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From Nature to Design Studio: Analyzing Biomimicry-based Curricula in Architectural Education

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Abstract:- Conventional learning curricula in architectural education are not always conducive to promoting creativity, innovation, and sustainability, posing a problem for architectural students. The study explores the potential of integrated biomimicry-based curricula to enhance architectural students' learning experience by investigating the principles of Biomimicry. The analytical study emphasizes the possibilities of integrating biomimetic curriculum programs in the architectural practice of architectural students to improve students' learning efficiency. The methodology involves analyzing case studies that demonstrate these approaches' effectiveness in enhancing architectural students' learning experience. The results offer valuable insights and recommendations for using biomimicry in integrating effective curricula for architectural students, concluding that this integration can positively impact students' learning outcomes.

Keywords:- *Biomimicry; architectural learning; curriculum design; education.*

I. INTRODUCTION

Architectural education is crucial in shaping the future of our built environment and providing an effective learning experience that promotes creativity, innovation, and sustainability is essential. However, traditional architectural learning curricula may not always be conducive to these objectives, with many students feeling uninspired and disengaged during conventional curricula. Biomimicry has emerged as a promising approach to address these issues and enhance the efficiency of architectural students' learning. This approach draws on the natural world (Pawlyn, 2016) to inform design solutions for architectural students using the two aspects of biomimicry, the solution-based and the problem-based approaches. The integration of both in architectural education has the potential to transform students' learning experience into an inspiring motive (Arumugam, et al., 2023). By incorporating principles and strategies inspired by Nature, students can develop a deeper understanding of ecological systems and sustainable design practices (Ruiz-Pastor, et al., 2022).

II. BIOMIMICRY IN ARCHITECTURAL EDUCATION

A. Biomimicry Approaches

The combination of biomimicry and architecture can be accessed through two approaches: (a) the problem-based or top-down approach, and (b) the solution-based or bottom-up approach. The problem-based approach involves designing with biology in mind, studying natural solutions, and selecting an analogy to imitate and abstract into an architectural design. This approach is then combined with the traditional architectural design process, which consists of eight stages, including committing to considering numerous possibilities, clearly articulating objectives and goals, collecting resources, analyzing information, ideating creative solutions, choosing the best concept, implementing it, and evaluating the outcome (Kilmer & Kilmer, 2014). The solution-based or bottom-up approach involves studying natural solutions, understanding abstracting principles, setting technical implementation, and identifying the design challenge. The Design Spiral is a six-step process for turning inspiration into the architectural design by applying the steps of the solution-based approach, involving identifying observations of nature, translating functions into architectural terms, discovering biomimicry thinking in nature sources, abstracting nature's strategies back to the architectural engineering profession, emulating strategies using comparative analysis methods, and evaluating the design solution (Purwaningsih, et al., 2018).

B. Biomimicry Levels

Biomimicry can be integrated with architecture at three levels: (a) organism, (b) behavior, and (c) ecosystem (Benyoucef & Razin, 2018). The organism level involves replicating the forms, materials, functions, and processes of individual organisms. The behavior level involves observing how organisms interact with their environment to survive, which can help designers create solutions that better understand and appreciate nature. The ecosystem level provides a comprehensive understanding of the relationship of an organism with its environment, including how different elements work together in a cycle for survival and adaptation (Zari & Storey, 2007). By utilizing the benefits of these levels in architectural education, biomimicry can offer creative

solutions rooted in natural intelligence to enhance students' knowledge, inspiration, and productivity.

C. Enhancing Learning Experience Through Biomimicry in Architectural Education

- Promoting the cognitive abilities of architectural students

Biomimicry has the potential to foster the reasoning abilities of architectural students by providing them with inspiring resources to help them to pay attention, extract information, analyze it, and apply the results in their projects world (Gamage & Dayarathne, 2012). By following the strategy of either of the two approaches of biomimicry, architectural students can learn to design more energy-efficient, sustainable, and adaptable buildings in addition to encouraging them to consider the relationship between the built environment and the natural world design (AskNature, 2021).

