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A Biomimetic Design Experience in Informal Interior Architecture Education

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Abstract
Biomimetic design is the process of creating innovative ideas inspired by nature. This approach adapts processes of natural organisms to solve design problems and guides design in interior architecture, similar to many other disciplines. This study aims to present the process of implementing the biomimetic approach to interior architectural design in an informal education environment and to discuss the outcomes of this experience. In this context, the approach and implementation methods of biomimetic design have been examined and a workshop study called "BIOStructure", which was intended to integrate these methods into spatial design, has been analysed. This workshop was organized as part of an International Student Triennial in order to experience the approach of biomimetic design as an informal education tool. In the workshop, students were asked to experiment with biomimetic design in either a solution-driven approach, or a problem-driven approach. As a result, it was observed that most of the students preferred a solution-driven approach to a problem-driven approach and students in earlier stages of design education tended towards form-oriented abstraction of biological knowledge, whereas students with more design experience tended towards principle-oriented abstraction.

Keywords
biomimetic design; interior architecture education; biomimicry; design education; informal learning; workshops

Introduction
Biomimicry is an applied science that is the source of inspiration for solving human problems through the study of natural organisms, processes and systems. The use of nature as a source of inspiration to develop new concepts for human conceived systems has occurred throughout human history. Systematic studies of how biological knowledge can improve the generation of ideas are relatively new (Salgueiredo, 2013). The term "Biomimicry" (bios: life, mimesis: imitation) was coined in 1962 by the naturalist Janine M. Benyus. Benyus describes Biomimicry as "*The conscious emulation of nature's genius*" (Benyus, 1997). Another definition of Biomimicry is "*Mimicking the functional basis of biological forms, processes and systems to produce sustainable solutions*" (Pawlyn, 2011).

Designers take inspiration from various sources to solve challenging design problems. Nature is an important source of inspiration for scientists, designers and engineers from different fields of interest. Every organism in nature is unique and fully adapted to its environment. This lasts through generations, while passing the test of survival to reach its next generation (El-Zeiny, 2012). Disciplines such as architecture, construction, information processing, robotics, etc. use bioinspiraton for generating new ideas (Speck, Speck, Beheshti & McIntosh, 2008). Similar to other design disciplines, various biomimetic design methods have been developed for the discipline of interior architecture. In this research, a literature review was previously conducted on the methods that designers and interior architects who want to use biomimicry could use to improve the built environment. The workshop experience realized with the help of the determined method as a result of this review has been shared, and the students' feedback related to the biomimetic design process has been evaluated.

Biomimetic Design Approaches

Biomimetic design is an emerging research field in design that seeks for systematically mining biological knowledge to solve design problems (Stone, Goel & McAdams, 2014). This approach has inspired many designers in the history of design. However, it is relatively new that it has become a movement by the growing need for sustainability and desire for creativity and innovation in design (Goel, Vattam, Wiltgen & Helms, 2014).

The literature review on the biomimetic design approach demonstrates that the approach has a bidirectional design process (Zari, 2007; Helms, Vattam & Goel, 2009; Speck et al., 2008; El-Zeiny, 2012; Salgueiredo, 2013; Helfman & Reich, 2016; Nkandu & Alibaba, 2018; Farel & Yannou, 2013). These two directions could be cited such as "solution-driven" (also named the bottom-up or biology push) approach and the "problem-driven" (top-down or technology pull) approach (Salgueiredo, 2013). Starting from solution (biology) and ending with problem (technology) or vice versa, at the end, knowledge is being transferred from biology to technology to solve technological problems (Helfman & Reich, 2016). (Table 1)

Table 1. The steps of solution-driven and problem-driven approaches (adapted from Salgueiredo, 2013)

