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INNOVATION BY IMITATION IN DESIGN EDUCATION

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Abstract:

Within a cross-disciplinary framework of design knowledge management, an exploratory approach to architectural designing is proposed. In this approach, Biomimetics is explored for its potentials as a generative tool that uses organisms from an environment to inspire designs of buildings that emerge from, and function in harmony with, that environment. The approach is designed to encourage designers to derive innovative products by imitating solutions from nature and biology. Its applicability is tested in digital design studio settings where visualization and communication are augmented by multi-media configurations of kinetics, ergonomics and responsive models. Reflections about the approach seem to encourage its addition to architects' toolkit as a template of innovative solutions, and guidance for sustainable contextual customization of designs.

Keywords: *design methods, Biomimetics, digital studio, BioTecture, design education, inter-disciplinary design.*

1. Biomimetics in engineering design

Driven by the continuous search of innovative solutions to engineering design problems, cross-disciplinary knowledge recycling and networking may propose new sources. These are based on the extrapolation of solutions in one field to problems in another. An example of this is represented by Biomimicry, where extrapolation can be analogical or metaphorical from biology to other disciplines.
Based on the epistemological and methodological assumptions that underlie its structure, Biomimicry represents a cross-disciplinary approach that adopts knowledge recycling techniques (Eilouti, 2009, 2010). In this approach, parallels are drawn between biology and other disciplines such as engineering. As a result, natural organisms and man-made products are mapped to draw some attributes from the former to inform and inspire the latter. Upon mapping, nature can be imitated directly as a template (analogy) or indirectly as a symbol (metaphor).
Based on the principles and concepts of Biomimicry, Biomimetics or biologically-inspired technology is most frequently used in scientific and engineering literature to indicate the process of applying biological principles that underlie the morphology, systems, and functionality of biological entities to

artificial product design. Study of Biomimicry and Biomimetics and their applications in engineering design is relatively new and increasingly growing. For example, engineering solutions include those inspired by beetles (Knight, 2001), sustainable designs inspired by nature (Reap et al, 2005), ecological engineering guided by non-human species (Rosemond and Anderson, 2003), waste management solutions inspired by living organisms (Todd and Josephson, 1996). and ecological machines for the treatment of polluted environments (Todd, 2004). Other examples of Biomimetics applications include photovoltaic cells that convert solar radiation into electricity, mechanical engineering solutions inspired by natural organisms (Wainwright et al, 1976), and fuel cells that power automobiles and release water instead of carbon dioxide. In addition, more detailed description of Biomimetics-based engineering design process and methods can be found in recent literature (e.g. Cohen and Reich, 2016). Most of the examples use analogical transfer of knowledge from a design solution to another (Goel and Bhatta, 2004, Goel et al, 2011) to optimize sustainability in design.

2. Biomimetics in architectural design

The increasing globalization of repeated building forms coupled with the continuous search for new resources of inspiration amplifies the demand for new design solutions that accommodate diversity and contextual customization. One way to customize a design of a building to its environment and to generate innovative solutions is to use the inductive and deductive analysis of living creatures in a given environment and their systems of adaptations to conclude new design concepts.

Although engineering applications of Biomimetics are increasingly growing, a much slower rate of knowledge networking between Biomimetics and architectural design is witnessed. Some examples of this networking include the animal architecture (Hansell, 2005), living buildings that apply technology to achieve interaction with the environment (Berkebile and McLennan, 2004), eco-systems and sustainable solutions in the built environment and city planning (Doughty and Hammond, 2004; Pedersen and Storey, 2007), nature impact on urban design and architecture (Hastrich, 2006; Knowles, 2006), and biomorphic architecture where architectural morphology is influenced by animals and humans (Feuerstein, 2002).