- *Encouraging hands-on learning in the design studio.*

Biomimicry-based curricula in architecture education not only provide students with a deeper understanding of sustainable building design but also enhance their hands-on experience and teamwork spirit (Schleicher, et al., 2019). By studying natural systems and processes, students are encouraged to collaborate and apply biological principles to real-world design challenges. Through biomimicry-based projects, students learn to work together, share ideas, and develop solutions that are efficient, resilient, and harmonious with the environment identity (Chemi, 2017). This collaborative approach helps students to hone their problem-solving skills and creativity (Yurtkuran, et al., 2013), preparing them to become responsible and innovative designers, encouraging cooperation between students, and enhancing their hands-on experience, preparing them for a successful career in sustainable building design (Gruber & Imhof, 2017).

- *Adopting the incubation phase of creative thinking.*

Biomimicry is a valuable tool for architectural students during the incubation phase of their creative thinking process. This phase is when the mind unconsciously processes information and makes connections between knowledge that can lead to breakthrough solutions (Kahvecioglu, 2007). By studying nature and its solutions to problems, students can gain new perspectives and ideas for their designs as it provides an open-ended task based on discussion and puzzles (Kalantari, et al., 2020). Therefore, the biomimicry-based curriculum is a stimulating and relevant method of learning that encourages students to think creatively and adopt an incubation phase, leading to more innovative and sustainable solutions in architecture (Stevens, et al., 2019).

- *Providing an immersive intuition-based architectural experience.*

Intuition is a concept that has been studied extensively in psychology and philosophy. It is a nonverbal, non-analytical method of comprehending and making decisions, often referred to as a "gut feeling" or "sixth sense" (Yalcin, 2021). In architecture, intuition is a crucial component of the illumination phase, which is the foundation of creative thinking (Alipour, 2019). By experiencing the biomimicry-based curriculum and tapping its insights into the unconscious mind, students can access a vast store of knowledge and experiences that can lead to new and unexpected connections between ideas and concepts. This provides a visualized approach to the learning process in a holistic and interdisciplinary manner that enriches students' imagination and illuminates design themes and details (Fiorentino & Montana-Hoyos, 2014).

III. OBJECTIVES OF THE STUDY

- To analyze previous attempts at implementing biomimicry in architectural education and identify the key principles and strategies used in these curricula.
- To identify the challenges and barriers faced in implementing biomimicry-based curricula in architectural education and propose potential solutions.
- To provide valuable insights and recommendations for integrating effective biomimicry curricula in architectural education, based on the analysis of case studies demonstrating successful implementation.

IV. DATA AND METHODOLOGY

The data presented in this study uses a thematic analytical study of eight case studies implementing biomimicry in architectural education. To guide our analysis, we have developed a strategy that involves several steps. The first step is to understand the curriculum objectives of each case study. This includes identifying the specific learning outcomes and goals that were targeted by incorporating biomimicry into the curriculum. The second step is to identify the biomimicry-based approaches used in each case study. This involves examining the teaching methods, assignments, and projects that were designed to introduce biomimicry concepts and principles to students. The third step is to consider the design process arrangements followed in each case study. This includes understanding how biomimicry was integrated into different stages of the design process, how many students participated in each case study, and their academic level. By following this strategy, the study identifies a SWOT analysis for each case study and recommends improvements that can create more effective learning spaces for architecture students.

A. Nature Analogs for Early Design Students

The study was conducted in 2011 at Texas Tech University on a class of early design students for an academic semester aiming to bring the principles of sustainability and nature-inspired metaphors and analogies into students' projects by using the solution-based approach of biomimicry thinking to draw inspiration from nature solutions on organism level (Ajlouni, 2011). However, as shown in the analysis in Table I, the focus on analogs and metaphors led to the oversimplification of understanding natural systems. Additionally, the curriculum objectives focused on appreciating nature's artistic and conceptual aspects but overlooked the ecological and social complexities.

