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THE ESM APPROACH: 8 MECHANISMS TO EFFICIENTLY SUPPORT ECO-IDEATION

B. Tyl, F. Vallet, O. Pialot, D. Millet, J. Le Duigou and G. Graves

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1. Introduction

The environmental consequences of mass manufacturing and consumption require to completely rethink our way of designing, manufacturing and consuming by implementing, for instance, an eco-innovation strategy. To do so, companies have to integrate the different system dimensions (environment, social, technology, stakeholders) from the upstream phase of the eco-innovation process. The purpose of this action is to put on the market products and services with a high environmental and societal ambition.
One of the main challenges of the eco-innovation process is the generation of ideas with a high level of originality and economical potential. In eco-innovation, the idea generation phase is essential and has to be carefully supported. This phase, also called eco-ideation, is the central part of a creativity session and takes place upstream of the eco-innovation process. It is defined by Bocken et al. [2011] as the phase during which ideas with great potential for reducing environmental impact are generated. At the end of the session, the group comes up with a set of eco-innovative ideas. The success of eco-ideation depends on the ability of the socio-economic partners to open new perspectives. That is to say to look for a new point of view by deconstructing the context of the problem and so to put into perspective alternatives and new situations.
The field of business model innovation for sustainability has received noticeable attention from researchers in the past years [Boons and Lüdeke Freund 2013], [O'Hare et al. 2014]. For instance, this led Bocken et al. [2014] to unify bodies of knowledge into 8 sustainable business model archetypes.
Eco-ideation has received less attention in the meantime. The global research question is hence "How to unify the many innovative approaches to deliver sustainability into actionable mechanisms helping eco-ideation?". Therefore, the objective is to develop easy to use mechanism to foster the generation of eco-innovative ideas.
After describing the tools and methods to support eco-ideation processes in Section 2, this paper presents in Section 3 a model of an Eco-ideation Stimulation Mechanism (ESM), as well as the construction of a set of ESMs.To finish, through the example of biomimicry, section 4 exposes a detailed example of how to use an ESM in practice. Conclusions and future developments around the ESM concept are eventually proposed in section 5.

2. State of the art on eco-ideation

2.1 Eco-ideation tools

Creativity in eco-innovation is widely considered as critical in literature. Consequently, some researchers have analysed how to support eco-ideation stages, through the development of specific eco-ideation tools.

Eco-ideation sessions have firstly been supported by diagrams or radars, such as the LiDS Wheel [Brezet 1997] or the Eco-Compass [Fussler and James 1996]. The creative operation roughly consists in performing a brainstorming session on each axis of the diagram or wheel. Focused on the limitation of greenhouse gas emissions, Bocken et al. [2011] proposed a specific eco-ideation tool to facilitate the generation of radical ideas. This tool is based on a set of key indicators predicting greenhouse gas emissions through the entire life cycle.

A wide literature on eco-ideation methods and tools is based on TRIZ methodology. TRIZ is a systematic creative method to solve design contradictions [Altshuller 1988]. More concretely, TRIZ is composed of several tools which have been adapted for eco-innovation [Chen and Liu 2003], [Kobayachi 2006] but also mixed with biology patterns [Bogatyrev and Bogatyreva 2014].

Some works have been developed with a simplifed TRIZ approach. Dekoninck et al. [2007] proposed simplified tools based on TRIZ for eco-innovation, using physical and technical contradiction and Ideal Final Result (IFR) statement. More recently, Tyl et al. [2014] proposed a TRIZ-oriented tool to generate sustainable ideas, called EcoASIT.

Lastly, recent developments in eco-innovation tools have relied on busines model innovation as a way to generate sustainable ideas. In this state of mind, the Value Mapping Tool proposes to cover the different values for key stakeholders and to transform missed or destroyed values into opportunities [Bocken et al. 2013]. The MIRAS tool proposes to help organizations develop eco-innovative concepts by anticipating stakeholder network changes [Real 2015]. In the UNEP eco-innovation manual, four reinterpretations of tools are included to enhance sustainable business model generation, namely: 9 windows on the world, People Profit Diagram, Product Prompts based on LiDS Wheel and Sustainable Final Result [O'Hare et al. 2014].

