Exploring Biomimicry in the Students' Design Process

Miray Boga-Akyol, Res. Asst. - PhD Student, Department of Industrial Product Design, Istanbul Technical University

Sebnem Timur-Ogut, Assoc. Prof. Dr., Department of Industrial Product Design, Istanbul Technical University

Abstract

Since the very early days of history, human beings 'designed' things by looking at nature. In our days, the use of nature in design has become more systematic and detailed. Although as old as humanity itself, use of nature especially in the field of design still offers novelty and often brings success in solving problems in a sustainable way.

When it comes to industrial design education specifically, it seems to be a promising method to mimic the nature in designing new products; however different dynamics effect and sometimes prevent students to use natural analogy in their projects. It is observed that industrial design students aren't eager to use biomimicry which is a type of natural analogy in their design projects although they learn about it in different courses as a creativity method.

The study therefore aimed to find out about two issues related to the matter: a) trying to find out and understand the reasons behind this reluctance against the use of nature, b) if they were presented a methodology, in what ways this reluctance would be overcome and they would go beyond taking nature as not only a formal source of inspiration.

Key words

biomimicry, bio-inspired design, natural analogy, design education, industrial design, interdisciplinary study

Introduction

Using nature in design is not born in present-day; human beings looked at nature to refer what they had made since they had relationship to artificial things. However the techniques that people use to mimic nature had changed due to the developments in technology in our day. It became more systematic and detailed. There are many ways to use nature in design; analogy is one of them. It is used frequently to bring nature and design together. Further, there are many ways to use Natural Analogy. It takes different names in different fields. It appears as Biomimetics, Bionics, Biomimicry, Bio-inspiration, etc. although all of these terms express nearly the same meaning: copied, adapted or converted from nature (Vincent, 2007). Reed, Klumb, Koobatian, & Viney (2009) defined the difference between Biomimicry and Biomimetic clearly. They claimed that besides having the same meaning, Biomimicry is a process; Biomimetic is the study field (Reed et al, 2009). Biomimicry is frequently preferred in design as a term, while Biomimetics is used mostly in engineering. The fields where natural analogy is used are not limited with design and engineering. Social sciences like Economy, Psychology, Culture, etc. use nature as a guide to explain a process. That is why this research is built on Natural Analogy as a more inclusive heading; and Biomimicry is specific to design. All of these fields share a common dialect in their own way which leads to the concept of Sustainability.

As the use of Natural Analogy increases dramatically in various fields, it is not in demand that much for industrial design. It is observed that the industrial product design students were not eager to use natural analogy in their studio projects. While the modernist understanding of education keeps students out of figural applications, use of nature -most of the time- is practiced as a one-to-one tracing of the formal qualities of the natural model to an imaginary project. The search for abstraction in using nature in projects and thus trying to avoid from the label of 'kitsch' keep them away from this method.

Use of Nature in Various Fields

There are number of fields which use nature as an inspiration source for research. The fields of science, technology and even social sciences use this method for more efficient solutions. It is used for mechanical solutions, marketing strategies, styling, environmental policies, etc. The common aim is to reach more efficient and sustainable solutions in the process of creating products, programs, systems, services, etc.

Donald Norman states in 'Why Design Education Must Change' that many design students prefer design because they do not like science and mathematics; and he adds design education can't be considered without science (Norman, 2010). Although what Norman intends to say as 'science' are statistics, mathematics, social sciences; biology can be also considered with them. Even the Biology was not mentioned in Norman's words; a science-based education would help to develop the method of biomimicry in a systematic way. The reason behind the

failure of biomimicry in order to use in design is the lack of science knowledge.

Science and Technology

It would be fair to say that biologists have more to say about Biomimicry than designers. Biological knowledge is a significant point for Biomimicry. Janine Benyus, who is one of the founders of Biomimicry Institute, has written a book about biomimicry. She mentioned the usage of it in various fields including agriculture and medicine. As the biologically based fields, there are various studies to discover the natural strategies in agriculture and medicine (Benyus, 1997). To achieve more sustainable farming or different cure methods for disease, nature is used as a mentor. Benyus gives an example of the Land Institute in Kansas where the farming fields were left to its natural conditions like nature has its own cycles. The system depends on rain and solar energy; there are no chemicals, erosion and fossil fuel. The system works by the cycle of water, mineral and waste with genetic know-how (Benyus, 1997:21-27).

In medicine, there are some studies which imitate the natural process where living beings can prevent certain health problems. Docksai tells about the electrode named 'nanoflowers', which has been developed for the visually impaired people. It uses solar energy like a leaf and transmits the image to the brain by this energy (Docksai, 2011). Using biological knowledge in a biologically based field is not surprising; meanwhile the way of transferring this knowledge is not as clear as in the field of engineering.

The engineering based fields like mechanics, construction, materials and information technologies use natural dynamics, structures, molecules and coding systems to reach more creative and sustainable models. In material science, projects are developed to create materials which mimic the structure and process of natural systems instead of using natural materials directly. For example a biotechnology firm called Zeneca produced a polymer named Biopol by inspiring from Alcaligenes eutrophus bacteria. This polymer has similar features as polypropylene and can be molded (Rao, 2003). Besides mimicking nature on a molecular level; -like water and dirt resistant painting inspired by the hydrophobic lotus leaves- there are structural mimesis examples in architecture. Eastgate Centre in Zimbabwe has been designed like termite mounds which have a passive cooling system. It saves energy more than the current air-conditioning systems (Cattano et al, 2011).