Table 1: SWOT Analysis of "Nature Analogs for Early Design Students" Case Stud

Strength	Weaknessess	Opportunities	Threats
• Promoting an innovative approach to problem-solving that goes beyond traditional technical solutions. • Using metaphor and analogies as tools for enhancing creative design.	• The study didn't mention any relativity to the process of the "Design Spiral". • Students architectural practice was referred to as individual architectural work.	• The approach of problem-solving could attract students who are interested in exploring new ways of thinking and creating.	• Counting on only metaphors and analogies may not be effective for all students. • The lack of a structured approach to problem-solving made it difficult for students to reach the final presentation.

B. Arthropods-Architectural Articulation for First-Year Students

The study is an exercise conducted in 2012 at Uludag University on a class of 48 first-year architectural students for three weeks, of seminars, designs, and evaluations, aiming to enhance three-dimensional thinking and problem-solving skills by understanding the biomimetic design principles and analyzing nature models on the organism level. Using the approach of problem-based, the exercise asked students to figure out a biomimetic-based design for a mobile space drawing inspiration from different kinds of arthropods, like bees. In the first week, students formed groups and researched arthropods in a seminar on "articulation." The second week focused on studio work. In the final week, students presented their designs in a classroom setting, showcasing models, digital videos, and creative dramas (Yurtkuran, et al., 2013). Although the teamwork of the 12 groups enabled students to cooperate and discuss their analytical study effectively, as shown in the analysis of Table II, the study confirmed that two weeks weren't sufficient for almost all groups, except for one group.

Table 2: SWOT Analysis of "Arthropods-Architectural Articulation for First-Year Students" Case Study

Strength	Weaknessess	Opportunities	Threats
• Encouraging creativity and problem-solving skills through the study of arthropods. • Understanding biomimicry principles in architecture.	• Oversimplifying the understanding of the complex biological system • Not addressing the social and cultural aspects of biomimicry in architecture.	• Potential to inspire new and innovative biomimetic design solutions in architecture through the problem-based approach.	• Risk of perpetuating a narrow view of biomimicry • Not addressing the causes of environmental and social problems in architecture.

C. Using Inspiration from Nature

The study was conducted in 2014 at Karadeniz Technical University on a class of 100 second-year architectural students through six steps, biomimicry presentation, literature research, analytical study, brainstorming, design configuration, and final presentation. By using the approach of problem-based, students managed to articulate biomimicry into an architectural project, Life Under the Sea, aiming to help students to board the method of finding solutions by looking at nature and strengthening students' perspective of the relationship between architecture and nature. Students worked individually to submit a final poster for the project presenting their attempts at the micro or macro-organism level inspired by sea creatures (Tavsan, et al., 2015). As shown in Table III, despite students showing a great commitment to participate with their biomimetic insights, the individual practice tied up their creativity with limited possibilities for imitating one natural organism in their design process.

D. Sustainable Design and Environment Through Biomimicry

The study was conducted as an undergraduate elective course in 2015 at Ozyegin University on a group of 19 architectural students for 15 weeks aiming to improve students' algorithmic thinking and problem-solving skills to enhance their performance in multifaceted architectural projects. The methodology adopted the solution-based approach of biomimicry throughout three mimicking levels, organism, behavior, and ecosystem by dividing students into three categories each to apply one mimicking level. In the first group, students emphasized analogies and metaphorical properties, in the second group, students translated the properties from a performance-based perspective, and in the third group, students optimized the nature-based processes (Yazici, 2015). Although the study method is a motive for other institutions to adopt comparable educational programs, it is crucial to acknowledge the shortcomings, including its limited sample size and absence of a control group, to enhance the curriculum's efficacy, as shown in the analysis of Table IV.

Table 3: SWOT Analysis of "Using Inspiration from Nature" Case Study

Strength	Weaknessess	Opportunities	Threats
• Increasing motivation, conceptual change, and support contact among concepts by embracing an untraditional design problem for students. • Promoting student-centered learning, and enhancing problem-solving abilities.	• The duration of the study and the time distance between the design process stages were not published, which could affect the reliability of the results.	• The use of analogies in teaching scientific concepts could be applied to other fields of study, promoting interdisciplinary learning.	• Limiting the application of biomimicry to fictional life under the sea may result in the neglect of using biomimicry in the traditional type of projects.

