Ain Shams Engineering Journal 10 (2019) 499–506

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Architectural Engineering

Biomimetic Approach in Architectural Education: Case study of 'Biomimicry in Architecture' Course

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ARTICLE INFO

Article history:
Received 4 March 2018
Revised 7 October 2018
Accepted 9 November 2018
Available online 16 February 2019

Keywords:
Biomimicry
Design projects
Architectural education

ABSTRACT

Environmental aspects are crucial in designing sustainable buildings in relation to context. World is suffering from climate change due to green-house gas emissions. The present work shows the importance of teaching future architects how to implement biomimetic approach as a diverse sustainable way in architectural design. It is intended to clarify potentials of biomimicry as design generators in the course 'Biomimicry in Architecture'ASE433ba-Fall2017 for 4th year architectural students, MSA University, Cairo. This is achieved by analysing the process of teaching biomimicry, staff and students' perception. A questionnaire was distributed among students to evaluate their gained experience of applying biomimicry concept. 18 students attended the course and responded to the questionnaire. Their perception was measured through statistical analysis of questionnaire results. Students enthusiastically applied biomimetic principles in their designs. Incorporating biomimetic approach in architectural design will raise awareness of its importance in professional practice through students' exposure to existing biomimicry projects.

1. Introduction

Creative methods and innovative techniques in architectural education are continuously developing. Widening the scope of vision of the students in architectural design studios gives them the chance to think critically, evaluate and develop. Designers are usually inspired from different sources to address challenging design problems. One of the methods is to study Nature and comprehend the ways it has developed to address environmental challenges [1]. Looking at Nature and finding solutions are valuable for designers. By choosing the most appropriate material for design, providing recycling and solutions according to local conditions, Nature is an immense factory which is durable and aesthetic [2]. Nature denotes the world or Universe as created by God. The glory of wisdom is witnessed by looking carefully to living organisms. Nature optimizes rather than maximizes, using the least materials and energy needed for perfect performance. Nature uses little material and places it in the right place. "Lo! We have created everything by measures" [3]. Searching for solutions to the design problems by taking inspiration from nature is one of the innovative approaches that should be supported in design education. Biomimetic is the process of applying biological principles that underlie morphology, structures and functionality of biological entities to man-made design. It is "An engineering discipline that emulates nature's design and processes to create a healthier, more sustainable planet" [4]. The sustainable development strategy of Egypt's vision 2030 includes several goals, among which: increasing substantially the share of renewable energy in the global energy mix and doubling the global rate of improvement in energy efficiency by 2030 [5]. Aiming for 'zero' environmental impact buildings in terms of energy, carbon, waste or water is a worthwhile but difficult target. Built environments will need to go beyond having little negative environmental impact in the future to having net positive environmental benefits [6]. Such architecture is termed as regenerative design [7]. The key to regenerative design is a transfer of knowledge from biology and ecology into architectural design. By looking at the living world, there may be organisms or systems that can be mimicked to create and maintain a resilient and adaptable built environment, and improve its capacity for regeneration of the health of ecosystems [8].

The aim of the present work is to clarify the potentials of biomimicry as design generators in an elective course entitled 'Biomimicry in Architecture'ASE433ba-Fall2017 for the 4th year

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Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.asej.2018.11.005
2090-4479/

architectural students in MSA University in Cairo. The paper clarifies how the course instructors incorporated biomimicry in the design studio and how students responded to this challenge. This study is an action research as it practically assesses the impact of introducing biomimicry concepts on the students' design. "Action research is inquiry conducted by a practitioner to improve the quality of that practice in a social setting through the researching of action by the practitioner in a reflective manner" [9]. The overall experience of the course can be evaluated through staff and students' perception of the course. Staff perception considers instructors' reflection on the students' performance during the course, while the students' perception is simply clarifying their degree of acquiring the biomimicry concept through a questionnaire.

