) Transferring some functions to the supersystem (saving material costs). Using super-system material resources
	Prevent waste for better usage of resources	8) Synchronizing system parameters to prevent waste
		9) Improving the conductivity of energy through the system to provide easier access and prevent waste of energy
		10) Give up redundant parts

2 THE IDEALITY TOOL - CASE STUDIES

The *ideality* tool has two major uses. First, it is a tool for sustainable design, not necessarily in a biomimetic context. *Ideality* tool is a list of sustainability strategies and design principles. The source of these strategies and principles is nature and in that manner they are bio-inspired, but once they are defined they can be used as any other sustainability checklist tool.

Second, it is a tool for addressing sustainability aspects of biomimetic design. It is clear that imitating nature solution per se, without an intention to implement nature sustainability design principles, is not a guarantee for sustainability. In fact, the relation between biomimicry and sustainability is questionable. A product may be designed based on a nature innovative mechanism but later manufactured using toxins or large amount of energy. The *ideality* tool addresses this need for intendedly integrating nature sustainability aspects during the biomimetic design process. In the context of biomimetic design the *ideality* tool serves two purposes:

(i) Analysing sustainability aspects of an observed biological system in order to implement them in the biomimetic solution.

(ii) Assessing sustainability aspects of a biomimetic solution compared to the biological system –Did we lose some degrees of ideality / sustainability during the biomimetic transfer?

Table 2. Design concept suggestions for an ideal multiphase bicycle

Increase benefits	
More functions	**Multifunctional Design** 1. Multiphase bicycle – Modular design enables to use the bicycle during different phase of the infant physical and mental development. By a possibility to add or remove the auxiliary handle or wheels, changing the size and height of the spear and seat or changing the distance between wheels or the size of the wheels, one may adjust the bicycle to different development stages and ages during childhood. 2. Board Wheel – the wheel surface will be used as a board to sketch a map or impressions during the ride breaks. 3. Folding mechanism – enables to fold and carry the bicycle in a bag or car trunk. 4. Inflatable chassis or wheels – adapt to changing storage room. 5. Auxiliary handle functions as a steering device that can substitute the spear when necessary.
Reduce costs	
Stronger effect	1. Stronger grasp in ground (by repetition of tire grooves). 2. Stronger grasp in ground (by larger surface contact between the tires and ground through the use of small protrusions on wheel, or by larger tire width).
Defensive strategy	**Reduction of disturbances** 1. Prevent wheel punctures (by airless tires made of fully structured material). 2. Prevent contact of clothing or legs with shrubs. 3. Defend the chassis against corrosion and other weather injuries (through coatings technologies).
Opportunistic Strategy	**Usage of physical, chemical, geometrical and other effects and gradients as energy resources** 1. Using the cycling energy for transportation/ light (via Dynamo). 2. Using heat energy.
Prevent Waste	**Synchronize system parameters to prevent waste** 1. Synchronizing the bicycles characteristics such as size, height and auxiliary devices to the child age, prevents waste of money. 2. Synchronizing bicycles feedback with riding performance - Emotional & physical self-feedback system provides the rider a feedback on his stability and balance (vocal feedback system). This feedback system prevents an emotional waste of frustration, physical waste of injuries and time waste by a shorter learning curve.
	Improve the conductivity of energy through the system to provide easier access and prevent waste of energy Pedals positioning system: One difficulty of children is to stop the pedals in the right position to launch the ride. This pedals positioning system locates the pedals in the right position for launching rides. The child just need to step on the pedal and does not need to locate it in the right position. This feature may facilitate the ride in young ages. It can be abolished in older ages when eye-body coordination is better developed.
	Give up redundant parts 1. Unnecessary parts such as auxiliary handling system, auxiliary wheels or pedals positioning system are removed when the child is getting older and does not need them. 2. Service of bicycle rental. 3. Cradle to cradle production, use and recycling strategy.

2.1 Sustainable design case study: An ideal multiphase bicycle

This case study was developed as a class experiment in an engineering college during a course in engineering design during the third year of mechanical engineering degree. 20 B.Sc. students got an explanation about the *ideality* tool from an industrial designer, highly experienced in design processes and familiar with the *ideality* tool. Later, they got a design task and were asked to use the *ideality* tool during the design process.