2.2 From eco-ideation tool to eco-ideation mechanisms

During eco-ideation sessions, designers have to generate a large variety of sustainable ideas and concepts. So eco-ideation tools should put into perspective alternatives and new situations [Vidal 2007]. Eco-ideation tools are more or less complex, with one or several stages. Therefore, to analyse and classify them, one must analyse their cognitive strategies, or *"ideation mechanisms", "design heuristic", "stimulation mechanisms"* [Yilmaz et al. 2010]. These mechanisms help designers to descontruct the problem and find new ways to solve it. More recently, Yilmaz proposed to define them as specific content patterns reflecting the cognitive strategies used to create new concepts [Yilmaz 2015]. In line with Yilmaz, ideation mechanisms in eco-ideation must provide designers cognitive strategies to create sustainable solutions.

In previous research, a first proposal of classification of the ideation mechanisms provided by eco-ideation tools was developed [Tyl et al. 2014]. This classification relied on the level of the mechanism, according to the following scale: a micro level mechanism, i.e. a specific and technical mechanism (for example the innovation principles of TRIZ); a macro level mechanism, i.e. a broad and abstract mechanism with no specification to guide the designer to use it, but which encourages a systemic view (for example Eco-compass or the Sustainable Final Result); a meso level mechanism, i.e. a compromise between a systemic vision and a technical sharpness (for example EcoASIT).

Table 1 proposes to strengthen previous analysis of eco-ideation tools specifically distinguising: (1) the systemic level of the different "object" manipulated through the eco-ideation tool (sub system, i.e system components; system, i.e. the life cycle; super system, i.e. the an extended view of the system)

(2) the sharpness of the ideation mechanism (specific, ie. technical ideation mechanism; generic, i.e. broad ideation mechanism or intermediate). The level of the ideation mechanism (LIM) corresponds to a combination between the sharpness of the mechanism and the system level of the "object" manipulated proposed by the eco-ideation tool.

As an example, the Eco-compass tool embeds 6 axes, called in this paper 'objects', to be manipulated. The objects corresponds to a life cycle and multicrietria thinking (conservation and the use of renewable materials, reuse and revalorization of wastes, human health and environmental potential risk)., i.e. at a system level. The objects are questionned through a brainstorming, so a generic mechanism. Therefore, this ideation mechanism corresponds to a macro level.

Table 1. Analysis of eco-ideation tools

Tool	System level proposed by the tool	Sharpness of the ideation mechanism	LIM
LiDS Wheel [Brezet 1997]	Sub System: Life cycle (except "new concept development")	Specific: Guidelines rules	Micro
Eco-compass [Fussler and James 1996]	System: Mix between Life cycle and multicriteria approach	Generic: Brainstorming rule on each axis	Macro
EcoASIT [Tyl et al. 2014]	Super System: natural resources, production, sales, waste, perception, usage and local activity	Intermediate: Modification, Integration and Object removal	Meso
Simplified TRIZ [Dekoninck et al. 2007]	No clear feature. Function of the system with cultural, social and practical themes	Generic: IFR Statement Specific: Technical and physical contradiction	Macro/ Micro
Eco-ideation [Bocken et al. 2012]	System: Product design / processing and value chain	Specific: Metric	Micro
Value Mapping tool [Bocken et al. 2013]	Super System: Extended Stakeholders	Intermediate: Identify opportunities for business model design for the stakeholders in the value network	Meso
MIRAS [Real 2015]	Super system: stakeholder and triple bottom line approach	Intermediate Add/Delete/Zoom	Meso
PIT Diagram [Jones et al. 2001]	Depends of the key starting point.	Specific: Map according to the process stage	Macro/ Micro
BioTRIZ [Bogatyrev and Bogatyreva 2014]	Biological and engieneering axioms	Generic : BioTRIZ rules for eco-innovation	Macro
TRIZ - CBR [Yang and Chen 2003]	Sub system: technical element of the system	Specific: contradiction matrix	Micro

It was emphasized that an eco-ideation tool with 'meso' ideation mechanisms guarantees effective eco-ideation sessions, especially in terms of rate of idea generation and of variety of the ideas, for several user profiles [Tyl et al. 2014]. In this paper it is proposed to use "meso" Eco-ideation Stimulation Mechanisms to support eco-ideation sessions, allowing to have a systemic vision of the problem, while efficiently stimulating the design team during the whole eco-innovative process. This paper aims to address a more focused research question: *"How to support eco-ideation with appropriate meso ideation mechanisms?"*

Through the concept of Eco-ideation Stimulation Mechanism (ESM), this paper proposes two main hypotheses and contributions: (1) the span of the mechanisms has to be defined, leading to the development of a set of ESMs to explore the dimensions of eco-innovation; (2) a transformation process of ideas is required, hence the development of a model of an Eco-ideation Stimulation Mechanism.