Figure 1. Eastgate Centre and termite mounds. Source: Url-1

Nicholas Grimshaw & Partners designed the Waterloo Train Station and solved the air pressure problem which occurred when the train passed, by using the structure of pangolin which can adjust the flexibility of its scales with the change of pressure (Zari, 2007).

It is significant that when a search is driven through the literature with the keyword "biomimicry", the results that come from the information technology sources are considerably high. Eren mentioned that the method of evolutionary computation had really significant effects on efficiency and he related this situation to three common features between evolution and information technologies: the ability of parallel thinking, randomness, complicated design as a result of a simple process (Eren, 2009). Hughes Aircraft tested a digital information storage system that imitated a type of bacteria which could react to the difference of light incredibly fast and flexibly. This made the system more efficient and leaded to more advanced studies like three-dimensioned storage systems (Reed, 2004).

Social Sciences

In social sciences, the use of natural analogy can't be seen as clear as in physical sciences. However this does not mean that natural analogy is not used in social sciences. For example the strategies of nature are used in Economy. Benyus argued that economical sustainability could not be achieved by using natural materials but mimicking nature holistically. She said that a forest ecosystem had cyclic system where nothing was wasted (Benyus, 1997). Güları has a master thesis about a type of 'killer algae' in the sea

ecosystem which was related to 'killer products' in the market. Caulerpa taxifolia is a type of ornamental aquarium algae but it was released to the sea by accident. It did not let other types of algae to live and invaded the ecosystem. Güları built an analogy between that algae type and the products which invade the market that do not let its competitors survive, like the iPod (Güları, 2008).

There are important studies in psychology, especially about evolutionary psychology. The studies about the user preferences are associated to prehistoric behaviors of human beings, primates and monkeys. Spörrle and Stich have a research about the tendency of people to choose the place of the bed in the bedroom. Most of them preferred to place their beds behind the door where they could see the door and window clearly, just like the monkeys and primates had done to be protected from attacks and see where the attack may come from (Spörrle and Stich, 2010). A similar study has been done by Heerwagen who is an urban designer. She mentioned about biophilic design which comes from E. O. Wilson's definition of 'biophilia': 'the tendency to focus on life and life-like processes' (Heerwagen, 2003). Heerwagen told that biophilia had been considered for design of some places like shopping malls, parks and entertainment areas. The interest of people in open grasslands, clear sky, plants, big trees, etc. is used in the design of these places to attract the people more to go (Heerwagen, 2003).

The studies in culture are affected by nature as much as other fields although it seems as a field far away from nature. On the contrary, nature and culture affect and feed each other. Memetics is the most important proof of it. Dawkins who coined the term of 'meme' made an analogy between genetics and memetics. Meme is a replicator like a gene, which copies itself by words, motto, music, texts and through all channels of communication from brain to brain. The word of 'meme' comes from Greek word 'mimesis' which means imitation. Dawkins told that some of the memes are more successful to survive like some of the genes do and the culture is evolving by this way (Dawkins, 1976). John Langrish took this subject a step further and he offered new terms building upon the concept of meme: 'Recipeme' describes how to do things; these are the ideas which compete with each other. 'Selecteme' is the most successful idea to survive; the idea which won the competition. 'Explaneme' interrogates the reason of the work of things and how things work better (Langrish, 1999). From this point of view, Langrish makes a connection between memes and design ideas. The ideas of design competes with each other first in the designer's mind, then in an organization, then for purchaser and then in the selective world of users similar to the way natural selection works (Langrish, 2004).

In the world of non-sustainable products and processes, there is a serious need for changing this non-sustainable approach holistically. Mimicking the nature can be seen as a method for designing by nature for sustainable solutions; but it needs to be applied to all phases of design, from developing a concept to the issues related to disposal or recycle. Otherwise, mimicking nature only on a formal level may result with the category of 'kitsch' objects that would not reflect the holistic approach suggested in the natural process itself. To achieve a sustainable and integrated system, it would be useful to look at what nature presents to the people. Benyus has a successful system and process in terms of sustainability and she summarizes it under nine topics (Benyus, 1997:7):

- Nature runs on sunlight.
- Nature uses only the energy it needs.
- Nature fits form to function.
- Nature recycles everything.
- Nature rewards cooperation.
- Nature banks on diversity.
- Nature demands local expertise.
- Nature curbs excesses from within.
- Nature taps the power of limits.

Nature in Design and Biomimicry

As the issue of sustainability has become very important, critical and vital than ever before, design academicians and practitioners' role also increased drastically in terms of applying the scientific knowledge in man-made structures by compromising research with know-how. What is implied here is a holistic approach: using nature as a guide to learn the secrets of sustainability as a process would help; but it needs to be reflected to all phases of design. Biomimicry or use of nature in design should not be taken as only imitating nature.

We may talk about three types and levels of using Biomimicry in design according to the Boğa's master thesis. These are using biomimicry on a morphological and Structural level; on a molecular level and the use of biomimicry as a process (Boğa, 2013).