Table 4: SWOT Analysis of "Sustainable Design and Environment Through Biomimicry" Case Study

Strength	Weaknessess	Opportunities	Threats
• Providing a comprehensive approach to integrating biomimicry principles into architectural design education. • Encouraging active learning by enhancing students' technical skills in software programs, like Rhino, and Grasshopper.	• The study did not include a control group, which makes it difficult to determine the effectiveness of the course. • The study adopted the application of biomimicry only on single or independent items without considering the wider frame of the design concept.	• Inspiring other institutions to incorporate biomimicry principles into their architectural design curricula. • Building interdisciplinary collaborations between architectural and biology students to develop new biomimetic designs.	• The resistance of traditional design approaches and teaching methods may hinder the adoption of biomimicry principles.

E. Mission Mars 2024: Biomimetic Structural Organism

The study was conducted as a workshop part of the coursework of architecture design for 15 teams of second-year architectural students (six to seven students each) in 2017 at Izmir University of Economics for two weeks aiming at improving critical thinking and problem-solving skills and enhancing their digital skills in multifaceted architectural projects in addition to expanding their imagination beyond the traditional terms of design projects. The methodology adopted the problem-based approach using the organism level of biomimicry to build a home for the first settlers on Mars (Varinlioglu, et al., 2018). Table V indicated that although the workshop had a limited two weeks of practice, using biomimicry as a supplementary design approach positively impacts architectural students.

Table 5: SWOT Analysis of "Mission Mars 2024: Biomimetic Structural Organism" Case Study

Strength	Weaknessess	Opportunities	Threats
• Providing practical and hands-on experience. • Using digital tools alongside biomimicry as an advanced method of creating models. • Encouraging students to think creatively of unconventional solutions and widen their imagination.	• The limited duration of two weeks, which may not have been enough time for students to fully grasp the concepts of biomimicry and apply them effectively.	• Inspiring other institutions to incorporate biomimicry principles into their architectural design curricula. • The focus on designing for new environments, such as Mars, can lead to new innovations in sustainable design practices.	• The resistance of traditional design approaches and teaching methods may hinder the adoption of biomimicry principles.

F. Biomimetic Design in Construction Systems

The study was conducted for a whole semester in 2019 at Port Said University for six teams of third-year architectural students aiming at fostering students' creativity by promoting observing structural systems found in nature. Moreover, the study also used the problem-based approach including the organism level of biomimicry to guide students' submission of the posters of virtual models with physical 3D models. The design process consisted of four phases, starting with introductory lectures and active learning, followed by cooperative discussion and self-learning, then research and analysis of nature-based examples, and finally the application of the analyzed system to a physical for peer review and instructor discussion during the final submission (Shahda, 2019). As shown in Table VI, the methodology fosters critical thinking and creativity. However, it lacks information on participants and comparison to other methods. The proposed approach can be extended to other design fields but may face challenges due to a lack of resources and resistance to traditional teaching methods.

G. Biomimicry in Architecture

The study was conducted for 12 weeks as an elective course for 18 senior students in 2018 at the Architecture Department of MSA University aiming to foster students' capabilities of creativity and originality in their architectural practice using parametric design and software programs like Rhino and Grasshopper to apply the solution-based approach of biomimicry. During the course, fourth-year architecture students were introduced to the biomimicry approach through a combination of lectures and active learning. The lectures focused on various topics related to using biomimicry in building design, such as how plants inspire facades and biomimicry with steel sheets. Students then participated in idea generation by mapping out their ideas, which were later classified using a provided system. As mentioned in Table VII, students were asked to complete a questionnaire to evaluate their experience and provide feedback on the course (Amer, 2019).