3. Proposal of a model of eco-ideation stimulation mechanism

This section introduces the core concept of Eco-ideation Stimulation Mechanism to help designers to generate eco-innovative ideas in the early design phases of the eco-innovation process. The field of exploration goes far beyond the product perimeter while engaging designers to elaborate on sustainability principles thanks to the construction of an ESM toolbox (section 3.2). In the section 3.3, the features and means of influence of a generic ESM on emerging concepts are then detailed.

3.1 Research methodology

The development of the Eco-ideation Stimulation Mechanism concept results from a preliminary research on meso ideation mechanisms [Tyl et al. 2014] and an extensive literature survey carried out by the authors. The survey involved most cited peer-reviewed articles in international journal and papers of conference proceedings, related to the following key words: *eco-innovation, sustainable innovation, sustainable business models.* Through an inductive approach, 8 classes of issues related to eco-innovation emerged. A simple micro-process of innovation was settled for each class of issue. The notion of meso Eco-ideation Stimulation Mechanism was then elaborated by the normalization of each process. Thanks to several illustrative examples and experimental tests, each ESM was independently tested and updated for more relevance (see example in section 4). The entire research method is summarized in Figure 1.

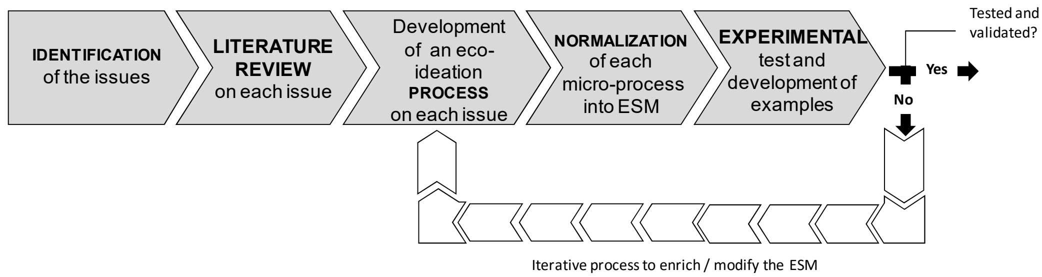

Figure 1. Iterative development process of ESMs

3.2 Exploration of eco-innovation issues and construction of ESM toolbox

Eco-innovation requires a holistic approach. In order to develop a first set of ESMs, a categorization of eco-innovation issues was performed. A limited, but meaningful number of ESMs is expected at the end of the process. It was more precisely operated as follows:

- A brainstorming to elaborate a first list of 10 ESMs based on available literature;
- A mapping of eco-innovation issues based on [Osterwalder and Pigneur 2010], [O'Hare et al. 2014], [Bocken et al. 2014], see Figure 2;
- A checking of the coherence between eco-innovation issues and ESMs, followed by updating the list. As a consequence, some gaps were bridged (for instance introduction of 'Innovate through new funding outlines'); some ESMs were merged (for instance ESM1 merges 'Innovate through value creation' and 'Innovate with stakeholders').

In order to give an overview of eco-innovation issues, the structure of the UNEP manual in three parts was taken as a backbone [O'Hare et al. 2014]: (1) the business strategy level, i.e. the long term goals of the company and the markets in which the company will operate; (2) the business model level, i.e. the translation of strategic issues into value proposition, value creation and value capture; (3) the operational level, i.e. the development of product or services.

The business strategy level was unfolded thanks to the archetypes of sustainable business models defined in [Bocken et al. 2014], for instance Organisational/'Develop scale up solutions'. Each of these archetypes were grouped at a higher level of classification: Technological, Social, and Organisational innovations.

The business model level elaborates on the business model canvas [Osterwalder and Pigneur 2010], and its adaptation for sustainability [Joyce et al. 2015]. They developed an adaptation of the canvas for a social purpose: the value proposition (i.e. the social value, the target end user, the societal culture and the scale of outreach), the value creation and delivery system (i.e. the local communities, the governance, the employees) and the value capture system (i.e. social impact and benefit) [Joyce et al. 2015].