Mercedes-Benz developed a concept car which inspired by the structure of boxfish that reduced the friction and increased the efficiency in terms of energy saving and strength of the structure (Volstad and Boks, 2008). Similarly the form of kingfisher's beak is used for the

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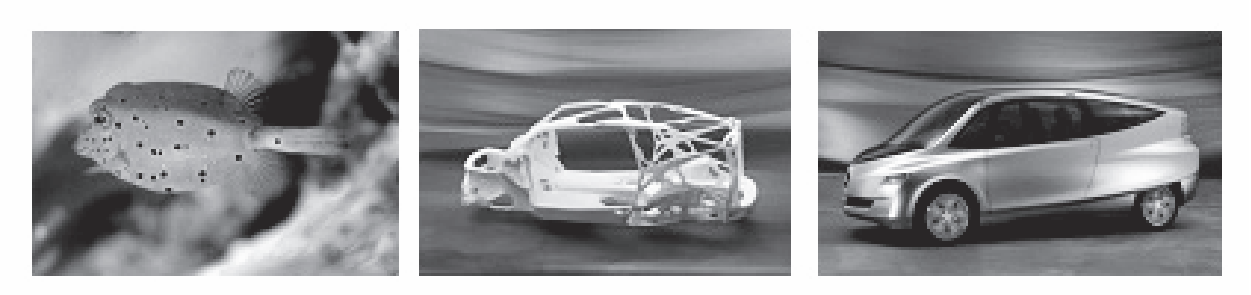

Figure 2. Boxfish and the concept car of Mercedes Benz. Source: Url-2

Figure 3 Kingfisher and the train. Source: Url-3

design of the train (in Figure 3) to reduce the vibration and noise which occur when the train passes (van Boeijen and Daalhuizen, 2010). These are the examples of morphological and structural use of Biomimicry in design. The advantages of natural beings' form are used to solve the design problems.

Some of the mimicking examples are at the molecular level like the tape which imitates the feet of gecko. The tape has billions of little plastic fibers as the gecko has little hair under its feet which provide a strong (1cm^2 of tape can weigh 1kg) adhesion (Volstad and Boks, 2008). A concept work of underwater electric generator has the shape of tuna tail. It moves like the tuna tail and transform the kinetic energy to electric energy (Url-4). These are the examples of functional imitation of nature. Certainly the biomimicry examples are not limited the ones in this paper; there are quite a number of them and the number increases every day.

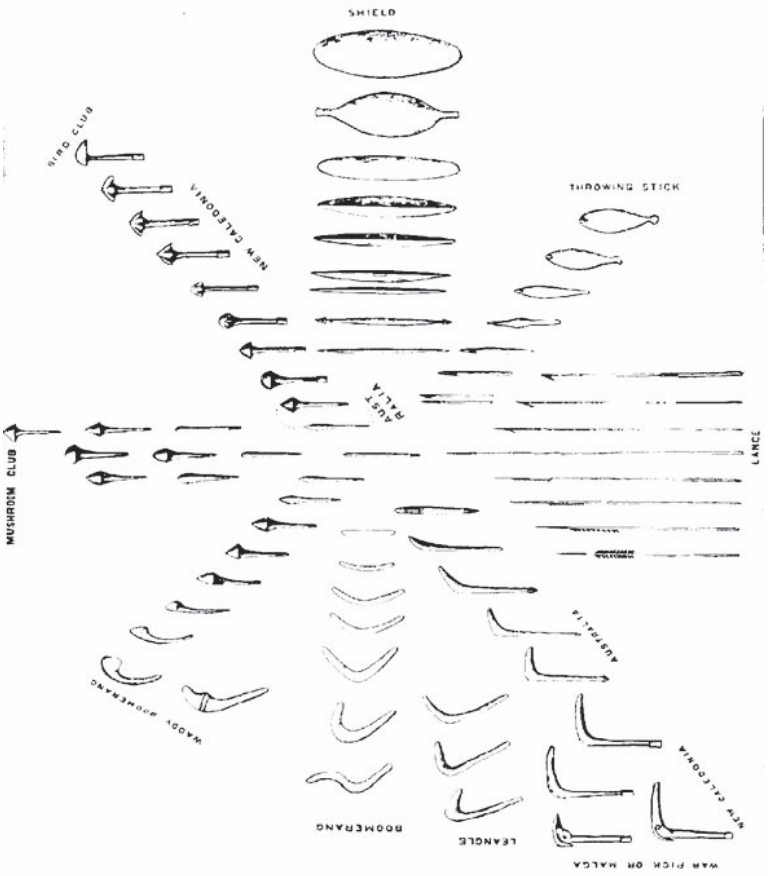

Figure 4 Evolution of the weapons. Source: Basalla (1988:25).

Another type of mimicking is about process. Natural process, especially Darwinian approach and natural selection can be used as a model to explain the historical side of design. Susan Blackmore mentioned that universal Darwinism can be applied to a lot of fields including the evolution of science. She told that inventions can be seen as memes which spread form community to community (Blackmore, 1999). Some of the approaches are based on evolution and some of them are based on Darwinian Theory. Basalla in his book Evolution of Technology gives the scheme (which was done by Pitt-Rivers) of evolutionary development that belongs to the weapons of Australian natives (Basalla, 1988).

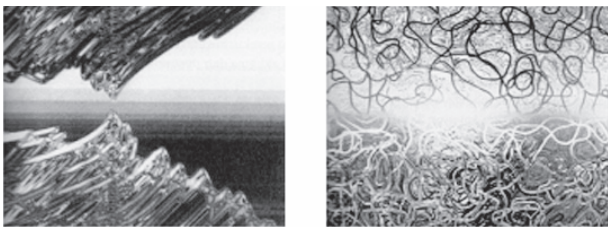

Figure 5. The 10th and 40th generation of the images. Source: Eren (2009:159).