2. Literature review

The term biomimetic was introduced by Otto Schmitt in 1982 [10], and it was rediscovered by Janine Benyus in 1997, who is an innovation consultant and co-founder of the Biomimicry Institute [4]. The concept of biomimicry is sometimes misrepresented as creating buildings that look like natural organisms, i.e., buildings shaped like shells, which is another different approach in design called Biomorphology. Mimicking natural systems or processes would affect the form, but that is not the fundamental point in biomimicry [11]. Therefore, biomimetic is not the simple imitation of Nature, neither in material and function nor in creative regard, rather than the grasping of natural principles to aid in the comprehension of analogous, technological questions, which would then be solved by the applications of optimized technologies. Biomimetic is practiced through learning from nature for the improvement of technology. It is interesting and fascinating for the architect to explore the wealth of living nature, but one must be cautious of a too direct interpretation. Inspiration from Nature for architecture will not function if architects do not follow the in between step of abstraction. Application of biomimetic is then a 3-step process: Research – Abstraction – Implementation [12]. There are two main approaches to the design process in biomimicry: the problem-based approach and the solution-based approach. The problem-based approach is a 'Design to Biology'. It relies on identification of goals and design limitation. The designer in this approach starts by the identification of the problem, then search for solutions from natural organisms. The biologists and designers match the problem to an organism that has solved a similar problem. This approach can also be called 'Challenge to Biology' which is seeking answers in biology for human problem. The designer enhances a specific design or solves a design problem by exploring and looking to nature. The solution-based approach is a 'Biology to Design' which is used when the biological principle is the source for design ideas [13]. The design process originally depends on the scientific knowledge of biologists and scientists instead of human design problems. The designer identifies a useful characteristic from nature, that is abstracted and translated to a technological context before the goal of the design is defined [14]. There are three main levels of biomimicry: organism, behaviour, and ecosystem. On the organism level buildings may imitate the characteristics of an individual organism. On the behavioural level the design may be inspired by how the organism behaves or relates to its larger context. On the ecosystem level, design may draw from the entire ecosystem of an organism and its surrounding. It emphasizes natural process and cycle of the greater environment [2]. There are further five dimensions of biomimicry within each of these levels. The design could be biomimetic in terms of its form and what it looks like, its material and what it is made out of, its construction and how it is made, its process and how it works and its function and what it is able to do [15]. The most apparent dimension of biomimicry is the emulation of nature's function. Emulating Nature on the process level involves learning from the way Nature evolves or produces things. Biomimicry looks at Nature's system and examines how it deals with waste and regeneration inside closed-looped lifecycles [11].

On the other hand, biomimetic approach has been introduced into architectural programs in some universities all around the world in the last few years. Alawad, A. and Mahgoub, Y., 2014, studied the impact of teaching biomimicry as a tool for enhancing thinking skills for students in art education. They studied a sample of 30 students in the third level at University of Khartoum in 2012/2013. Their research findings showed that biomimicry has a number of major benefits. It offers spiritual development as it gives them the opportunity to mediate and appreciate God's creation. It awakens students' perception of nature realizing that everything in nature has a purpose and function. Moreover, biomimicry can positively impact early years' education. The results also showed that biomimicry has long-lasting effect skills. They develop their self-reflection, critical and creative thinking, and problem-solving techniques. Their recommendation included the need to consider this topic as a main component of the design education system [16]. Tavsan, S. and Tavsan, F., 2015, considered design and nature in relation to architectural design education. They delivered architectural design course for second grade students at Karandeniz Technical University in Turkey within the scope of the concept of biomimicry. They indicated that analogies aroused interest and wonder and increased motivation. Students developed their analytical ability and learned that many problems have a solution in nature [2]. Mansour, H., 2010, in University of Dammam in Saudi Arabia taught interior architects how to open their eyes to the genius of natural world in an attempt to inspire new paths for living sustainably on Earth. She stated that teaching students how to use biomimicry as a tool for innovation will increase the integration of the built environment with nature in a sustainable way [17]. Pankina, M. and Zakharova, S, 2015, Russian State Vocational-Pedagogical University, mentioned that the principles of biomimicry will help in providing design smarter, and connect the work with the natural environment. They stated that in the future biomimetic design is becoming more and more popular in the field of architecture. They also stated that the application of biomimetic principles and adaptive strategies of natural organisms would improve the adaptive behaviour of building skins [18].