The operational level reflects more traditional environmental attributes: life cycle, multiple criteria and consideration of system level and perimeter.

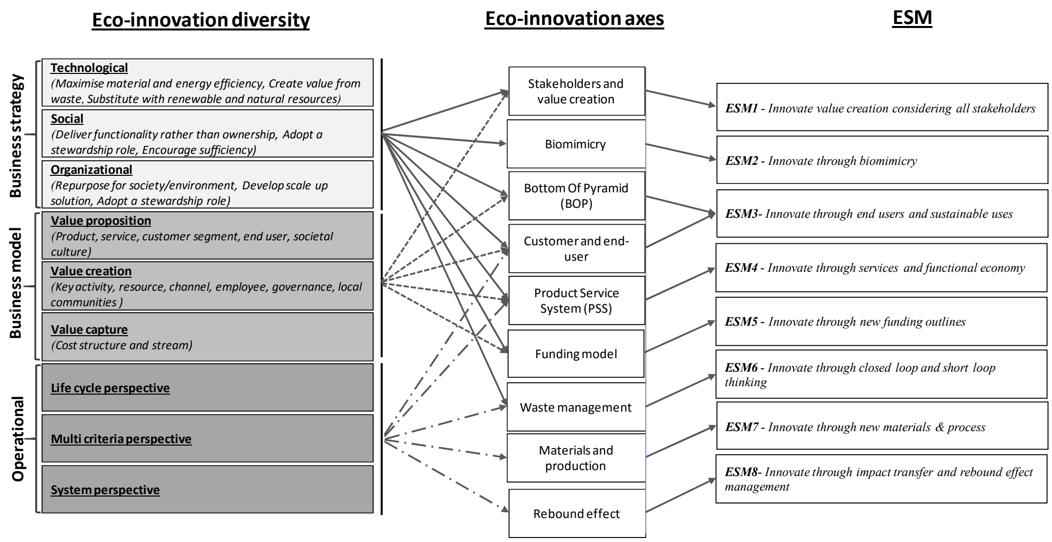

Figure 2. Construction of the ESM toolbox

Table 2 proposes an initial toolbox of 8 ESMs to cover the whole eco-innovation space. Each ESM elaborates on issues and axes mentioned in Figure 2 and main key factors are identified. For clarity and in line with [Bocken et al. 2014], ESMs predominantly challenge how innovations are brought to society ('Innovate through value creation considering all stakeholders' and 'Innovate through end-user and sustainable uses'); are technologically developed ('Innovate through new material and processes' and 'Innovate through closed loop and short loop thinking'); are embedded into new economic frameworks ('Innovate through services and functional economy' and 'Innovate through new funding outlines') and into organisational frameworks ('Innovate through biomimicry' and 'Innovate through impact transfer and rebound effect management').

Table 2. Presentation of the initial ESM toolbox

ESM	Justification	Key factors
ESM1: Innovate through value creation considering all stakeholders Main references: [Bocken et al. 2014], [Tyl et al. 2015]	This ESM raises the question of value creation for all stakeholders (customers, business, environment and society).	Stakeholders and Value (captured, destroyed, missed, opportunity)
ESM2: Innovate through biomimicry Main references: [Benyus 1997], [Marshall and Loveza 2009], [De Paw et al. 2014]	This ESM raises the contradiction between man-made industrials practices and natural strategies of development at several system levels (organ, organism, ecosystem).	Physical flow (i.e. resources, energy) Informational flow
ESM3: Innovate through end-user and sustainable uses Main references: [Lockton 2012], [Serna et al. 2014]	This ESM raises the question of the unsustainable use of product/service and of the bottom of pyramid approach. Behaviour of the consumer is a source of uncertainty and affect the environmental benefit of the product/service.	Eco-usage drift, inform/ pervasive/ forced functionnality/behaviour steering; Personalization; Neo-craftmanship
ESM4: Innovate through services and functional economy Main references: [Tan et al. 2007], [Lindahl et al. 2014]	This ESM raises the question of reducing the material intensity of innovations, of improving the customer experience.	Consumer life cycle Product and service life cycle, infrastructure, stakeholder network