Solution-driven approach		Problem-driven approach	
Starting Point	Fundamental research (biologists)	Starting Point	A design problem
Research	Understanding the biological model	Search for Analogies	Analogy search in biological knowledge
Principle Extraction	Identification of principles in biological models	Selection of suitable principles	Suitable principles of one or more biological models analysed
Abstraction	Transforming the biological principle in a "solution-neutral form"; reframing the solution for designers'	Abstraction	Transforming the biological principle in a "solution-neutral form" and reframing for designers' understanding

	understanding of the potential for technical implementation		of the potential for technical implementation
Development	Technical implementation of the biological principle extracted	Development	Technical implementation of the biological principle extracted

Solution-driven approach

In a solution-driven approach, the biologist determines the behaviour, functions and other characteristics of biological knowledge and the designer designs for an existing need; thus biological knowledge influences human design. The advantage of this approach is that the knowledge of biology may influence the design in ways other than the predetermined design problem. The disadvantage is that a comprehensive biological research should be conducted and then the information gathered should be determined as relevant in a design context (Zari, 2007). Biologists and ecologists should therefore be able to know the potential of the research in the innovation of design implementation (El-Zeiny, 2012).

Problem-driven approach

In a problem-driven approach, where designers look to the living world for solutions, designers are required to identify problems and then biologists are to match these to biological systems that have solved similar issues (Zari, 2007).

The steps for solution-driven and problem-driven approaches are demonstrated in Table 1. In the former, the research of biological phenomena reveals some interesting property that could be useful for design applications and in the latter, a design problem triggers the quest for biological solutions that could be helpful for solving the problem. In both cases, inspiration from nature is seen as a transfer between biology and design fields for generating ideas (Salgueiredo, 2013).

Biomimicry Levels and Abstraction Stage in Design Process

Biomimicry Levels

Benyus (1997) divides solution-driven and problem-driven approaches into three levels of mimicry, namely Form (Organism), Process (Behaviour) and Eco-system. They provide a framework for designers to determine which aspect of “bio” to “mimic” (Zari, 2007). The first level of biomimicry is the mimicking of natural form. This type copies an organism for its morphological attributes like its components, materials or visual shape (Arslan, 2014). The second level is to mimic the natural processes. The behaviour level involves imitating how an organism interacts with its environment in order to design a structure that it can fit in the surrounding environment (Nkandu & Alibaba, 2018). The third level is the mimicking of natural ecosystems. This involves more complex processes than the first two levels. To imitate ecosystems requires considering not only the designed object but also how it affects explicitly and implicitly its environment (Arslan, 2014). (Table 2)

Table 2. Levels of biomimicry and aspects examples of levels (adapted from El-Zeiny, 2012)

Form (Organism)	Process (Behaviour)	Eco-system
Formal attributes include colour, shape, transparency, etc.	Survival techniques	Response to climate by cooling, heating and ventilation solutions
Structure, stability	Collaboration and Teamwork	Waste management
Morphology, anatomy, patterns	Communication	Adaptation to various light and sound levels, self-illumination, shading, etc.

Abstraction Stage in Biomimetic Design: "Principle-Oriented Abstraction"/"Form-Oriented Abstraction"

Biomimetic design is a specific type of "design by analogy" based on analogies of nature. Designers, who attempts to implement biomimetic design by analogy, face a number of challenges (Linsey & Viswanathan, 2014). Biomimicry levels are used to build analogies in the idea generation stage of the design process. Analogies involve the use of similarities between different situations to transfer knowledge across concepts and domains for problem solving (Salgueiredo, 2013). During the abstraction stage of a biomimetic design process, the relation between biology and technology is built and the biological system is presented in the context of analogical reasoning. The transfer of knowledge is realised from a model of a biological system to a model of a technological system. This model should explain how the problem is solved in biology, and may contain references to functions, behaviours or design principles in case they are related to the solution (Helfman & Reich, 2016). Stone et al. (2014) classify inspiration through the forms of nature in three different types such as *visual*, *conceptual* and *computational*. In *visual inspiration*, pictures or other visuals of a biological system are used to create the design sharing the same visual appearance. In *conceptual inspiration,* the use of the knowledge found in biology forms design principles. *Computational inspiration* is searching through nature to find algorithms as evolutionary computation (Stone et al., 2014).