On the other hand, a process like Darwinian natural selection was built for computer graphics by Karl Sims. The computer itself codes the colours in pixels by a programmed set of commands and therefore images are created. The criterion for selection of the images is the time people spend in front of their monitors. If people like the image, they keep looking at the monitor and the computer uses this as an input to create a command. Thereby the image evolves; the 10th and 40th generation of the samples can be seen in Figure 5 (Eren, 2009).

Although there are mostly positive approaches to natural analogy, there are some negative opinions about it in design. Tonkinwise said that associating evolution and design was not appropriate because evolution was not a designed process; it was 'anti-design'. Nevertheless he mentions some similarities between design and evolution such as mutation, sexual selection, co-evolution. These similarities to the so-called weaker designs or the ones which were selected only because of their appearance and the products that was indigent to the others to be the survivor. He said that design process does not fit to neither evolutionary nor artificial selective process (Tonkinwise, 2005). Langrish's explanation can throw some light on this. He argues that Spencerian approach of linear ordered evolution is not suitable to apply to the design, instead, Darwinian approach of selection would fit better. What he told about is the evolution of ideas which is related to Memetics (Langrish, 2004). This is not a direct match; this is the discovery of the convergence between the Darwinian or Neo-Darwinian process and design process. Tonkinwise also told that the important point of the evolution, 'inheritance' was contrary to the objectives of design. It was not suitable to copy or reproduce someone else's design but the mechanism of evolution is based on replication (Tonkinwise, 2005). From another view it can be thought that nature has a significant diversity which is provided by the replication of the genetic code. The inheritance creates the diversity itself by copying a code which can also be a successful design principle.

The Approach of Industrial Design Students to Biomimicry

The courses about biology are mostly not included in the curricula in industrial design education 'by its nature'. The knowledge of biology that students have is limited to their high school education. It is certain that biological knowledge is critical to use biomimicry holistically instead of superficially.

There are some studies where biomimicry is used in design education. Santulli and Langella (2011) said that in order to use biomimetic design in education there was need to put some courses in the curricula which supported biological knowledge. Although the methods like Ashby diagrams, TRIZ, etc. were used with natural analogy to make it more systematic, the students needed biological background. The study which had been done with engineering students showed that the materials, items and solutions which the students used were not efficient in the perspective of engineering and sustainability. Santulli and Langella thought that this method needed to be improved (Santulli and Langella, 2011). Cattano, Nikou and Klotz (2011) used biomimetic method in civil engineering education by using a database about the natural beings and biomimicry examples (Cattano et al, 2011).

Although the number of events, workshops, education programs, summits, projects and sources about biomimicry increases; and despite the fact that students learn the technique of mimicking nature in different courses – especially creativity techniques courses, they are not eager to use it in their studio projects. This study aims to reveal the reasons behind the reluctance of industrial design students to use Natural Analogy in design projects and explore the reflections of Natural Analogy in their minds.

Aim of the Study

It is observed that even the students had learned about Biomimicry in different courses, they were not willing to use it in their studio projects while they had used the other creativity techniques like SWOT Analysis, metaphorical design, synectics, etc. Nevertheless, if they had used it in a project, it did not go beyond a form based study. They could not use biological solutions to solve their technical or systematic problems. Due to the structure of education system, the Biology knowledge that the design students have is not enough to use as a problem solution. Hence, it was thought that there is a need to inform the students about Biomimicry and how they can use biological data as a source of inspiration and solution.

Workshops

Before the main workshop, a pilot study was done in the course entitled Design Theories and Method in X University, Department of Industrial Product Design. The subject 'Synectics' was presented by the students through five types of Analogy: Direct Analogy, Personal Analogy, Paradoxal Analogy, Fantastic Analogy and Natural Analogy. After a presentation was made related to these types of analogies what they are, how they are used; two problems were given and the students were expected to set up a group of five people and select one of the problems. They would look for solutions for the selected problem by two of the analogy types. One of the analogy types must be Natural Analogy; the other one depends on their choice.

One of the problems was about sound and the other was about light: how to get a better acoustics within the studio; and how to get a better lighting within the studio. The results of natural analogy studies that were proposed by students were directly related to the images they had in their minds; as offering solutions like the ear of the elephant, a sunflower and leaves of trees. This showed that the inspiration was limited by the Biology knowledge and they can only refer to what they have in their minds. There is a need of a larger database to consult for problem solutions.

In view of the fact that the students do not have adequate knowledge about Biology and biomimicry, two workshops in two universities were organized taking this ignorance as a starting point; telling what biomimicry is and what it is not. The workshop attendees were informed about the website www.asknature.org that could be used as a biological database to consult for academic information to be used as inspiration to generate design ideas which is copyrighted by Biomimicry 3.8 Institute. This database could be used to search by the words belonged to nature terminology or engineering/design terminology like functions, materials, parts, etc.

The first workshop was held in a private university's Department of Industrial Product Design. The number of the students who had completed it was eight. After the workshop, the students were expected to fill in a questionnaire which had questions about the subject of their studio projects, the problems they need to solve and which keywords they intended to use to lead them efficient search results. Then they searched those keywords on www.asknature.org. The biological results that came from the website were also searched on the search engines such as Google and Youtube.