ESM5: Innovate through new funding outlines Main references: [Mollick 2014], [Bocken 2015]	This ESM raises the question of the current difficulty to fund eco-innovative projects. Emergent ways of funding, labels, can affect the design process of a product/service.	Governance, investor, investment scheme
ESM6: Innovate through closed loop and short loop thinking Main references: [Gehin et al. 2008], [Pialot et al. 2014], [Tyl et al. 2015]	This ESM raises the the different possibilities to design a more circular and closed economy through remanufacturing, upgradability, or recycling. Local and short loop issues are paramount parameters.	Cost of lost flows, Environmental impact of lost flows, Recyclability/ Remanufacturing/ Reuse
ESM7: Innovate through new material and processes Main references: [Corti et al. 2011], [Kothala 2014]	This ESM raises the question of new ways to manufacture products, from traditional techniques to new production means as additive manufacturing.	Subtractive production/additive production/composite production, Mass customization;
ESM8: Innovate through impact transfer and rebound effect management Main references: [Hertwich 2005], [Figge et al. 2014]	This ESM considers the different types of rebound effects , implying a modification of environmental impacts due to systemic changes (technology, consumption patterns etc.)	Technical risk, Performance risk, Structural risk

3.3 Features of an ESM

The rationale is to develop ESMs in an easy, systematic and actionable manner for designers, inspired by the concept of tiny or micro-tool. Indeed, an ESM embeds three main features, defined as follows: (1) it is a meso-mechanism, meaning that it leads to a compromise between a generic (holistic) vision and a technical sharpness; (2) it is based on eco-innovation principles, which are all principles including life cycle and system thinking; (3) it includes systemic dimensions beyond the traditional product space. Thus, an ESM may be characterized as a transformation process that makes a system evolve according to sustainability principles. It is not just a stimulus or ideation component, but a sustainable disruptive intention to help designers characterize an initial state of a system, unstructure it and lastly obtain a new stage of the system. More precisely, the engine of each ESM is structured according to the following process (Figure 3):

- a systematic exploration of the problem components (CKi) of the initial system Si, identified thanks to specific key factors Ki;
- a set of ideation component (IC);
- a set of solutions CKi+1 in order to build a complete scenario or proposition for eco-innovation (concepts Ci+1, Ci'+1, etc.).

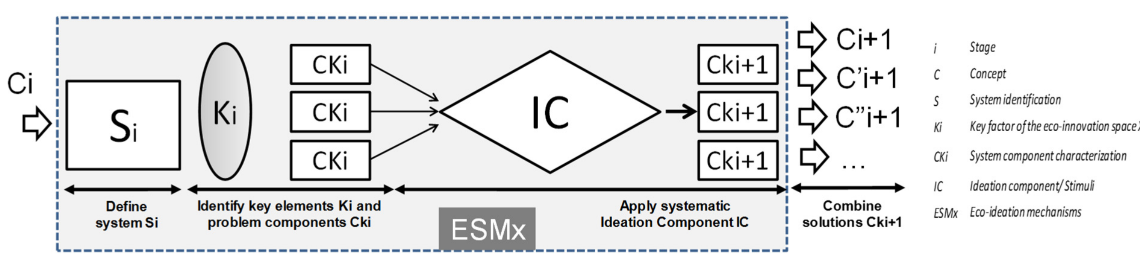

Figure 3. Exploration of a concept by an ESM

The definition of the key factors and the ideation components come from an extensive survey on each issue of the different ESMs. Authors defined those in a collaborative work for each ESM, such as actors (stakeholders, user segment), activities (mass customization), situations (usage) or indicators of global performance (scale, value) (see Table 2). Each ESM was then developed relying on combinations between key factors. ESM2 (Biomimicry) presents the detailed use of key factors in the case of a water boiler (section 4).

4. Illustration of ESM2: Innovate through biomimicry

4.1 Principle of ESM2

Biomimicry was first described by Benyus [1997], under the assumption that nature develops in essence highly effective and sustainable solutions to nurture living species and systems. Nature is hence considered as a valuable source of inspiration for designers. Although eco-design and biomimicry focus on merging environmental aspects in the design process, the viewpoints are somehow different. Where eco-design aims at reducing environmental impacts of products throughout their lifecycles, biomimicry seeks to "*develop products that benefit their environment*" [De Paw et al. 2014]. For many authors, it is acknowledged that biomimicry appears to be an interesting trigger to find eco-innovative solutions. Conversely, other authors pinpoint that, under certain conditions, biomimicry may also lead to drastically unsustainable systems [Marshall and Lozeva 2009], [Fayemi et al. 2014], as carried out in the defense sector to develop weapons for instance.