The abstraction stage is the core of the biomimetic design process. Abstraction is the stage of refining the biological knowledge to some working principles that explain the biological solution and could be further transferred to the end-design (Helfman & Reich, 2016). According to Santulli & Langella (2011), "bio-inspiration" is not a formal imitation of the natural geometry (biomorphism); in contrast, it implies transferring new strategies inspired by the natural systems to the culture of design, via an abstraction stage. In biomimetic design, "principle-oriented abstraction" of biological knowledge (organism, process or eco-system by conceptual or computational inspiration), rather than just "form-oriented abstraction” (by visual inspiration), appears to be one of the most difficult challenges. In the field of interior architecture, biology is commonly used as a library of shapes or decoration (Art Nouveau, Jugendstil), however, imitating or being inspired by natural-looking forms without abstraction stage is not biomimetics (El-Zeiny, 2012). Rossin’s study (2010) asserts that interior architecture practice should "biologise" design problems by using time-tested principles of nature in the design process as a source of inspiration (Rossin, 2010). This means that, in order to be biomimetic, a design must be informed by nature's science, not just its appearance (El-Zeiny, 2012).

Implementation of Biomimetic Design Methods in Informal Interior Architecture Education: BIOStructure Workshop

The ways of using the biomimetic design approach as a tool to solve design problems have been investigated in design disciplines as well as in design education. Using a biomimetic design approach for generating innovative ideas requires the students to acquire new educational tools, and an increased collaboration between the disciplines. This would enable the students to receive some information from other disciplines, and to apply this knowledge to the design problem (Santulli & Langella, 2011). Bioinspired design experiences in architectural design education provides also an introduction of students to alternative design methods and multidimensional thinking (Yurtkuran, Kırlı & Taneli, 2013). In this context, in order to experience biomimetic design with design students, a workshop organization has been preferred as an informal learning environment facilitating flexibility, collaboration and creativity rather than a formal education environment (Karsli & Ozker, 2015).

Workshop Structure

BIOStructure workshop was conducted as part of the student triennial activities in Istanbul, with 18 participants studying in interior architecture, industrial product design and architecture undergraduate programs. The coordinators of the workshop were interior architecture department members. The purpose of these workshops was to experience the process of generating innovative ideas by imitating nature. The workshop involved the biomimetic design of a lightweight pavilion that defines an urban space, mimicking nature or a natural process, and concretization of the design idea by the models. The participants were free to select the function of the pavilion and to work individually, or in groups during the idea generation and model making stages of the workshop process. The two-day workshop achieved an intense, and productive working environment.

Learning Expectations

Learning expectations that have been envisaged for the workshop are:

- To be able to use biomimetic design approaches in solving design problems,
- To get acquainted about how to access similar problems observable in nature, to list possible biological systems and analogies,
- To be able to establish appropriate analogies between design problems and problems in nature, and to adapt the solutions in nature for the solution of the design problem,

- To be able to develop innovative solutions that meet the physical, behavioural and technical requirements of the design problem by using biological references as inspiration.

Seminar

The first step of the workshop involved a seminar held by the coordinator on biomimetic design approaches. The students were briefed on the definition of biomimetic design, related research fields, definition and steps of solution-driven and problem-driven approaches, levels of biomimicry, aspects examples of these levels, abstraction stage and biomimetic design practice cases. The seminar provided students with design clues and engaged a sharing environment.

Design Process

Following the seminar, the design problem was submitted to participants: "design of a lightweight pavilion defining an urban space, through biomimetic design approaches". The students were asked to start the biomimetic design process by selecting either solution-driven or problem-driven approaches, before research and creating design scenarios stages. At this point, a design guide consisting of steps to be followed for two approaches was submitted to the students (Table 3,4). After the design approach decision, the participants did research on the internet for the natural organisms/ecosystems or processes to imitate and drew sketches based on the scenarios they developed (Figure 1, 2). The research assignment required students to prepare a digital presentation on biological references they selected, and on the types of behaviour these references engaged in adapting to their respective climatic, geographical and physical conditions.