2.1.1 The multiphase bicycle

Current bicycle products are adjusted to various mental and physical development stages during childhood. As a result, parents are required to purchase several different bicycles from the age of two till the child acquires the ability to ride independently and pay the extra costs of replacing bicycles frequently. There is a need of a multiphase bicycle that can be adjusted to a longer period during childhood. Therefore, the design task was to offer a design concept for a multiphase children bicycle, by using the *ideality* tool. The suggestions for the multiphase bicycle design concept, presented in Table 2, were developed during the class experiment and elaborated later by the industrial designer who was in charge of this experimental session. Following this design exercise the industrial designer reflected on the design process and results.

2.1.2 Case study discussion

The industrial designer reflected on the design results. Using the *ideality* tool yielded innovative product features such as pedals positioning system or self-feedback system that would be doubtfully defined without the *ideality* tool. Thus, the tool served as innovation leverage, reaching design zone beyond the designer thinking fixations. Using the *ideality* tool yielded also sustainable and resilient features. The proposed bicycle concept have extended product life cycle due to the multiphase modular design and the damages prevention.

The industrial designer reflected also on the design process. The tool supports mainly the product specifications stage, a critical stage that affects the visible value of the product. The tool guides the designer thinking process by extending the scope of evaluated criteria under the lens of ideal design. The tool is adjusted to a customer quest for ideal products. Whether this quest is conscious or not, ideal products provide added value for customers in various dimensions.

The industrial designer defined the tool as a compass for ideal design. The main value of this tool is clarifying the difference between "What" is needed to be designed and "How" it is going to be designed. The tool forces designers to focus on the "What" stage of product characterisation and prevents the natural tendency of designers to move directly to the "How" stage. In Table 2, content related to the "How" stage is mentioned in brackets while most of the content refers to the "What" stage.

2.2 Biomimetic Design case study: An ideal unidirectional valve

This case study was developed by two mechanical engineers, submitted as part of a final project of their M.Sc. degree in mechanical engineering. They were instructed to locate a biological system with a unique mechanism and develop a biomimetic solution following the structural biomimetic design method (Helfman, 2014), (Helfman et al., 2014a). Here we focus only on the sustainability aspects of their project, addressed by the *ideality* tool. The two mechanical engineers reflected on their experience and elaborated on their difficulties and improvement suggestions.

2.2.1 The Papilionaceae seed

The Papilionaceae seed is kept dry by a humidity reduction mechanism (Hyde, 1954). When the seed is detached from the plant, the scar (hilum) functions as a unidirectional valve, keeping the humidity levels inside the seed lower or equal to the humidity levels in the environment. The hilum itself is an asymmetric oval-shaped scar constructed of two epidermis layers made of vertical pillar cells (Fig. 1a). An impermeable tissue separates the external and internal epidermis layers. When the internal epidermis cells absorb more humidity comparing to the cells in the external epidermis layer, they swell and extract pressure that opens the hilum to release humidity.

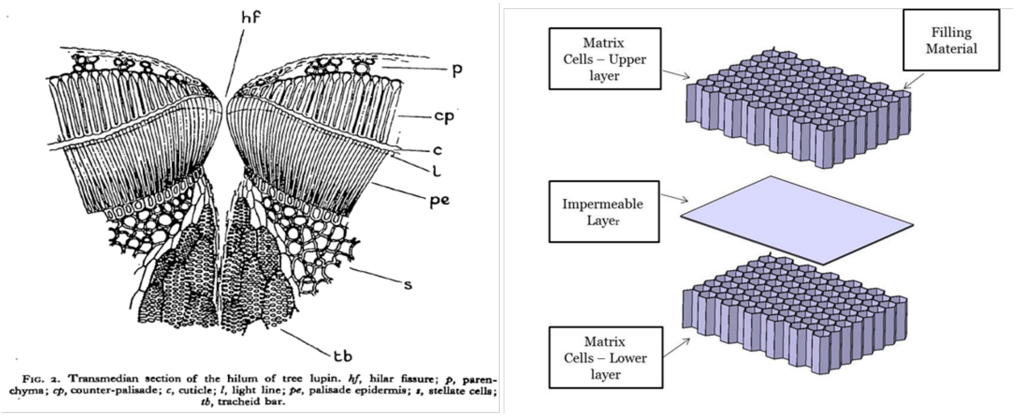

Figure 1:a. Schematic figure of the scar and the hilum area. b. A unidirectional biomimetic valve. Reproduced with permission of the copyright owner

Table 3. Ideality analysis of the Papilionaceae seed and the unidirectional biomimetic valve.