There are two ways to refer to nature for a designer [Macnab 2012]: (1) Biomimicry Design Spiral-'Challenge to biology', meaning to identify a design problem first and find inspiration in the natural world; (2) Biomimicry Design Spiral-'Biology to design' meaning to identify natural models first and then look for design applications. This is also referred to (1) the direct approach where the designer mimics nature based on an analogical translation of his engineering challenge; (2) the indirect approach, where the designer abstracts ideas and concepts from an existing solution in nature [Gamage and Hyde 2011]. It can be noted that the transfer of natural strategy can be operated at three main hierarchical levels, which are the organ, the organism and on the broader scale the ecosystem. In [Gamage and Hyde 2011], four analogical translation approaches (namely Natural Studies Analysis, Typological Analysis, Design Spiral and BioTRIZ) are analysed, showing usage at different levels.

Our objective is to figure out mechanisms which are typical of natural ways of solving problems. The starting point is thus to favor the use of an acknowledged database of natural examples (http//www.asknature.org) by sticking to the developed taxonomy. We suggest to adopt a problem-based approach and enable the formulation of the design challenge by means of 'functions' (verb and noun). This enables to retrieve relevant sources of inspiration. In order to propose a simple ESM, the 8 strategies proposed in the Biomimicry taxonomy of Asknature.org are embedded into 4 polarities, which represent the natural processes found in nature (Figure 4):

- The first polarity is represented by the balance between 'Maintain/Stay Ki' and ' Modify/Evolve/ Move Kj';
- The second polarity is represented by the balanced functions 'Generate/Create Km while Capture/Absorb/Breakdown Kn';

Ki, Kj, Km and Kn represent key factors which are relevant to the eco-innovation challenge, such as: physical flows (energy, water, liquid, gas, information flows etc). The entire ESM is described in section 4.2.

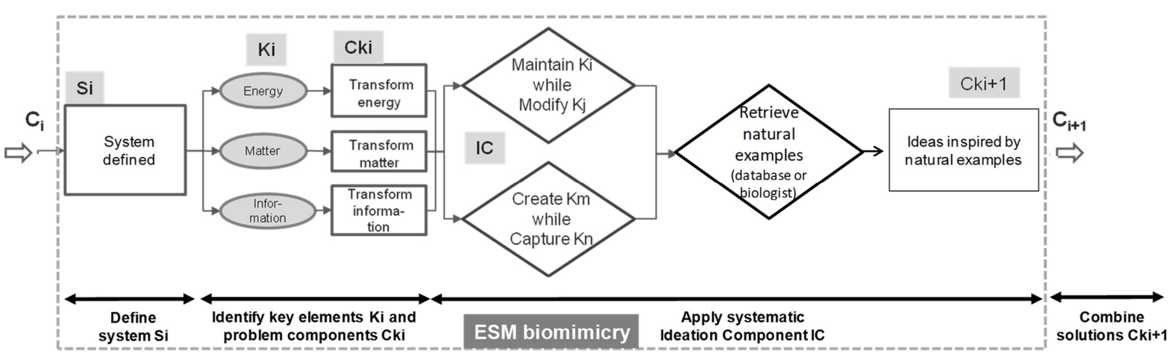

Figure 4. Generic description of ESM2

4.2 Example of the Nautilus boiler

The example of the Nautilus water boiler[1] illustrates the approach. This project was carried out in 2012 by an industrial designer and a bio-engineer with the aim to build a methodical process and demonstrate the relevance of biomimicry principles to design everyday products. The resulting concept is currently being adapted to achieve its industrialization. Main stages of the method experienced by the two creators of the Nautilus are : (0) Identify the environmental hotspots thanks to an LCA approach (1) Decompose the problem based on the main hotspot (i.e. energy consumption in this case); (2) Explore nature on 4 key functions; (3) Explore 100 species and generate 100 elemental ideas; (4) Filter ideas thanks to technical feasability, environment and user friendliness criteria, (5) Combine the 4 most promising ideas in a qualitative and quantitative way into the Nautilus concept.The creators more precisely stated the functions (Cki) to fulfil as 'Optimize heat'; 'Control volume of water', 'Control temperature' and 'Isolate from the outside'.