Table 3. Biomimetic design guide through solution-driven approach

Solution-driven approach
Step 1: Determination of nature-based solution: Identify the natural object or process that influences you by any aspect of nature: (for example: Spider web for flexibility; micro strips of shark skin for surface resistance of water, clam shell for durability, etc.) Specify the natural object or process to imitate:
Step 2: Defining nature-based solution: Investigate how the natural object or process has this feature. (For example: The silk yarn produced by spiders, which is smaller than one thousandth of a millimeter in diameter, is five times stronger than the steel wire of the same thickness and can stretch up to four times its own length. This conveying system allows the spider to build up a wide area of web without compromising its durability.) Specify how the natural object or process has / produced this property:
Step 3: Abstraction of principle: Adapt the way the natural object or process acquires this feature to the pavilion design: (For example: developing a structure solution using the microscope images of the spider web)

Include images of the natural object or process you will emulate: Specify which aspect of the natural object or process you will imitate to reflect on the design (form, material, technology, etc.):
Step 4: Defining the problem: Specify the feature and the function of the pavilion you will design by imitating the natural object or process that you selected: (For example: modularity, flexibility, durability, lightness, waterproofing, self-cleaning, breathing, self-generating, transparency, interchangeability, camouflage, self-luminescence, recyclability, structure / stability, mutation according to need, portability, easy maintenance and repair, etc.) Specify the feature that your pavilion will acquire as a result of the biomimetic design process: Specify the function of the pavilion:
Step 5: Application of the principle Submit sketch drawings of your design. Select modelling materials according to your design idea. Prepare model of the pavilion on A3 base (scale: 1/50)
Information about group members: **Name/ Surname:** **Student's grade:**

Table 4. Biomimetic design guide through problem-driven approach

Problem-driven approach
Step 1: Identification of the problem: Specify the function and the feature you want to have the pavilion you will design (For example: modularity, flexibility, durability, lightness, waterproofing, self-cleaning, breathing, self-generating, transparency, interchangeability, camouflage, self-luminescence, recyclability, structure / stability, mutation according to need, portability, easy maintenance and repair, etc.) Specify the function of the pavilion: Specify the feature of the pavilion:
Step 2: Looking for nature-based solution: Identify the natural object or process that successfully possess or produces the selected feature in nature: (For example: spider web for elasticity; microstrips of shark skin for surface resistance of water, clam shell for durability, etc.) Specify the natural object or process to imitate:
Step 3: Defining nature-based solution: Investigate how the natural object or process has this feature. (For example: The silk yarn

produced by spiders, which is smaller than one thousandth of a millimetre in diameter, is five times stronger than the steel wire of the same thickness and can stretch up to four times its own length. This conveying system allows the spider to build up a wide area of web without compromising its durability.)
Specify how the natural object or process has / produced this property:

Step 4: Abstraction of principle:
Adapt the way the natural object or process acquires this feature to the pavilion design: (For example: developing a structure solution using the microscope images of the spider web)
Include images of the natural object or process you will emulate:
Specify which aspect of the natural object or process you will imitate to reflect on the design (form, material, technology, etc.):

Step 5: Application of the principle
Submit sketch drawings of your design.
Select modelling materials according to your design idea.
Prepare model of the pavilion on A3 base (scale: 1/50)

Information about group members:
Name/ Surname:
Student's grade:

At the end of the first day, all the sketches pinned on the idea wall and digital presentations were presented by the students to the whole group. In this presentation, the students explained the steps they followed in line with the design guide, their design approach preferences, the biological reference and which feature of this reference they used for bio inspiration, how they adapted this reference on the pavilion, and the scenario of function they determined for this pavilion. After a peer review process, the first design ideas were approved. The students were asked to bring materials for model making on the following day. The second day, models of the designs were made on the scale of 1/50 (Figure 3,4). During the model making, the designs were re-evaluated and initial ideas were constantly developed.