In the final presentation of studio projects there were no students who had used Biomimicry in technical solutions for the problems. The results of questionnaire showed that the students thought the workshop had worked out in order to understand the capabilities of nature in problem solving but they could not achieve to use it in their

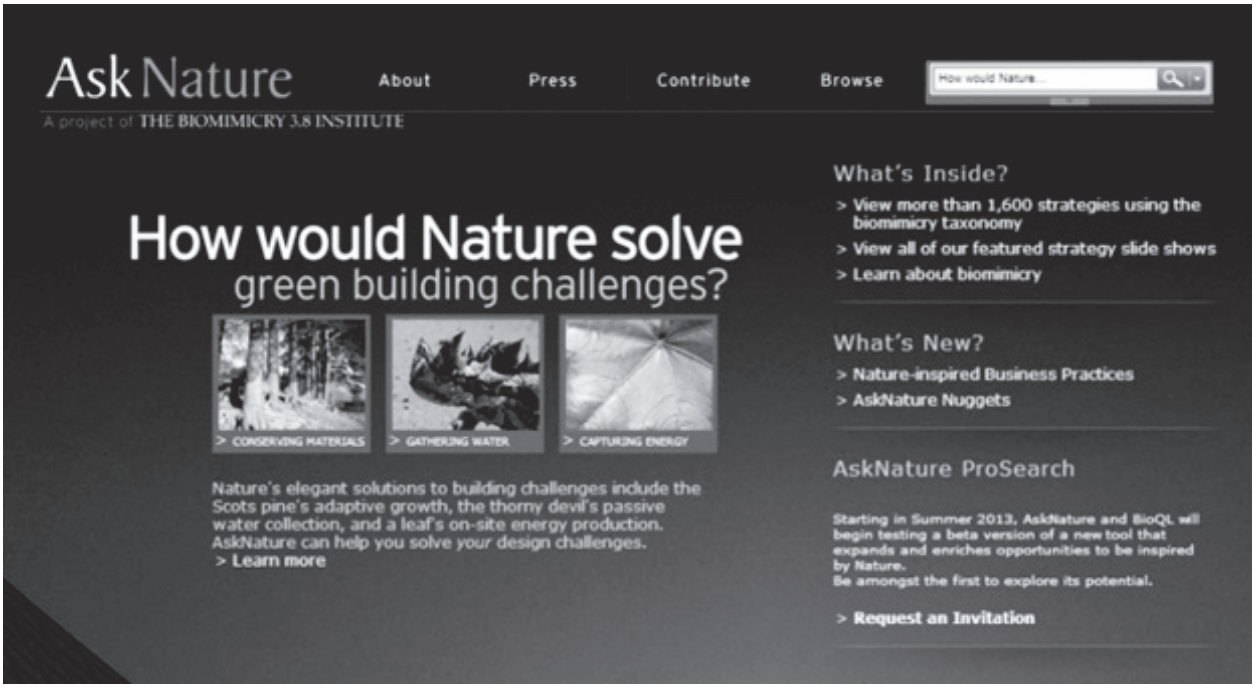

Figure 6 Homepage of the website www.asknature.org

projects practically. Some of them indicated that the problems of project were too mechanical and complicated to be solved by nature.

Meanwhile, simultaneously and totally unaware of this workshop, another group of students who did not learn about biomimicry before; decided to inspire from nature for their graduation projects, by themselves. The subject of the graduation project was a 'sheltering unit' for disasters or camping. Although we argue that students are reluctant to use natural analogy in their projects by their own initiatives, they claim that as this was a project that would be located in nature, they tended to start from nature. Although they did not know about biomimicry while they started the project, they considered that nature inspiration is a good start for camping unit; because the product would be used in nature. Then these students were invited to participate in the workshop and they were introduced with the www.asknature.org website, biomimicry and they were informed about the matter. Before the workshop; they answered a few questions about their choice to use 'bio-inspiration' (as in their words). First, 3 out of 5 graduation project students started with biomimicry; in the end, 4 of them completed their project with it. However, in the end, the use of natural analogy was only about mimicking the form of the life beings or colours; there were no systematic bio-inspiration at the problem solutions. Only one student, who had not started with biomimicry, used a biological form because of its aerodynamic advantage.

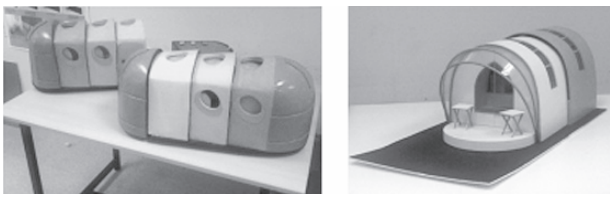

Figure 7. Examples of graduation projects which only imitates form or colours

Figure 8. The graduation project which inspires from calamari because of its aerodynamic structure.

It was found out that both of the two groups of students could not use the website efficiently because their English was not sufficient to understand biological terminology. And also their biological background was inadequate to understand the technique quickly and direct it to solve a design problem, because they were not in the Science Class in the High School. That is why another workshop was organized with a group of students who were better in English and Science in order to use the database.

The second workshop was held in X University with the 2nd class students of Industrial Product Design Department. 25 students participated in the workshop which is constituted by three phases:

1. In the first phase, the students studied on the design of a camera and a dish rack by using natural analogy, without any prior information given to them.
2. In the second phase, a presentation about biomimicry took place.
3. In the third phase, the students were expected to identify problems, define the keywords to search and search the Asknature database. It was thought that a specific method would help the students to search through the website. This step by step method is adapted from the concept generation method (Five-Step Method) by Ulrich and Eppinger. The original method's steps are in order: 1. Clarify the problem. 2-3. Search externally- Search internally. 4. Explore systematically. 5. Reflect on the solutions and the process. (Ulrich and Eppinger, 1995:100).