Despite these scholarly efforts, using Biomimetics as a point of departure to approach architectural design in ways other than formal analogy did not receive enough attention from researchers. Few efforts were made in this area. Some of the few examples include the description of Biomimetics applications in architectural design (Pawlyn, 2011; Brownell and Swackhamer, 2015; Pohl and Nachtigall, 2015), Biomimetic design process in architecture for the transformation of nature's solutions into innovative architectural designs (Eilouti, 2010), and implementing environmental knowledge to manage design processing (Eilouti, 2011). However, knowledge transformation and application in this area is still under researched. As a contribution to this significant area of knowledge, and as a continuation to the previous efforts, methods of Biomimetics-based design are proposed. In this paper, these are described in the framework of non-formalistic approach to architectural design processing. These methods are further developed and implemented in architectural design studio settings.

3. Biomimetics-driven approach to architectural designing

Benyus (1997) proposed a 3M role of nature in Biomimicry, that is, the functionality of nature as a Model, a Measure, and a Mentor. In the first, nature is used for ***derivative*** purposes, where models of organism structures or systems are directly imitated or indirectly inspired to develop product design solutions. In the second, nature is used for ***evaluative*** purposes to compare manmade products to its standards and criteria. In the third, nature is employed as an ***explorative*** guide, where it stands out as a source of learning from which design guidelines are deduced.

Including these 3M roles within its structure, a 4M strategy is proposed in this paper to describe three methods within the Biomimetics-Driven Design (BDD) approach to architectural designing. The 4M structure describes four stages of the approach processing. The first is to **Manage** the process of extrapolation. This includes the first steps of each method as illustrated in the first three rows of

Figure 1. The second is to **Match** a building design aspect to a correspondent living organism feature. The third is to **Model** the inspired solutions into a new design by using nature as a template for both the product and the process. The fourth concludes the first cycle of designing by **Measuring** its resultant design and comparing it to the standards and performance criteria of nature. In this 4M strategy:

1. The process starts with a building design problem, an organism, or an engineering application in which Biomimicry is already used. Upon the identification of a starting point, an end point is identified, and information about both are collected, interpreted and analyzed.
2. A living creature is, then, mapped directly or indirectly – where an engineering application is the start point- to a building in order to explore potential sub-solutions or solutions.
3. In the third stage, a solution as recommended by the first and second stages can be developed to model a design product for the problem at hand.
4. In the fourth stage, the proposed designs are assessed to test their strengths and weaknesses, and to check their applicability and compatibility with the design problem at hand.

Within this approach and based on the management of the first stage, three methods to design can be identified. The categorization of these methods depends mainly on the start and end points of the analogy. In other words, the role of Biomimetics as a source of inspiration in which a living organism is used as a case study can form either the origin or the destination of the analogy process.

The three methods are: 1) **Building-Based Design (BBD)**, 2) **Organism-Based Design (OBD)** and 3) **Application-Based Design (ABD)**.

In the **BBD**, the process starts from a given architectural design problem, where a specific gap is identified. Then, a designer searches for a creature that deals successfully with that problem. As a result, a solution from a creature or more is suggested to solve the pre-defined problem/s.

In the **OBD**, an organism forms a point of departure for designing. As such, a living creature may be scrutinized for distinguished attributes or performances, some of which may inspire a new design concept or solution.

In the **ABD**, the process starts from a middle point that represents an existing application in engineering design that can be adapted to match another problem in architecture. A designer using this method does not start from a creature, or from a given design. Instead, s/he finds an engineering or technology application that is already inspired by biology and modifies that application to fit the problem at hand.