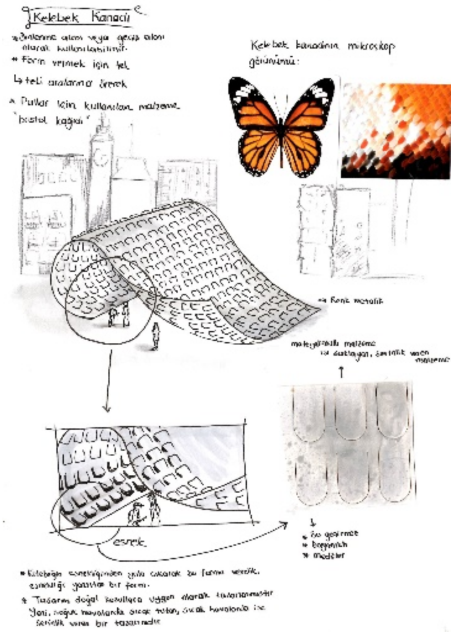
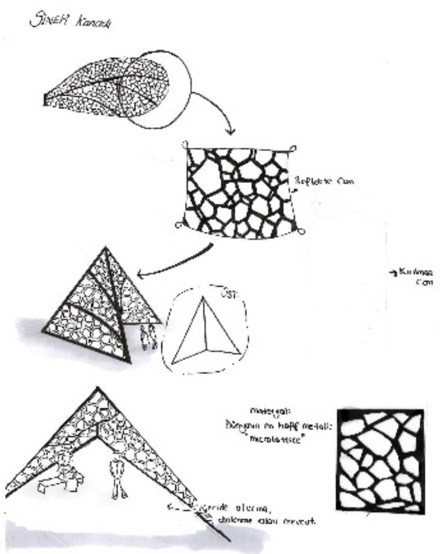



Figure 1, 2. Biomimetic design scenario sketches

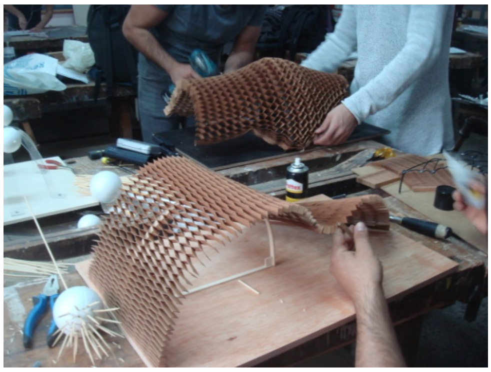



Figure 3,4. Workshop model making process

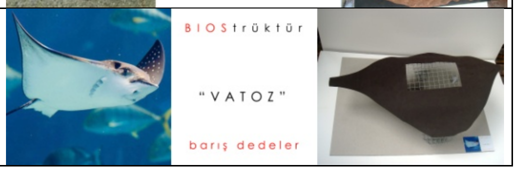
Final Peer Review

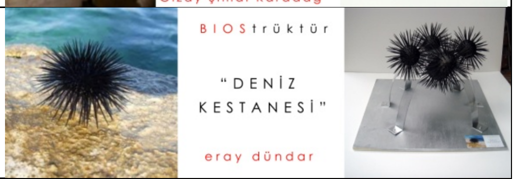
The workshop ended with student presentations. The students shared the steps of the design approach they used, the biomimetic design process and the problems they faced during the process with the whole group. Design solutions were evaluated by a final peer review. The models were prepared for the exhibition and the workshop session was closed by sharing suggestions for future studies.

Results and Evaluation

BIOStructure workshop's primary aim was to experience the implementation methods of biomimetic design and integrate these methods into spatial design. Another aim of the workshop was to examine the problems faced by the students in the design process, to investigate the students' design approach preferences, abstraction orientations and the relationship between these issues and the level of design experience of the students. Design guide notes of participants, field notes and periodic interviews during the workshop were used for data gathering. A table was prepared based on the design guide notes and images of models built during the workshop (Table 5).