Table 6: SWOT Analysis of "Biomimetic Design in Construction Systems" Case Study

Strength	Weaknessess	Opportunities	Threats
• Providing a holistic framework of biomimetic construction systems. • Creating a diversity of students' applications by integrating physical and virtual 3D models. • Employing assessment criteria for evaluating students' performance.	• The lack of information on the number of participants makes it difficult to assess students' teamwork. • The study did not compare the effectiveness of the proposed methodology to other biomimetic curricula.	• Inspiring other institutions to incorporate biomimicry principles into their architectural design curricula. • The constructional approach has the potential to revolutionize design education across various disciplines.	• The resistance of traditional design approaches and teaching methods may hinder the adoption of biomimicry principles.

Table 7: SWOT Analysis of "Biomimetic Design in Construction Systems" Case Study

Strength	Weaknessess	Opportunities	Threats
• The course content covers fundamental issues of the biomimicry concept and helps students form creative and sustainable designs through parametric design. • Incorporating parametric design in the course gives students opportunities to implement biomimetic ideas.	• Few students faced difficulties in fulfilling all the course tasks. • Students did not have enough time for physical models as the elective course is only a three-credit hour course.	• The course could be delivered within a multi-disciplined approach through coordination between the architectural department and other disciplines, giving students more opportunities to design workable dynamic models.	• The resistance of traditional design approaches and teaching methods may hinder the adoption of biomimicry principles. • Limiting the biomimicry application to the building envelope may cause a further misunderstanding of biomimicry associations with architecture.

H. Studio One: Discovering Bio-Inspired Design and Fabrication

The study was conducted for two semesters as a master's program for four teams of post-graduates in 2019 at the Architecture Department of the University of California. The curriculum focuses on developing 21st-century skills like critical thinking and problem-solving through studio classes and tailored seminars. The program also collaborates with academic research institutions, professionals in the building industry, museums, and industry partners to support its teaching structure. Additionally, Studio One hosts guest lectures from leading experts in the field. The curriculum objectives include providing a multidisciplinary learning experience, promoting inquiry-based research, encouraging students to explore larger-scale prototypes, and applying biomimicry through collaborations with museums and industry partners. By applying both the problem-based and the solution-based approaches, the course integrated four phases: creating a design brief, investigating natural organisms, studying bio-inspired design principles, and building a physical model for testing. The course focused on analyzing modern design and fabrication techniques, as well as exploring natural models from a different perspective. The teaching approach involved two angles: starting the development process from fundamental biological knowledge and resolving technical issues to enhance existing design solutions. Students were exposed to scientific publications and tasked with finding inspirational examples from nature to address architectural challenges, as shown in the analysis in Table VIII. While students' achievements varied from 2D sketches and virtual 3D models to physical models at the end of the project (Schleicher, et al., 2019).

Table 8: SWOT Analysis of "Biomimetic Design in Construction Systems" Case Study

Strength	Weaknessess	Opportunities	Threats
• Providing a multidisciplinary learning experience that combines architecture, engineering, and biology. • Encouraging students to push their initial ideas beyond the usual scale of small models into larger-scale prototypes and pavilions. • The teaching approach involves pursuing the work from two angles: the "Biology Push" and the "Technology Pull", which encourages students to think creatively.	• Not providing an exact number of students who participated in the experiment. • Not referring to any type of questionnaire or field survey to press the perspective of students at the end of the semester.	• The study could be expanded to include a larger number of students and evaluate its impact on a larger scale. • The study could incorporate feedback from students through questionnaires or field surveys to improve the teaching approach.	• The resistance of traditional design approaches and teaching methods may hinder the adoption of biomimicry principles. • The study may face challenges in terms of funding and resources required to collaborate with museums and industry partners.