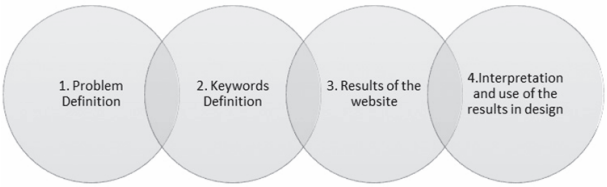

Figure 9. The step by step method which is advised to the students.

The students were asked first to define the problem and then they defined the keywords to be searched in the website. After that, they were supplied with a series of results retrieved from the database. Lastly they were asked to interpret and use the relevant results in their design projects. This method has enabled us to see the search and the results more clearly in a systematical way. It showed that in which steps natural analogy took place and how efficient it was. The method was also useful for the students in order to establish relationship between nature and the design process step by step.

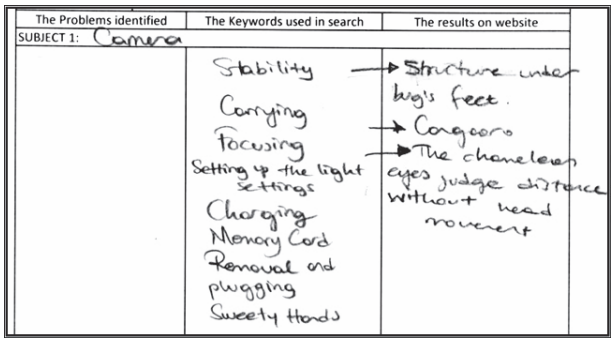

Figure 10. An example of a step by step form Evaluation.

The second workshop was more detailed and efficient than the previous one. The factors below affected the results of it:

- Beside the database, a systematic research method was recommended to the students. It has an important effect on the results of the second workshop, although the success was limited by the students' ability to use it.
- The students who participated in the second workshop were accepted to the university by their scientific knowledge degree. Their biological background was expected to be better than the ones who participated in the first workshop.

Recommendation of a systematic way for research helped the students to use the database more efficiently. At the end of the workshop, their approach changed from morphological imitation to using materials, textures and operations which can be seen in nature.

It was seen that when the students were asked to design by natural analogy; their first move was to imitate the natural entity that is taken as a model. They imitated the form of the entity in terms of its structure, function or only aesthetic properties. They did not analyse the problems or

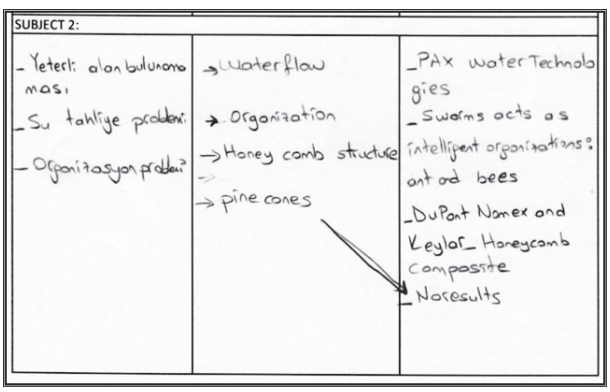

Figure 11. An example of a step by step form.

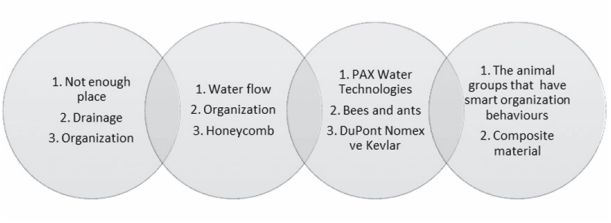

Figure 12. An example of step by step research structure.

potential solutions although they have been doing these kinds of analysis as a procedure in their studio projects. Interrogation to the problems and keywords helped them to analyse deeply. Supportively, some of the exercises in the workshop indicated that if the students did not define the problems and keywords strongly; they could not reach any effective results. An example of a strong research structure with a step by step method scheme can be seen in Figure 11.

Some of the students search the word 'honeycomb' for different products, the words about 'water' for the dish rack. It supports the thought that the efforts to use natural analogy by the students are limited to the connotations in their mind.

A group of students tried to make a relationship between an eye and the camera lens in the first part of the workshop or offering the layered outer shell of an armadillo for a dish rack that can be seen in Figure. 13, as expected before the briefing about the website. Same group searched about leaves for the same function for the camera lens and for holding the dishes after the information and the biomimicry introduction. It is consistent with the aims of the workshop; it affected the perception of the students. They tried to look at nature with a completely different point of view, relying on academic research and scientific information instead of the first images that come to their minds.

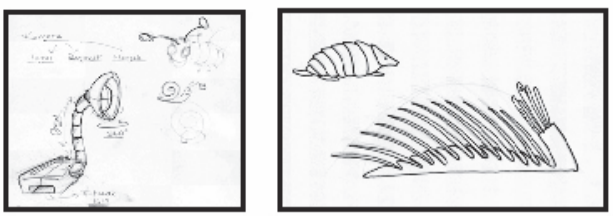

Figure 13. Examples of workshop studies before the briefing.