Table 5. Biomimetic designs and design approaches of the workshop

Natural organism/ Process/ Ecosystem imitated	**Post-imitation characteristic of the lightweight pavilion**	**Solution-driven/ Problem-driven design approach**	**Principle-oriented / Form-oriented abstraction**	**Stdt. Grade**	**Inspirational image / Model of the lightweight pavilion**
Cobweb	Flexibility	Solution-driven	Principle-oriented	3	
Radiolaria	Expandability/ Lightness	Solution-driven	Principle-oriented	3	
Butterfly wing	Flexibility	Solution-driven	Principle-oriented	2	
Coral	Durability	Problem-driven	Principle-oriented	1	
Webfoot	Flexibility	Problem-driven	Principle-oriented	3	
Fly wing	Transparency/ Lightness	Solution-driven	Principle-oriented	2	
Isopod	Durability/ Flexibility	Solution-driven	Form-oriented	1	
Ray	Electricity Generation	Solution-driven	Principle-oriented	4	

Albatross	Wingspread	Problem-driven	Form-oriented	1	
Synapse	Establishing Point Links/ Structure	Solution-driven	Principle-oriented	4	
Fish Scale	Sparkling	Solution-driven	Principle-oriented	4	
Mushroom	Soft Tissue	Solution-driven	Form-oriented	2	
Sea Urchin	Durability/ Lightness	Solution-driven	Form-oriented	1	
Tortoise Shell	Durability	Solution-driven	Principle-oriented	4	
Bat Wing	Lightness	Solution-driven	Form-oriented	1	

At the end of the workshop, final designs were examined to see participants' preferences related to type, feature and aspect of bio-inspiration model to reflect to their design. The results are listed:

- Most of the participants used animals (cobweb, radiolaria, butterfly, coral, webfoot, fly, isopod, ray, albatross, synapse, fish, sea urchin, tortoise, bat) as bio-inspiration model; bio-inspiration from plants was quite limited.
- The majority of projects used performance features for bio-inspiration such as "flexibility, lightness and durability". Other selected features are "sparkling, softness, electricity generation, structure and wingspread".
- The preference of aspect of bio-inspiration model to reflect to design was equal. 5 of groups selected to reflect "technology" aspect (coral, webfoot, ray, synapse, tortoise); 5 of groups selected to reflect "material" aspect (cobweb, radiolaria, butterfly, fly fish) and

5 of groups selected to reflect “form” aspect (isopod, albatross, mushroom, sea urchin, bat) of the bio-inspiration model to their design.

At the end of the workshop, design guide notes, field notes and interview notes were analysed to reveal participants’ preferences between solution- and problem-driven approaches in the biomimetic design process and between form- and principle-oriented abstraction in their designs as well as potential differences in the biomimetic design process between students in the earlier stages of design education (first grade and second grade students) and students with more experience in design education (third grade and fourth grade students). Design guide notes of the students were used to gather data on what grade the students were in, their preference between solution-driven and problem-driven design approaches similarly to biomimetic design approach, and how they implemented design steps like principle- and form-oriented abstraction. The results have been analysed and evaluated:

Evaluation of the preference between solution-driven or problem-driven approaches in biomimetic design among students:
Data based on the design guide notes of the participants show that the solution-driven approach was preferred to the problem-driven approach in 12 of 15 designs. In the interviews, participants expressed that the most important reason they preferred the solution-driven approach in the workshop was that it was easier to find a design problem based on an existing biological solution”. Accordingly, this case has confirmed the hypothesis presented by Helfman & Reich (2016): “*It might be easier to find analogical design problems to a given biological solution than finding an analogical biological model to a given problem among the millions of potential biological sources.*” Another reason for this orientation may be that the design problem has already been determined as a pavilion even if the function has not been specified. Three designs that employed the problem-driven approach were developed by both students in the early stages of design education (first grade and second grade) and students with design experience (third grade, fourth grade). In this sense, no significant difference has been observed in design approach among students’ grades.