According to the author knowledge integration of biomimetic approach in the design studios are not applied in the architectural program in the Egyptian universities. However, similar educational concepts of integrating other disciplines in the Egyptian architectural systems are found. Elshater, A., 2018, showed how to benefit from other disciplines to foster the teaching techniques. For example, integrating photography in urban design programs raises the visual skills and boosts the way that students see their external environment. The results of her research stem from the reports of the excellent students' feedback, comments on the course and experts interviews. "Urban design, as visual-aesthetic management, can benefit from a method for module revisited that provide themes for photography to boost the skills that students should gain" [19].

3. Methodology

One of the main goals of architectural education is to graduate architects who will pay special attention to environmental and sustainable issues. Students have to feel the architects' responsibility in preserving the planet's ecological health by changing the perception of what buildings should look like, and blend them with nature, rather than replacing nature with concrete. Architects need to make building more green and adaptable to our surroundings.

They need to avoid the sick building syndrome and create buildings that are energy efficient [20]. Utilizing the biomimetic principles in architecture design leads to the development of the required and attractive characteristics of the building product such as adaptive architectural envelopes, optimum lighting to spaces, healthy inspired environment, beautiful, sustainable and green surroundings [6].

The research objective is to show the importance and potentials of biomimetic as design generators in an elective course entitled 'Biomimicry in Architecture'. The goal is to test the impact of the course on the innovative capabilities of the students. This objective is achieved by: first presenting an overview of the course; second by describing the staff perception and insights of the students' performance, and third by analysing the students' perception on the course. The survey research technique is applied in the present work. The students' perception is tested through surveying their responses towards their gained experience in the course. Through a questionnaire and group discussion, the degree of gained benefits is investigated. Hard copies of the questionnaire were distributed to the 18 students who attended the course [Appendix A]. The students' answers were collected, classified, tabulated and statistically analysed. Group discussions were carried out to explore the students' overall opinions and to reach conclusive remarks.

4. Course overview

The course 'Biomimicry in Architecture' aims at motivating the students to be more innovative and creative in their designs while using Nature as a guiding spirit. The course focuses on achieving two main targets: how to design energy efficient buildings which are more adaptable to outer conditions and achieving optimum daylighting. The course consists of eight topics taught in the sequence shown in Table 1. Moreover, the course contained the following activities: research, assignments and design sketches. The students were introduced to the parametric design and practiced the Rhino and Grasshopper software. Grasshopper is a visual programming language and environment that runs within the Rhinoceros 3D computer-aided design application. Advanced uses of Grasshopper include parametric modelling for structural engineering, parametric modelling for architecture and fabrication [21]. The students were asked to apply biomimicry principles in their design mini-projects which has a theme of 'Lighting for Tomorrow'.

Table 1
Topics covered in the course 'Biomimicry in Architecture'.

Number of topics	Topics of lectures
1	Biomimicry in Integration with Nature
2	Biomimicry in Architecture
3	Requirements and Design Methodology
4	Biomimicry: Inspired Designs for Daylighting
5	How Plants Inspire Facades
6	Macroscopic Solar-Driven Energy Systems in Nature& Technology
7	Managing Daylighting & Energy Consumption in Office Buildings
8	Biomimicry with Steel Sheets

The objective of the first two lectures was to introduce biomimicry to the students in an interactive interesting way. The students were encouraged to explore the idea of biomimicry through a studio research where it was presented in an interactive session. 'Biomimicry in Integration with Nature' was the main topic while 'Function follows need' was the new slogan. The need to adapt our built environment to nature is a demanding issue. The staff intention was to guide the architectural students to learn from the nature searching for innovative methods to solve problems as adaptation to climate changes, in an attempt to improve the quality of life for upcoming generations and live sustainably on Earth. Then the question: 'How can architects build a new world of sustainable beauty' was raised.

In the third lecture requirements for architectural biomimicry and design methodology were identified. Collaboration of practices, complex surfaces 3D modelling, technology and specialized information from different practices were the main requirements. The fourth lecture focused on studying how organisms manage daylight. It clarifies the relation between organisms and lighting strategies. The design challenge is to maximize the use of daylight during the day. Fig. 1 orders all the information gathered about the organisms. It illustrates ten examples of organisms that manage daylight in different ways. The first column classifies four main functions: avoiding UV radiation, capturing light, blocking direct sunlight to avoid glare and transmitting light. The other four columns show the processes and factors accomplished by the organisms to interact with daylighting through the material or form [22].