V. CONCLUSION

Biomimicry is a valuable tool in architectural design education, as shown by the aforementioned eight case studies. By incorporating natural systems into the design process, students can develop sustainable and innovative solutions while improving their creative thinking and problem-solving skills. Metaphors and analogies are particularly helpful for early design students, providing a method to learn about sustainable design thinking. Also, observing and analyzing natural organisms can enhance three-dimensional thinking and problem-solving skills applicable to architectural design. While comparing natural systems to human-made products aids in teaching scientific concepts and promoting conceptual change. Furthermore, integrating computational design tools and biomimetic ideas into architecture education fosters algorithmic thinking and holistic design skills. Overall, integrating biomimicry into architectural curricula inspires creative thinking, cultivates algorithmic reasoning and all-encompassing design abilities, and stimulates imaginative thinking and unconventional resolutions. In addition, this interdisciplinary approach equips students with 21st-century abilities like ingenuity, collaboration, and scientific proficiency. Eventually, as shown in Table IX, integrating biomimetic design thinking should begin with early students in the first academic level by embracing an adventurous unconventional experience for students followed by a more professional and interdisciplinary practice in the higher educational levels.

Table 9: Thematic Analysis of the Architectural Articulation of Biomimicry-Based Curricula Case Studies

Case Study	Strategy	Approach	Duration	Participation	Achievements
Nature Analogs for Early Design Students	Exploring Nature using analogies and metaphors in an academic course for early design students	Solution-based	A whole semester	NOT MENTIONED (Individual submission)	Conceptual sketches & 3D Models
Arthropods-Architectural Articulation for First-Year Students	Enhancing the Problem-solving skills of novices by analyzing Arthropods' behavior, form, and movement	Problem-based	Three weeks	48 Students (12 Teams)	Conceptual sketches & 3D Models & Animated Videos
Using Inspiration from Nature	Enriching novices' imagination by designing a house for life under the sea inspired by Sea creatures	Problem-based	Not mentioned	100 Students (Individual submission)	Printed Posters & 3D Models & Virtual Models
Sustainable Design and Environment Through Biomimicry	Improving undergraduates' algorithmic thinking and problem-solving skills for holistic design	Solution-based	15 weeks	19 Students (Individual submission)	Virtual Models
Mission Mars 2024: Biomimetic Structural Organism	Developing second-year students' digital and fabrication skills by creating an unconventional design using inspiration from living organisms	Problem-based	Two weeks	15 Teams (six to seven students in each)	Printed Posters & Virtual Models & 3D Models
Biomimetic Design in Construction Systems	Promoting third-year students' deep understanding of construction systems by exploring the natural organisms	Problem-based	A whole semester	Six Teams (Students' number was NOT MENTIONED)	Printed Posters & 3D Models
Biomimicry in Architecture	Using Rhino and Grasshopper with seniors to practice to apply	Solution-based	A whole semester	18 Students (Individual submission)	Printed Posters & Virtual Models

	biomimicry on designing a sustainable building envelope				
Studio One: Discovering Bio-Inspired Design and Fabrication	Providing a cross-disciplinary course for one-year-post graduates involving fabrication phase by collaborating with various industry partners and museums	Solution-based & Problem-based	Two Semesters	Four Teams (Students' number was NOT MENTIONED)	Project Presentations & Virtual Models & 1:1 Physical Models

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1.] Ajlouni, R. (2011). *Biomimicry Studio: Nature-Inspired Sustainable Design Thinking Approach*. University of Nebraska, Lincoln, s.n., pp. 117-122.

[2.] Alipour, L. (2019). *Intuitive and Logical Way of Thinking in the Education of Architectural Design Courses*. Architect. Eng. Urban Plan, 29(2), pp. 161-170.

[3.] Amer, N. (2019). *Biomimetic Approach in Architectural Education: Case study of 'Biomimicry in Architecture' Course*. Ain Shams Engineering Journal, 10(3), pp. 499-500.

[4.] Arumugam, G., Abidin, S., Kusumo, C. & Jain, A. (2023). *Teaching Nature and Architecture: Student-Led Account of Biomimicry Innovations in the Tropics.* Biomimetics, 8(13), pp. 1-18.

[5.] Ask Nature (2021). *Biomimicry Global Design Challenge Gallery*. [Online] Available at: https://asknature.org/collection/biomimicry-global-design-challenge/[Accessed 22 January 2023].