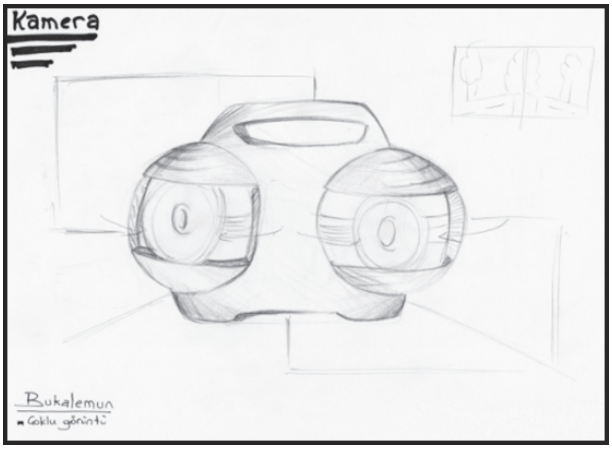

Figure 14. An example of student study before the workshop (chameleon and multiple vision).

The students did not reflect the 'Asknature research' results to their design studies visually but the questionnaires show that awareness of natural analogy and its technical usage has increased. The students think that using nature as a source for problem solving is harder than using as a source for form study. Below, there are some quotations from the questionnaires:

> "A complicated method but useful and enjoyable"
>
> "The database and using natural analogy are too technical and incomprehensible"

In both workshops it was seen that it is hard to break the bias against biomimicry. Due to the design education system which they get in, they force themselves to do abstraction and stay away from imitation because of the risk of doing kitsch. The research remained as verbal and was not reflected to design visually.

The approach of students was mostly morphological before the presentation about biomimicry. Some of them were morphological imitation because of the structure; some of them were because of the function. But all of them were morphological studies without digging it up technically. After the information, their approach changed by using biomimic materials, textures and operations.

On the other hand, introducing the natural analogy as a creativity method may cause not to be understood seriously. It needs to be emphasized that the natural analogy is more than a form searching method; it delves the nature to extract sustainable and responsible design.

As a positive result; the students could build up new relationships between their design projects and natural beings or entities which they did not intend to do before.

Conclusion

In the world where issues related to sustainability have becoming more critical, benefiting from nature can be a successful method. However there is the need to achieve this holistically, in every step of the process, as nature does. The method for nature inspired design which is mentioned by Tempelman, van der Grinten, Mul and de Pauw is based on eight elements and benefits from eight disciplines (Figure. 15). This method was developed as a mix of 'Cradle to Cradle' and 'Biomimicry' principles (Tempelman et al, 2015). It is a significant example of the holistic biomimicry and interdisciplinary approach. The researches and investments in various fields which are referred in the former chapters of this paper are promising in terms of developing new 'biomimic models'.

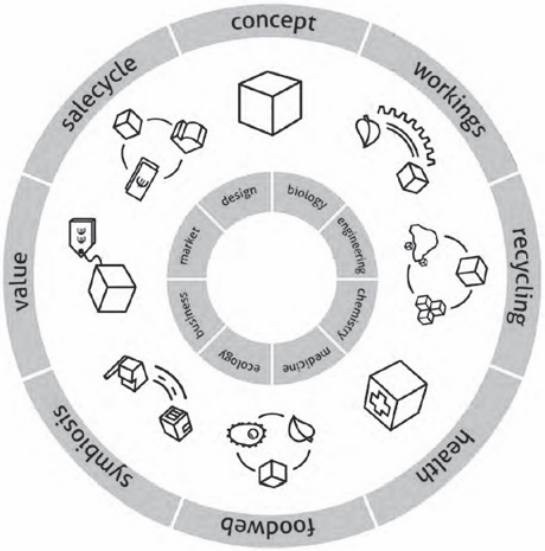

Figure 15. Eight elements and eight disciplines of Tempelman, et al.'s nature inspired design method. Source: Tempelman et al. (2015).

To use biomimicry in design properly, the designers need sufficient biological knowledge, a supportive method to use, go beyond what is visible and to avoid mere formal imitation. The students do not prefer to use biomimicry as a creativity method; if they use, it does not go further than a morphological imitation. When they are informed about it, they found the biological terminology too complicated to understand and they would not be eager to use it. Although students had a Science based education; using natural analogy needs a serious knowledge of biology. Due to the lack of proper biological infrastructure, natural

analogy could not be used in an efficient and accurate way. The designers would need a professional help to read, analyze and practice the biological information; and a systematic method to use it in a project. It requires a holistic view and can be achieved by giving place to Biology and related courses in the design curricula. Biomimicry Institute encouraged the participants of Biomimicry Student Design Challenge to make interdisciplinary teams include at least one biologist, probably due to the same reason.

Even it was a short briefing that was offered during the course of the workshop, it did help to make difference in the perspective of students. They noticed that natural analogy is a different method from any other creativity methods by being a holistic process of detail and technical solutions rather than a form searching method. However, to reach a pure success to use this method in design education and practice; it needs to be developed, a method special to biomimicry has to be generated. The literature review shows that natural analogy studies considerably increase in different fields. The results of workshops can be re-evaluated to lead new interdisciplinary models and researches.

A system which has created its own way by billions of years can be consulted as a loadstar; a new design method can be put forward through observing the cycle and the process of nature. New methods can be developed to integrate the natural sciences to the design theory and practice by inspecting and analysing the courses and curriculum, making collaborations with experts.