The fifth lecture introduced the topic of 'How plants inspire facades'. It presented the possibility of generating design concepts

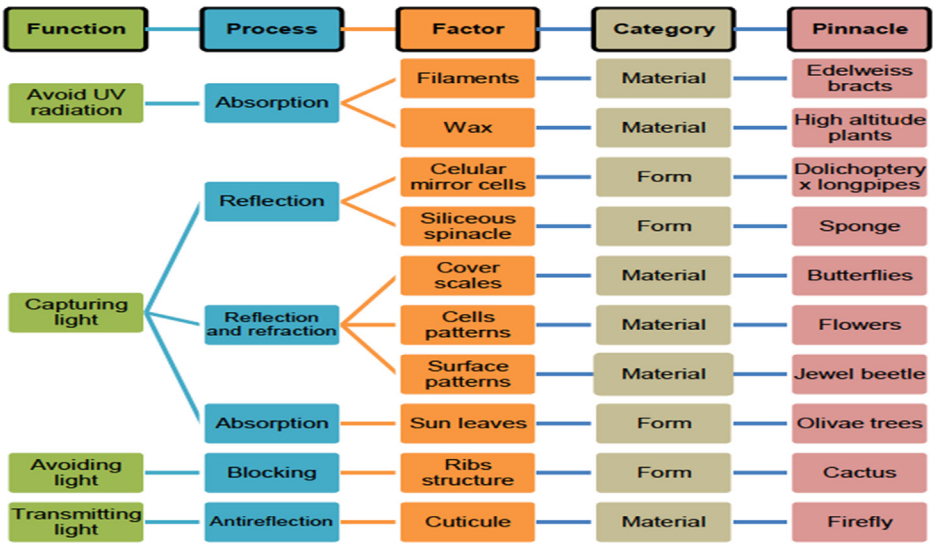

Fig. 1. Exploration model for daylighting [22].

for building envelopes that regulate the environmental aspects and comfort conditions based on adaptation strategies from plants. It proposed a design methodology through data collection and design concept generation. Information organized on a data collection uses a classification system to categorize the different ways in which plants adapt and interact with their environment. Then a biomimetic design methodology is suggested which leads to the concept designs for adaptive architectural envelopes. Mapping is proposed to facilitate the transfer of biological information into architectural application as shown in Fig. 2. In order to understand how plant principles can be utilized to create adaptive architectural envelopes the methodology is divided into two stages: nature and architecture. Nature is related to more analytical and scientific concept. It helps to identify adaptive strategies and mechanisms in plants in different climates. It combines with the architecture that is more deductive and creative. It helps to abstract and transform the selected ideas into innovative solutions for buildings. Climate data directly concerns both stages. The diagram in Fig. 2 shows 'design concept generation' that can be used in the analysis of transforming natural ideas into architectural application [23]. The sixth lecture discussed how can the analogous biological fibber optics system can be found in stone plants.

The seventh lecture clarified the potentials of applying biomimicry in office buildings and how it decreases its running cost and energy consumption while getting maximum use of daylighting. The eighth lecture introduced responsive facades made of perforated metallic screens which regulate the amount of natural light reaching the interior.

5. Staff perception

The following section describes staff perception of students' performance in different activities carried out during the course. The reasonable number of the students who attended the course was convenient during group discussions. It gave them the opportunity to grasp in-depth the concept of applying the biomimicry approach in the architectural design studio. Senior architectural students are more eligible to merge two different disciples, i.e. architecture and biology. Students were engaged in researches, assignments, design sketches, parametric design labs and the final mini-project.

5.1. Research activities

The students were enthusiastic in exploring the meaning of biomimicry, the nature's design principles, approaches to biomimicry and levels of biomimicry application in architecture. They worked in groups and presented their research in posters and power point presentations.