[6.] Benyoucef, Y. & Razin, A. (2018). *Biomimicry Architecture: from The Inspiration by Nature to The Innovation of The Saharan Architecture*. Architecture and Engineering, 3(4), p. 5.

[7.] Chemi, T. (2017). *A Safe Haven for Emotional Experiences: Learning Perspectives on Participation in the Arts*. In: Emotions and Pedagogical Innovation. Aalborg, Denmark: Sense Publishers: https://www.sensepublishers.com/, pp. 9-25.

[8.] Fiorentino, C. & Montana-Hoyos, C. (2014). *The Emerging Discipline of Biomimicry as a Paradigm Shift towards Design for Resilience*. The International Journal of Designed Objects, 8(1), pp. 6-13.

[9.] Gamage, A. & Dayarathne, R. (2012). *Learning from Nature: Towards an Earth-based Biomimicry Approach to Ecologically Sustainable Design (ESD)*. Dammam University, Saudi Arabia, s.n., pp. 2-13.

[10.] Gruber, P. & Imhof, B. (2017). *Patterns of Growth—Biomimetics and Architectural Design*. Buildings, 7(32), p. 7.

[11.] Kahvecioglu, N. (2007). *Architectural Design Studio Organization and Creativity*. A|Z ITU Journal of Faculty of Architecture, 4(2), p. 7.

[12.] Kalantari, B., Nourtaghani, A. & Farrokhzad, M. (2020). *An Educational Model of Creativity Enhancement in Design Studios Using Prior Researches*. Space Ontology International Journal, 9(3), pp. 19-22.

[13.] Kilmer, R & Kilmer, W. (2014). *Designing Interiors-Second Edition*. Hoboken, New Jersey: John Wiley & Sons, Inc.

[14.] Pawlyn, M. (2016). *Biomimicry in architecture*. British Library: Published by RIBA Publishing.

[15.] Purwaningsih, R. et al., 2018. *Product Development Using Bio-mimicry Design Spiral Approach of Swimming Aid*. Semarang, Indonesia, E3S Web Conf, pp. 2-4.

[16.] Ruiz-Pastor, L., Chulvi, V., Royo, M. & Sampaio, J. (2022). *Bio-inspired Design as A Solution to Generate Creative and Circular Product Concepts*. International Journal of Design Creativity and Innovation, pp. 1-20.

[17.] Schleicher, S. et al. (2019). *Studio One: A New Teaching Model for Exploring Bio-Inspired Design and Fabrication*. Biomimetics, 4(34), pp. 2-10.

[18.] Shahda, M. (2019). *Biomimicry as a Tool to Enhance the Skills of Architecture Students in Understanding Construction Systems*. Architecture Research, 9(5), pp. 126-142.

[19.] Stevens, L., De Vries, M., Mark, B. & Helen, K. (2019). *Biomimicry Design Education Essentials*. Delft, Netherlands, s.n., pp. 459-468.

[20.] Tavsan, C., Tavsan, F. & Sonmez, E. (2015). *Biomimicry in Architectural Design Education*. Trabzon, Turkey, Elsevier Ltd., pp. 489-496.

[21.] Varinlioglu, G., Pasin, B. & Clarke, H. (2018). *Unconventional Formulations in Architectural Curricula: An Atelier on Design for Outer Space Architecture*. A|Z ITU Journal of Faculty of Architecture, 15(1), pp. 93-105.

[22.] Yalcin, Z. (2021). *Intuition in the Design Studio: A Perspective on Student's Creativity and Design Process*. Design Studio, 3(1), pp. 38-43.

[23.] Yazici, S. (2015). *A Course on Biomimetic Design Strategies*. Vienna, Austria, CAAD Education, pp. 111-118.

[24.] Yurtkuran, S., Kırlı, G. & Taneli, Y. (2013). *Learning from Nature: Biomimetic Design in Architectural Education*. Bursa, Turkey, Elsevier Ltd, pp. 634-638.

[25.] Zari, M. & Storey, J. (2007). *An Ecosystem Based Biomimetic Theory for A Regenerative Built Environment*. Lisbon, Portugal, s.n., pp. 3-4.