	Biomimetic concept- unidirectional valve	Biological model - Papilionaceae seed
Increase benefits		
More functions	Multifunctional Designs: 1. Package contains the product and protects it against external humidity. 2. Valve can protect against penetration of humidity from the environment when it is closed, and compare the humidity level to external humidity level when it is open.	Multifunctional design: 1. Seed envelop contains the seed and protect it against the external humidity. 2. Hilum serves to connect the seed to the plant. When the seed falls it serves as a unidirectional valve. 3. Hilum can protect against penetration of humidity from the environment when it is closed, and compare the humidity level to external humidity level when it is open.
Stronger effect	Repetition of matrix pillar cells intensifies the opening / closing function.	Repetition of pillar cells intensifies the opening / closing function.
Reduce costs		
Defensive strategy	Isolate the product from humidity thus preventing damage to the product.	Isolate the seed from humidity thus preventing decomposition.
Opportunistic Strategy	Using humidity gradient as energy source to open and close the valve (hydrostatic engine).	Using humidity gradient as energy source to open and close the hilum (hydrostatic engine).
	The structure of the valve (asymmetric matrix layers) is adjusted to its function of opening under certain conditions (unidirectional valve).	The structure of the hilum (asymmetric epidermis layers) is adjusted to its function of opening under certain conditions (unidirectional valve).
	Transferring functions to supersystem – using water particles (humidity) for the opening process.	Transferring functions to supersystem – using water particles (humidity) for the opening process.
Prevent Waste	Synchronizing package with humidity level to extend life shelf and prevent waste of products.	Synchronizing germination with humidity levels for optimal usage of seeds. Prevent loss of seeds (waste).

The two engineers first analysed the Papilionaceae seed system by the *ideality* tool, identifying which ideality strategies and design principles are demonstrated by the seed humid reduction system. Analysis results appear in Table 3, right column. Next, the mechanical engineers offered a biomimetic design concept of a unidirectional valve (Fig. 1b) based on the biological mechanism and repeated the ideality analysis for the biomimetic concept. Analysis results appear in Table 3, left column. Table 3 is a comparison table that reflects which ideality strategies and principles were transferred from the biological system to the biomimetic concept, and which ones were abandoned during the transfer. In case of abandonment, a designer may rethink how he can nevertheless implement them it the biomimetic concept. In our case study, the ideality strategies of the biomimetic concept preserved all relevant ideality strategies of the papilionaceae seed humidity regulation system.

2.2.2 Case study discussion

The two mechanical designers reflected on the design process and results. Using the *ideality* tool yielded sustainable innovative product features such as using humidity gradient as energy source to open and close the valve (hydrostatic engine) or synchronizing package with humidity level to extend life shelf and prevent waste of products.
The mechanical engineers reflected also on the design process. They found the *ideality* tool simple, convenient and comprehensive as it is based on an intuitive engineering thinking of improving systems by adding benefits and cutting costs. As they did not have background in sustainable design, they felt that this tool directed them to address sustainability aspects they would not address otherwise. One of them even reported that he continued to use the tool as a mean to guide his thinking during his professional work when he coped with system design challenges. They also offered some improvement suggestions such as numbering the ideality strategies and provide a short name to each one of them for standard and easier presentation of analysis result.

3 BIOINSPIRED SUSTAINABILITY TOOLS - EXPERIMENT

Comparing the contents of the *life principles* and *ideality* tool reveals that the ideality strategies enrich current knowledge of life principles by new operative and descriptive strategies (Helfman et al., 2014b). *Life principles* provide more strategies, but some of them are general and their application in engineering is neither clear nor straightforward. Ideality strategies are derived from a technical view that might be more inherent and applicable for engineers, observing biological systems as if they were technical systems. Based on these differences one may expect a difference in the tools performances and user's experience, but it was not evaluated before. In the following experiment we compared the two tools. Both of them may be used during early design stages and are simple enough to be thought under the time frame of a class experiment. However, life principle knowledge base is more extended. Due to time limitation and in order to balance between the two tools, we chose only three life principles strategies out of the six as a base for comparison, the ones that most resemble the ideality strategies in contents. ('Adapt to changing conditions', 'Be locally attuned and responsive', 'Be resource efficient').

3.1 Subjects

38 industrial and mechanical B.Sc. & M.Sc. engineering students participated in this exercise as part of an engineering design course. Students were allocated randomly to one of two groups: *Ideality* or *life principle* group. There were no major differences between the groups in terms of age, gender, academic backgrounds, and previous knowledge in sustainability or sustainable design.

3.2 Experiment design

The research hypotheses, described in Table 5, were validated by a classical experiment design, including an experiment and a control group. Experiment design is presented in Table 4.