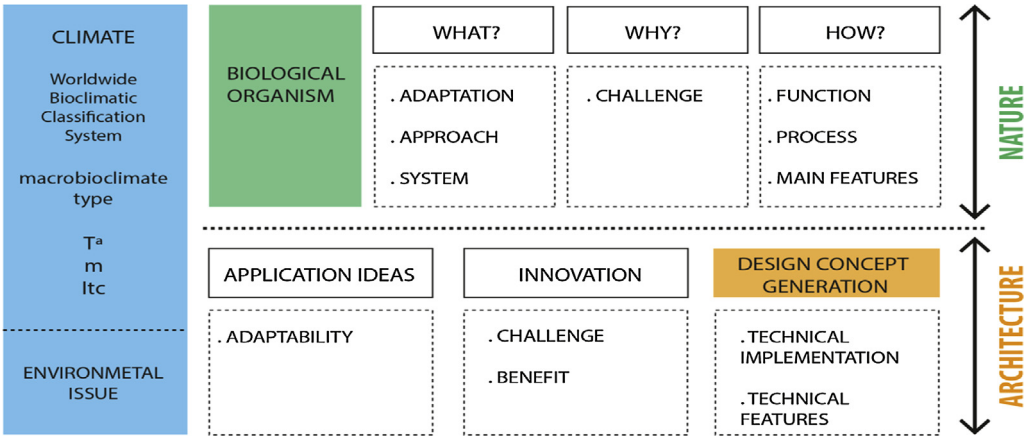

Fig. 2. Design Concept Generation [23].

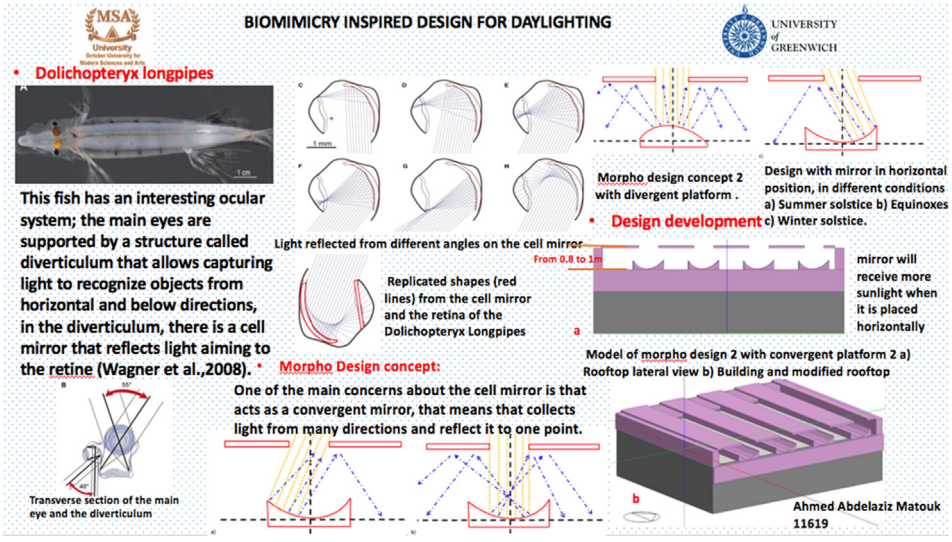

Fig. 3. A sample of a student's assignment of daylighting design.

5.2. Assignments

The students were engaged in individual assignments that developed their analytical and problem-solving skills. In the first two assignments each student was asked to search for two existing buildings that utilized the biomimicry approach. The students analysed and criticized different buildings showing how their designs were affected by the nature in terms of form, texture, material, function and construction. They realized its importance in the professional practice and how existing biomimicry projects are efficient in terms of climate control, adaptation, cost and energy efficiency. In the third assignment students gained the experience of rethinking the values of conscious daylighting design. They analysed lighting strategies of different organisms and how they respond to light showing the relation between organisms and light. Then they developed conceptual drawings based on natural organisms' strategies for lighting explaining the process of generating design concepts. There was an attempt to create a similar structure from the cell mirror in the Dolichopteryx longpipes fish. This structure would be able to receive sunlight all over the day, then sunlight would be reflected in a panel that provides diffused light to the room. A sample of this work is given in Fig. 3.