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References

Basalla, G., 2004, *Teknolojinin Evrimi*, transl. C. Soydemir, Tübitak, Ankara. (Originally published in 1988 as The Evolution of Technology).

Benyus, J., 1997, *Biomimicry: Innovation Inspired by Nature*, Harper Collins Publishers Inc, New York.

Blackmore, S., 2011, *Mem Makinesi* transl. N. Şimşek, Alfa, İstanbul. (Originally published in 1999 as The Meme Machine).

Boğa, M., 2013, '*Tasarımda Do al Analoji: Endüstri Ürünleri Tasarımı Ö rencilerinin yakla ımı üzerine bir çalı ma.' (Natural Analogy in Design: A Study on the Approach of Industrial Design Students)*. MSc thesis, Dept. of Industrial Product Design, Istanbul Technical University.

Cattano, C., Nikou, T. & Klotz, L., 2011, 'Teaching Systems Thinking and Biomimicry to Civil Engineering Students', *Journal of Professional Issues Engineering Education & Practice*, 137, 176-182. doi: 10.1061/(ASCE)EI.1943-5541.0000061

Dawkins, R., 1976, *The Selfish Gene*, Oxford University Press, New York.

Dawkins, R., 1986, *The Blind Watchmaker*, Norton, New York.

Docksai, R., 2011, 'Biomimicry to Fight Blindness', *The Futurist*, 45(5), 18-19.

Eren, A. M., 2009, 'Bir Problem Çözüm Metodu Olarak Evrim Kuramı', *Cogito- Darwin Devrimi: Evrim* 60-61, 155-162.

Güları, M. N., 2008, '*Killer Products*' *in the New Market Ecosystem: An Analogical Approach Inspiring Novel Ideas in the Field of Design*, MSc thesis, Dept. of Industrial Product Design, Istanbul Technical University.

Heerwagen, J., 2003, *Bio-Inspired Design: What Can We Learn from Nature?*, U.S. Green Building Council, viewed 13 April, 2013, from http://www.usgbc.org/Docs/Archive/External/Docs8542.pdf

Langrish, J. Z., 2004, 'Darwinian Design: The Memetic Evolution of Design Ideas', *Design Issues*, 20 (4), 4-19.

Langrish, J. Z., 1999, 'Different Types of Memes: Recipemes, Selectemes and Explanemes' *Journal of Memetics - Evolutionary Models of Information Transmission*, 3 (2).

Norman, D., 2010, 'Why Design Education Must Change', in Core77, viewed 09 April, 2013, from http:/www.core77.com/blog/columns/why_design_education_must_change_17993.asp

Rao, P. R., 2003, 'Biomimetics', *Sadhana*, 28 (3&4), 657-676.

Reed, P. A., 2004, 'Resources in Technology a Paradigm Shift: Biomimicry', *The Technology Teacher*, December/January, 23-27.

Reed, E. J., Klumb, L., Koobatian, M., & Viney, C., 2009, 'Biomimicry as a Route to New Materials: What kinds of Lessons are Useful?', *Philosophical Transactions Royal Society*, 367, 1571-1585.

Santulli, C. & Langella, C., 2011, 'Introducing Students to Bio-inspiration and Biomimetic Design: A Workshop Experience', *International Journal of Technology and Design Education*, 21, 471-485, doi: 10.1007/s10798-010-9132-6

Spörrle, M. & Stich, J., 2010, 'Sleeping in Safe Places: An Experimental Investigation of Human Sleeping Place Preferences from an Evolutionary Perspective', *Evolutionary Psychology*, 8 (3), 405-419.

Tempelman, E., van der Grinten, B., Mul, E. J. & de Pauw, I., 2015, *Nature Inspired Design*, TU Delft Nature Inspired Design, viewed 22 April 2015, from http://www.natureinspireddesign.nl/

Tonkinwise, C., 2005, 'Design+Evolution=Eugenics: Mimetological Analogies, or Why is Design so Enamoured with Evolution', *6th International Conference of the EAD: Design, System, Evolution*, Bremen, Germany.

Ulrich, K. T., & Eppinger, S. D., 1995, *Product Design and Development*, McGraw-Hill/Irwin, New York.

Url-1, n.d., viewed 10 January 2015, in *Or Not Magazine*, from http://www.ornotmagazine.com/project/biomimicry/

Url-2., 2005, viewed 29 January 2015, in *Gizmag*, from http://www.gizmag.com/go/4133/

Url-3, 2013, viewed 29 January 2015, in *Design with Purpose*, from http://interfacedesignwithpurpose.com.au/biomimicry-as-a-tool-for-solving-design-problems/

Url-4, n.d., viewed 20 April 2013, in *Asknature*, from http://www.asknature.org/product/22aa5601fcdb68b5d2dc9e3d3a22f7f1

van Boeijen, A., & Daalhuizen, J. (eds.), 2010, *The Delft Design Guide*. viewed 01 March 2012, in TU Delft OpenCourseWare, from http://ocw.tudelft.nl

Vincent, J. F., 2007, 'Background to Biomimetics', DTI Report *Biomimetics: Strategies for product design inspired by nature - a mission to the Netherlands and Germany*, 8-12, Pera: UK.

Volstad, N. L., & Boks, C., 2008, 'Biomimicry - A Useful Tool for the Industrial Designer', *NordDesign 2008*, Tallinn.

Zari, M. P., 2007, 'Biomimetic Approaches to Architectural Design for Increased Sustainability', *The SB07 NZ Sustainable Building Conference*, Auckland.