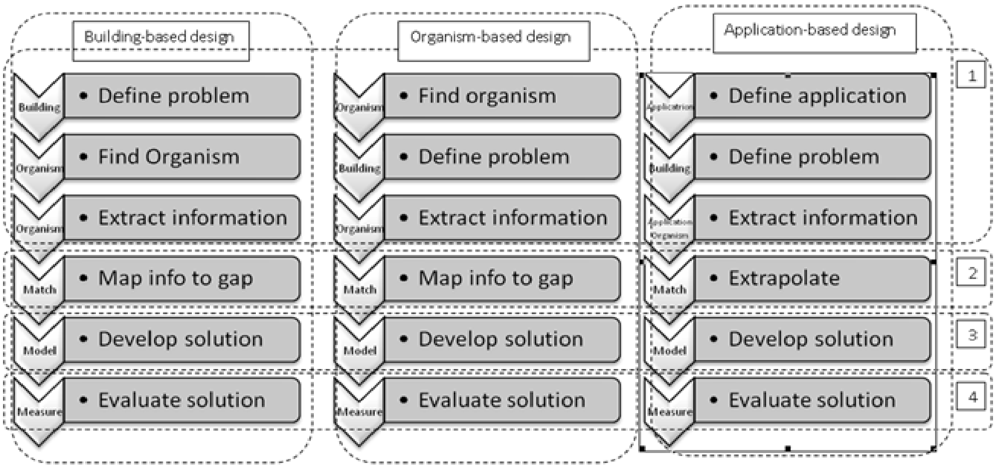
As illustrated in Figure 1, a juxtaposition of the 4M management plan with the three proposed methods produces a 6-step -organized within 4 stages- approach. This approach is represented as a matrix. The columns identify the three different methods of incorporating Biomimetics into architectural designing. The rows represent the steps needed to process the design extrapolation and derivation sequence.

The main 6-step process needed in each method is further illustrated in Figure 2. The sequence moves from the definition of the source and destination of the knowledge transfer, to the data collection about both, to the analysis of the collected information. The next major step is to map information from the destination to the source through bridging commonalities of both. Based on the mapping, a new design proposal is developed and evaluated. Another loop of analogy application may be added as needed until the design reaches a satisfactory performance level.

4. Implementation and discussion

4.1 A Biomimetics-based adaptive house design problem

A ‘BioTecture’ project is presented to test the applicability of the 4M approach. Its main goal is to design a self-sufficient adaptive house which addresses bio-inspired solutions. The project is designed for 18 undergraduate junior students in the digital design studio of the College of Architecture and Design in Jordan University of Science and Technology (JUST). The design program is intended to challenge the participants to design an autonomous and ecologically-oriented dwelling unit. The house is required to be designed flexibly in order to be adaptive to climatic variations, inhabitants' changing needs and functional modifications. The house design, as it addresses Biomimetics as its major approach, is assumed to take its cues from living creatures. These are typically tied harmoniously to their surrounding natural environments. They usually take only their needs from the indispensable resources (energy, water, etc.), generate recyclable and degradable waste; and respond to growth and environmental changes flexibly and dynamically. The main goal of this project is the development of an autonomous dwelling unit in which environmental responses, technological incorporations, sustainable solutions, flexible structures, ergonomics considerations, and kinetic components are essential elements of new architectural products. Hence, the design is expected to integrate principles of kinetics, interactive and responsive architecture to visualize and model the motion-related and time-morphed aspects of the 'bio-tectured' house and its adaptations to the internal and external forces that may influence its design during its lifecycle.



1-Manage, 2-Match, 3-Model, 4-Measure

Figure 1: Three Biomimetics methods of architectural designing

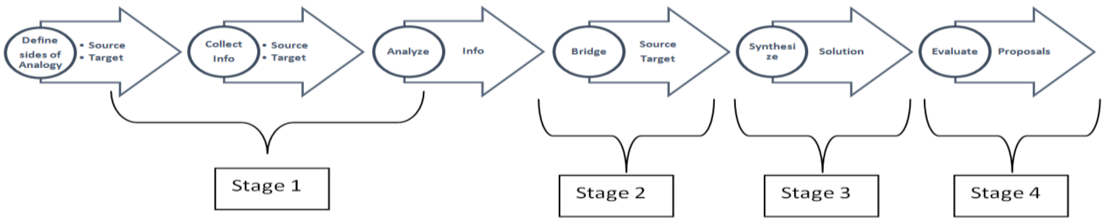


Figure 2: The 6-step process for the biomimetic-based design approach

4.2 Imitation levels

The study of each organism consists of multi-level data collection and analysis as shown in Figure 3, where parallels between architecture and biology can be drawn on multiple levels. These include the building, the urban, and the environmental levels. These correspond to the organism, the community, and the biome levels respectively.