The last assignment was analysing two different plants adaptation to the environment and abstracting a design concept for the adaptive building envelope. A sample of a student's assignment of the design concept generation from plant inspiration is shown in Fig. 4. In this figure, the student selected a plant called Lithops salicola that adopted physiological and morphological means for thermoregulation. This process is achieved by its structure and skin functioning as a thermal filter. The plant challenge is to enable daylight to enter the plant in a certain value to help the plant to grow while reducing UV rays. The process is achieved by developing a unique way of enhancing solar collection by means of 'windowpanes' on the surface of the leaf. This idea is abstracted to a roofing system that decreases temperature inside the building.

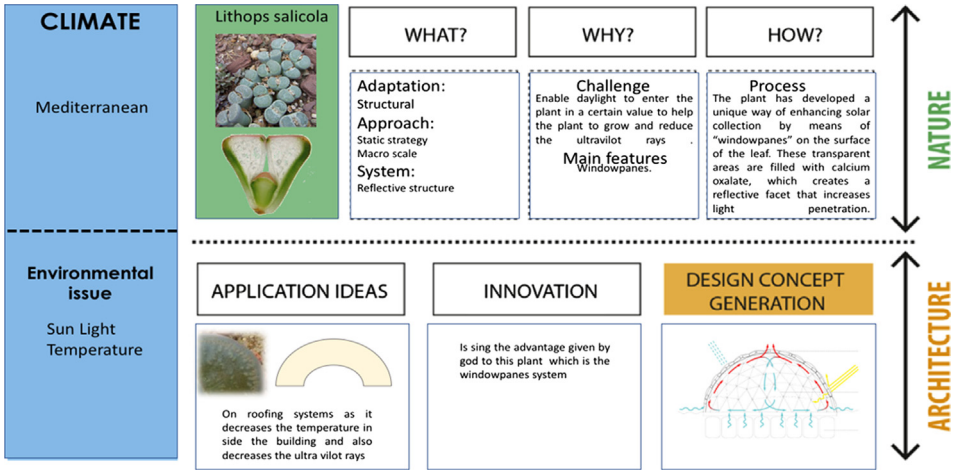

Fig. 4. A sample of a student's assignment of design concept generation.