Table 4. Experiment design

Group	Stage 1	Stage 2	Stage 3	Stage 4
Experiment Group A (*Ideality*)	General explanation about sustainability	Analysing sustainability aspects of a biological system (Stage A1)	Studying the *Ideality* tool	Analysing sustainability aspects of a different biological system, with the *ideality* tool (Stage A2)
Control Group B (*life principles*)		Analysing sustainability aspects of biological system (Stage B1)	Studying *life principles* tool	Analysing sustainability aspects of a different biological system with the *life principle* (Stage B2)
Time in minutes	20	20	45	20

3.3 Measures and measuring process

The following measurers and sub-measures were defined.

1. **Sustainability principles identification** which is the ability to use the tool for identifying sustainability strategies / principles of a given biological system: Two experts in *Ideality* and two experts in *life* principles, experienced in using these tools for sustainability analysis and design, identified the sustainability principles of each biological system. Each *ideality / life principle* identified at a given biological system was ranked with '1', and otherwise with '0'. The result is a list of '1' and '0' that represents the sustainability analysis by experts for each biological system per each sustainability tool. The same ranking was done for each student analysis. We compared each student analysis list of '1' and '0' to the expert solution list of '1' and '0' and calculated the following measures:
    1. Validity – Level of resemblance between the student's sustainability analyses to expert's sustainability analyses.
    2. Reliability – Level of resemblance between the students sustainability analyses to other student's sustainability analyses.
2. **Sustainable design which is** the ability to use the tool for sustainable design activities such as suggesting a design change was measured by:
    1. Number of changes suggested: Number of design changes offered by a student to a given biological system in order to improve its sustainability.
    2. Difficulty to suggest a change: How difficult was the process of suggesting changes to the system in order to increase its sustainability? Reported by students on VAS 1-10 scale.
3. **Perceived usability** which reflects personal experience in using the tool was measured by students' report of their level of agreement to statements on VAS 1-10 scales, regarding the following criteria:
    1. Level of confidence during the sustainability analysis
    2. Perceived difficulty during the sustainability analysis
    3. Level of understanding of sustainability aspects
    4. Satisfaction from the sustainability analysis
    5. Likelihood to use the tool in the future

3.4 Statistical analysis, results, and discussion

Statistical analyses and results to assess the research hypotheses are presented in Table 5. We assessed the *ideality* and *life principles* tools for identification of sustainability principles and for sustainable design. Using these tools yielded higher scores in several measurers compared to a state of using no tool (Hypothesis 1). Apparently, the major difference between the tools is in the objective measures such as the sustainability identification (validity) and number of suggested changes. This difference may be explained by the nature of each one of the tools. Some of the life principles are more general while the ideality principles are more operative and descriptive. Life principles are based on a holistic view while the ideality principles are based on a technical view that might be more inherent to engineers. As a result, ideality students could more clearly identify the ideality principles as well as use these principles to offer changes, compared to the life principle students.

In addition, we note that we included only half of the life principles in this experiment, that more resemble the ideality principles and are also more clear and applicable to design. There are other life principles related to the strategies of 'Evolve to survive', 'Development with growth' and 'Use friendly chemistry' that may be even less clear and descriptive, and incorporating them in this experiment might have even increased the difference between the tools.

As both students in stage 4 compared their sustainability analysis to stage 2, a stage of no tools, both of them felt major improvement. As a result, both tools demonstrate higher rates of perceived usability, without significant difference between them.