Evaluation of the preference between principle-oriented abstraction and form-oriented abstraction among students:
Data based on the design guide notes of the participants and field notes has shown that “principle-oriented abstraction of a natural organism/process/ecosystem” was preferred in 10 of 15 designs. None of the students with design experience preferred “form-oriented abstraction of a natural organism/process/ecosystem”; all five of the designs that employed form-oriented abstraction were developed by students in earlier stages of design education. Therefore, this case has showed that students in the early stages of design education (first grade and second grade) tended towards “form-oriented abstraction of a natural organism/process/ecosystem” and students with design experience (third grade, fourth grade) tended towards “principle-oriented abstraction of a natural organism/process/ecosystem.” In the interviews, students in the early stages of design education expressed the reason why abstraction could not go beyond form-oriented in the search of a biomimetic solution was that “they had difficulty in finding a starting point when they started designing and gravitated towards form”. According to Felek & Gül (2019)’s

research, implementation of various strategies to boost creativity of the students in the early stages of design education during the process of interior design is seen as beneficial. For this reason, in future workshops, a method of creativity can be integrated into the design guide in order to facilitate the principle abstraction phase for students with little experience in design. However, these students also expressed that "they preferred form oriented abstraction because they could not fully understand biological processes (survival techniques, response to climate, adaptation to environment) of biomimetic models" and stated "as they could not clearly understand the rationale behind the biological process, it was easy to use form as a design tool rather than the principle". According to Farel & Yannou (2013), the designers that practice biomimetic design suffer from a lack of biological knowledge, so through the participation of a biologist in the team, the team's knowledge base will expand and this will lead the team to innovative design solutions. For this reason, in future studies, a workshop open to design students and also to students from other disciplines such as biology may be organized in order to expand group's biological knowledge.

Conclusion

Biomimetic design has been the foundation of a many great innovative designs throughout history. However, there is still a lot to understand about design practices from the biomimetic approach, the underlying cognitive mechanisms, and methods preferred to implement and teach the approach. As one of the disciplines that use biomimicry for inspiration, interior architecture generally utilizes biology as a library of forms; however, this alone is not biomimetic; the design itself must involve biology. This workshop was useful to introduce students to the possibilities and significance of biomimetic design, to use biological principles as an inspiration tool in spatial design. The study, firstly examined the biomimetic design approach and application methods, and then analysed a workshop that aimed at integrating these methods into spatial design. In the final section, structure, learning expectations, outline and outcomes of the workshop were discussed. It was observed during the workshop that most of the students preferred the solution-driven approach to the problem-driven approach, because students mostly believed it to be easier to find an analogical design problem for a specific biological solution, therefore, gravitated towards the solution-driven approach. Another reason for this orientation may be that the design problem has already been determined as a pavilion even if the function has not been specified. The second research question was about the preferences of students between principle- and form-oriented abstractions. The goal of biomimetic design approach is not only being inspired by forms but also understanding and adapting the functions, characteristics and processes that constitute the form. It has been observed that first and second grade students have difficulty in the adaptation/abstraction process as they imitate a natural organism/process/ecosystem. These students have pointed out that it was difficult to find a starting point in design process and they found solutions by thinking form-oriented. They also stated that they were directed to form oriented abstraction because of their limited knowledge and understanding of biological references. All third and fourth grade students developed designs by using functions, characteristics or processes rather than the form of the natural organism/process they mimicked.

The limitation of this research is that the biomimetic approach has only been tested through one workshop. This is just a first step for discussing the experience of implementing the biomimetic approach to interior architectural design in an informal education environment. The approach needs to be tested further where the research is an experimental or testable protocol setup and with sufficient data collection to permit a comparative study (a statistically significant sample size). Besides, based on this biomimetic design experience, it is proposed for future studies to introduce a more flexible design problem to facilitate attempts to use the solution-driven approach as much as the problem-driven approach, and add to the biomimetic design model a guiding step that involves a method of creativity that facilitate abstraction and directs students who are in the earlier stages of design education to be oriented in principle rather than form. Another suggestion to facilitate this process is to organize a multidisciplinary workshop open to design students and also to students from other disciplines such as biology. In this way, biological knowledge transfer may become more accurate and efficient; so that design students could more easily understand, synthesize and use the principles of biological references as design data.

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