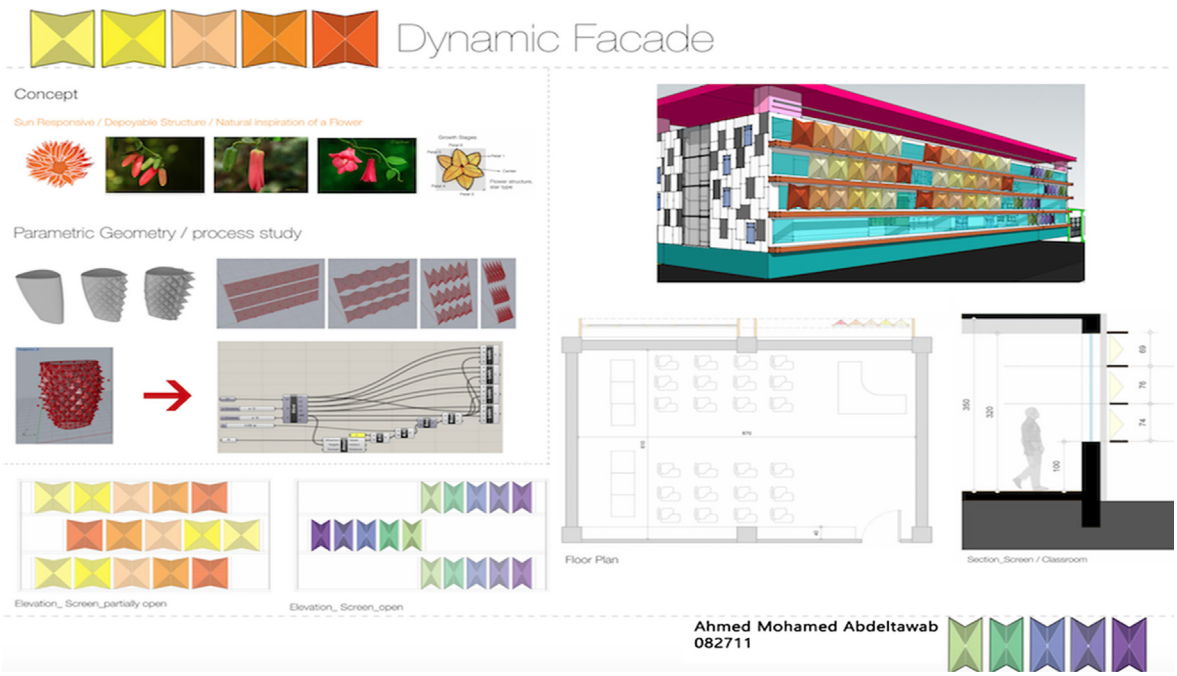

Fig. 5. A sample of a student's final mini-project.

5.3. Design sketches

The students began the design process by applying the biomimicry principles in their mini-projects. The natural daylighting and adaptive building envelope were the main design issues inspired from natural organisms. The parametric design tool was helpful as the Rhino and Grasshopper are essential software in visual programming and generative design. The projects were finally presented and evaluated through a design jury. The final mini-project presented in Fig. 5 shows how the student designed a dynamic façade to control daylighting inside the classroom. The design was inspired from a flower which has a deployable structure that responds to sun. The parametric design was a helpful tool in his project.

6. Student perception on the course

Through group discussions and the questionnaire students were asked to give their evaluation and comments on the fundamental issues of the course outline, content, organization and execution. Answers were collected during the 12th week of the semester. According to the analysis based on the item that reads "Choose the most interesting topic from your personal point of view": 50% chose the topic entitled "How Plants Inspired Façade", while 25% chose both " Biomimicry in Architecture" and " Biomimicry: Inspired Designs for Daylighting", as shown in Table 2. Also students were asked to evaluate their gained experience of the course topics and activities shown in Table 1. Figs. 6 and 7 represent the corresponding results of the statistical analyses. Excellent experience for the topic entitled "Biomimicry: Inspired Designs for Daylighting" took 73%, while "Solar-driven Energy System Network Technology" took 60% as given in Table 3 and Fig. 6.

Table 2
Most interesting topics for students.

Percentage of students	Most interesting topic
50%	How Plants Inspire Facades
25%	Biomimicry in Architecture
25%	Biomimicry: Inspired Designs For Daylighting

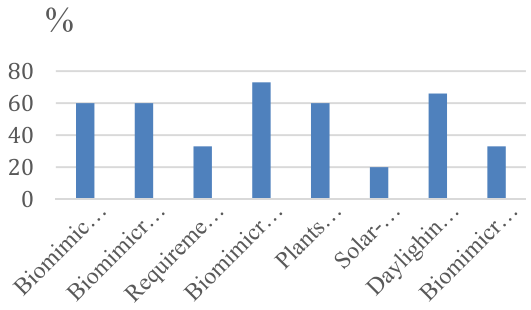

Fig. 6. Percentage of students who answered 'Good' on course topics.

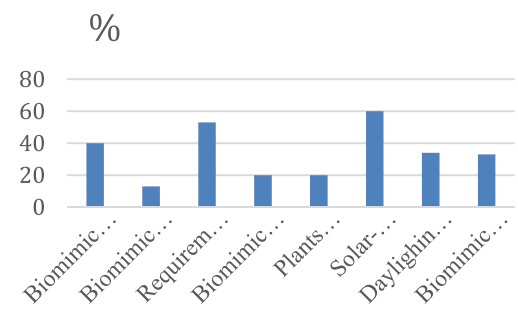

Fig. 7. Percentage of students who answered 'Excellent' on course topics.

Table 3
Evaluation of students' gained experience.

Percentage of students	**Excellent** gained experience	**Good** gained experience
73%	Biomimicry: Inspired Designs for Daylighting	
60%		Solar-driven energy system in Nature & Technology

Table 4
SWOT Analysis for 'Biomimicry in Architecture' Course.