Table 5. Experiment hypotheses, statistical tests and results

Hypothesis	Statistical Test	Results
Hypothesis 1 Students who are exposed to the sustainability tools (*ideality* or *life principles*) will get higher scores in the "Perceived usability" sub-measurers (1 to 4) compared to a state of using no tools.	Signed Rank Test (Mu0=0) to assess the difference between stage 4 & 2 (A2-A1, B2-B1).	Students reported on higher levels of confidence, sustainability understanding and satisfaction from the sustainability analysis, as well as less difficulties in the analysis process, after using the tools. This result demonstrates the huge impact sustainability tools have in general. Some students were even helpless, searching for guidance at stage 2, as they did not know how to address the sustainability analysis process. Hypothesis 1 is accepted.
Hypothesis 2 Students who are exposed to the *ideality* tool will get higher scores in the sub-measurements of "Sustainability principles identification" compared with students who are exposed to the *life principles* tool.	Two sample t-test to assess the difference after using the tools (A2-B2).	Validity: Students who used the *life principle* tool significantly missed more sustainability criteria identified by the experts compared to students who used the *ideality* tool. (28.95% miss vs. 14.74% in average, p= 0.0005). Reliability: Reliability of the *ideality* tool is higher but the difference between the two tools is not significant. The sample may be too small to indicate significance. Hypothesis 2 is accepted partially. The part of validity is supported statistically; the part of reliability is not supported statistically.
Hypothesis 3 Students who are exposed to the *ideality* tool will get higher scores in the sub-measures of "Sustainability design" compared to students who are exposed to the *life principles* tool.	Two sample t-test to assess the difference after using the tools (A2-B2).	The sub-measure of 'Number of changes' indicates higher scores for the *ideality* tool (border line significance). The sub-measure of 'difficulty to suggest a change' did not indicate higher scores for the *ideality* tool. Hypothesis 3 is accepted partially.
Hypothesis 4 Students who are exposed to the *ideality* tool will get higher scores in the measurements of "Perceived usability" compared with students who are exposed to the *life principles* tool.	Two sample t-test to assess the difference after using the tools (A2-B2).	No significant difference between the tools was found. Hypothesis 4 is rejected.

4 SUMMARY

The *ideality* tool is a bio-inspired sustainability tool, based on nature sustainability strategies defined under the TRIZ ideality lens. As a result, this tool is adjusted for technical and engineering thinking and might be more applicable to engineers. We demonstrated by two case studies how to use the tool in the context of sustainable and biomimetic design. Both case studies reflect the potential of this tool to promote sustainable innovation and illuminate its value in design processes, especially for designers without background in sustainable design. The tool is a compass for ideal design, guiding the designer to focus on the characterization phase – what makes a system a sustainable and ideal system. The experiment supported the case study conclusions by introducing the value of the *ideality* tool, as well as the life principle tool, for sustainable design. The advantage of the *ideality* tool in terms of validity was presented. Students who used this tool significantly identified more possible sustainability criteria compared to students who used the life principle tool.

Future study should be devoted first to searching of more ideality strategies in nature and second in assessing the *ideality* tool in other contexts and by additional case studies, both in design classes and in industry.

REFERENCES

Altshuller G. 1999. *The innovation algorithm, TRIZ, systematic innovation and technical creativity*, Worcester, MA: Technical Innovation Center, Inc.

Benyus J. 1997. Biomimicry: Innovation Inspired by Nature. Quill. New York.

Chen J. L., Yang Y.-C. 2011. Eco-Innovation by Integrating Biomimetic with TRIZ Ideality and Evolution Rules. *Glocalized Solutions for Sustainability in Manufacturing.* Springer.

Faludi J. 2012. Biomimicry place in green design *Zygote Quarterly.*

Fitzgerald D. P., Herrmann J. W., Sandborn P. A., Schmidt L. C. 2005. Beyond tools: a design for environment process. *International Journal of Performability Engineering,* 1**,** 105.

Goel A. K., Bras B., Helms M., Rugaber S., Tovey C., Vattam S., Weissburg M., Wiltgen B., Yen J. Design Patterns and Cross-Domain Analogies in Biologically Inspired Sustainable Design. 2011 AAAI Spring Symposium Series, 2011.

Helfman C, Y., 2014. *Biomimetic design method for innovation and sustainability,* PHD Thesis, Tel Aviv.

Helfman C. Y., Reich Y., Greenberg S. 2014a. Biomimetics: Structure-function patterns approach. *Journal of Mechanical Design,* 136(11), 11108.

Helfman C.Y., Reich Y., Greenberg S. 2014b. Sustainability strategies in nature. *Design & Nature.* Opatja: WIT Press.

Hoeller N., Salustri F., Deluca D., Pedersen Z., Love M., Mckeag T., Stephers F., Reap J., Sopchac L. 2007. Patterns from Nature. *Proceedings of the SEM Annual Conference and Exposition on Experimental and Applied Mechanics.* Massachusetts, USA.

Hyde E. 1954. The function of the hilum in some Papilionaceae in relation to the ripening of the seed and the permeability of the testa. *Annals of Botany,* 18**,** 241-256.

Russo D., Regazzoni D., Montecchi T. 2011. Eco-design with TRIZ laws of evolution. *Procedia Engineering,* 9**,** 311-322.

Tukker A. 2000. Life cycle assessment as a tool in environmental impact assessment. *Environmental Impact Assessment Review,* 20**,** 435-456.

Zari M. P. 2007. Biomimetic approaches to architectural design for increased sustainability. *School of architecture, Victoria University, NZ.*

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