In the reseach approach, it is taken advantage of this challenging project to illustrate how the eco-innovation problem can be formalized and solved thanks to ESM2 in a retrospective manner. The first step consists in the characterization of the key factors: temperature, heat and water in this case. Then, in line with the Biomimicry taxonomy, two contradictions (IC) associated to the water boiler are expressed: (a) Optimize heat while Isolate from the outside; (b) Control volume of water while Control temperature. Thanks to the strategy browser of Asknature database, four animal strategies (Cki+1) related to management of heat, temperature and volume of water were retrieved: mound-building termites keeping a constant temperature in the nest thanks to galleries; toucan's insulated beak from the outside; compartmentilization of nautilus shell; hollow hairs of polar bear for insulation. The creative combination of the four strategies was finally operated in the Nautilus prototype (Figure 5).

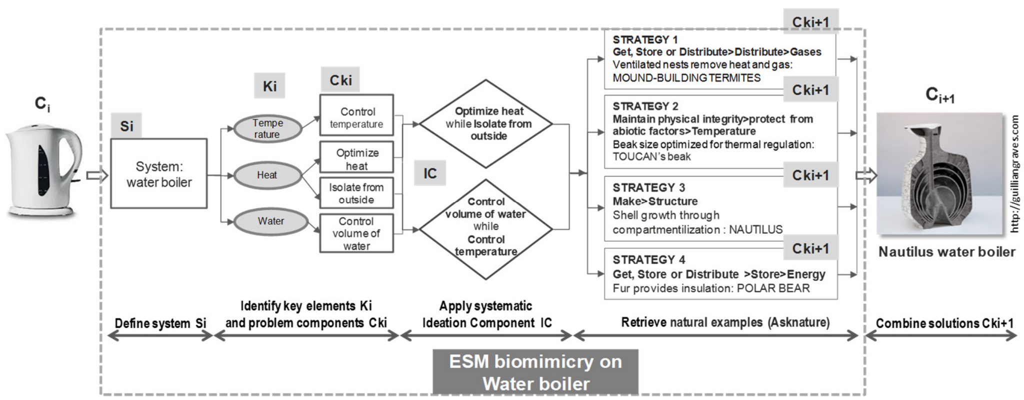

Figure 5. Use of ESM2 on the Nautilus water boiler case

5. Conclusion and perspectives

This article brings a contribution on how to support the eco-ideation stage in order to develop eco-innovative concepts in SMEs. Literature reveals that most current eco-ideation tools are based on macro or micro mechanisms, whereas the meso (or intermediate) level has been proved to be effective in previous work [Tyl et al. 2014].

The contribution of this article is twofold. Firstly the notion of ESM is defined as a meso mechanism which aims at generating eco-innovative concepts thanks to breaking operators, in the ASIT tradition [Horowitz 1999]. Secondly, acknowledged approaches to deliver sustainability in design are unified into a toolbox of 8 original ESMs. One of the mechanisms, ESM2-Innovate through biomimicry, is exemplified on the case of a water boiler.

Regarding ESM2, one limit was emphasized along the Nautilus project: the difficulty to directly transfer a natural inspiration to a human and industrial context. Such a transfer may imply a conflict with technological problems, but also with problems of usage, scale or culture. That accounts for the fact that

[1] See Guilian Graves website: http://guilliangraves.com

several ESMs are bound to be associated in eco-innovation, and finally merged into a more global process. It is believed by the authors that the strength of the approach is indeed related to the modularity and relevant combination of ESMs. This should be developed in further work.
Since the proposition is still is at its very early steps of formalization, the limit is the lack of validation so far. As the ESM toolbox seems to complement UNEP eco-innovation manual [O'Hare et al. 2014], it could be relevant to get feedback from authors and practitioners of this manual. Also, further work include more tests with companies, or consultancies willing to engage an eco-innovation approach.
Scalability of the ESM method, although not tested so far, may be envisaged under the assumption that meso-mechanisms have already been successfully deployed in different industrial sectors, with a various product complexity [Tyl et al. 2014].
A last issue is finally to support the choice and the order of appearance of the most suitable ESMs, depending on the context of the company. This research is part of a wider French research program (ALIENNOR), which should conduct to an open eco-innovation platform embedding: ESMs, eco-evaluation tools, and a database of original eco-innovation cases.

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Benjamin Tyl, Dr
APESA, Innovation
Technopole Izarbel n°45, allée Théodore Monod, 64210 Bidart, France
Email: benjamin.tyl@apesa.fr