SWOT	Course content	Student performance
Strength	The course content of 'Biomimicry in Architecture' covered the fundamental issues of biomimicry concept. It helps students to form creative shapes and sustainable buildings through parametric design	Students were very passionate about learning biomimicry in architecture. They creatively applied its principles in their design projects. Incorporating parametric design in the course gives students chances to implement biomimetic ideas
Weakness	More comprehensive arrangement between lectures & practical sessions of parametric design, Rhino Grasshopper has to be organized. The elective course 'Biomimicry in architecture' should be a core subject as it needs full concentration & time	Few students were reluctant towards the course and faced some difficulties in fulfilling all assignments. Students did not have enough time for physical models as the elective course is only a 3-credit hrs. course
Opportunities	The course could be delivered within a multi-disciplined approach through coordination between architectural department and other disciplines, i.e., mechatronics, where students will have more opportunities of designing a workable dynamic models	Cooperation between architectural students and other disciplines as mechatronics or biotechnology under the theme of biomimetic will give a chance for students to have a holistic approach and produce outputs beneficially
Threats	Dealing with other disciplines such as Biotechnology/Mechatronics is complex since each discipline has its own system	Students who attended the course faced difficulties in dealing with other disciplines

7. Discussion

The research findings based on the questionnaire analysis show that half of the students were very interested in exploring ways for designing dynamic facades through inspiration from plants. The rest of the students were motivated to explore the application of biomimicry in architecture and to maximize the use of daylight in building design by inspiration from natural organisms as witnessed in Table 2. The SWOT analysis is conducted to clarify the impact of the course content of "Biomimicry in Architecture" on the student performance as demonstrated in Table 4.

8. Conclusion

Professors have a responsible obligation towards architectural engineering students to paradigm shift their way of thinking in design towards not only enhancing the identity, functionality and aesthetic values but also towards interpreting sustainable strategies and methodologies in integration with Nature. The topics and activities covered in 'Biomimicry in Architecture' course, ASE433ba

Fall 2017, in the present work along with the students' performance were assessed. The students showed full interest towards the subject. They were passionate about learning 'Biomimicry in Architecture' and enthusiastic about applying its principles in their design projects. Students needed more time for acquiring practical skills in the parametric design and utilizing the Rhino and Grasshopper software in their design process. It is recommended for future program enhancement to incorporate biomimetic approach in design studios which will raise awareness for architectural students of its importance in designing and building sustainable buildings during their professional practice. According to the results of the questionnaire it is clear that it is needed to consider the subject of 'Biomimicry in Architecture' as a core course rather than an elective. It is worthwhile to consider the course to be included in the curriculum of architectural education.

Acknowledgement

The author wishes to thank Architect Mustafa Magdy who assisted in teaching the course. Thanks are extended to the students for their efforts and cooperation.

Appendix A. The questionnaire used in the present work:

October University of Modern Sciences and Arts
Faculty of Engineering
Department of Architecture

Biomimicry in Architecture
Elective Course for Senior Students
ASE433ba
Fall 2017
QUESTIONNAIRE
Evaluation Form by the Students

Dear Students,

This questionnaire should provide useful information on several aspects related to the organization and execution of the elective course "Biomimicry in Architecture". Your objective evaluation and comments will be highly appreciated and helpful for future improvements of organization, structure and execution of the course in the coming years. Please read the questionnaire carefully before answering. The evaluations are anonymous. Please give your evaluations and comments on the following issues:

A. Choose the most interesting topic listed in the given Table from your personal point of view.
B. Give your evaluation on the sequence on which the different Biomimic topics are taught.
C. Rank the different topics given in the Table according to your interest (out of 10).
D. Did you have the passion of exploring the new concept of Biomimicry .
   - Yes ……. No……..

E. Evaluate your gained experience of the topics/activities given in the following table:

Topics/Activities	Evaluation				Rank
	Excellent	Good	Fair	Bad	
1. Biomimicry in Integration with Nature					
2. Biomimciry in Architecture					
3. Requirements and Design Methodology					
4. Biomimicry Inspired Designs for Daylighting					
5. How Plants Inspire Facades					
6. Macroscopic Solar-Driven Energy Systems in Nature and Technology					
7. Biomimicry in Managing Dayligting and Energy Consumption in Office Buildings					
8. Biomimicry with Steel Sheets					
• Research					
• Assignments					
• Design Sketches					

F. Give your overall opinion and conclusive remarks on the usefulness of Biomimicry in Architecture Design

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