4.3 Project examples

Some examples of the Biomimetics-inspired approach applications in the "BioTecture" project are illustrated in Figure 4. It includes two examples. The left image illustrates a coastal house inspired by a flamingo bird, and the right illustrates two houses; the upper is a desert house inspired by an ant,

and the lower is a coastal house that is inspired by a turtle. The inspiration in all designs was translated into functional and performance-enhancement solutions.
While architectural design is typically mostly concerned with form, this project helped shift the focus into building's performance. It helped highlight aspects of responsive design that accommodate the changing needs and requirements of the inhabitants. It also tested how a building may respond dynamically to the climatic forces.
The project development was enhanced by digital studio settings where motion-related aspects, kinetics of structures, ergonomics of user interactions, simulation of organisms' reactions, responses to stimuli, and representations of house mutations and lifecycle growth were emphasized, visualized and animated.

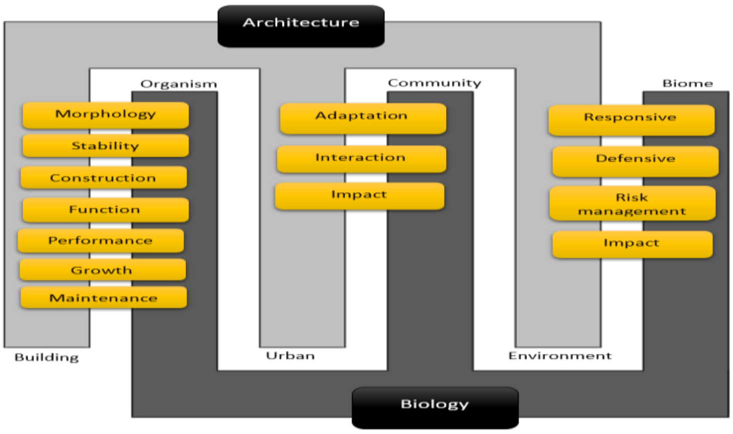


Figure 3: Levels of biology/architecture analogy

Figure 4: Biotecture project example

5. Reflections and feedback

Feedback from the participants about this experimental project was measured by an anonymous structured questionnaire in addition to multiple informal discussions and jury reflections. The structured questionnaire was conducted after the conclusion of the project and after the end of the semester it was assigned in, to reduce subjectivity and concern of students. It was designed to examine various areas, aspects and phases of architectural design using the different methods. As it tested participants' feedback to multiple aspects of the new Biomimetics approach and methods, it compared the before and after attributes and contributions of the new approach with the previous conventional ones that were mostly heuristic-based approaches that rely on trial/error processes.
The comparison was made in the three major phases of design: the pre-design reasoning, the design processing, and the post-design evaluation. In all design phases, the participants significantly favored the Biomimetics approach over the conventional ones in terms of its derivative, explorative and investigative powers. The list of questions and participants' responses are illustrated in Table 1.
The criteria of comparison included:

1. The level of student involvement, challenge and enthusiasm in each approach.

Table 1: Biotecture project feedback

Phase	Aspect	Contribution		Question	Conventional	Biomimetics
Design Processing	Involvement	Challenge	1	I feel more challenged to work	6	8.96
		Enthusiasm	2	I feel more excited to design	6.34	8.56
	Innovation	Enhance creativity	3	The design problem develops my creativity	6.6	8.9
		Widen imagination	4	The design problem improves my imagination	6.08	9.08
		Concept generation	5	The design problem helps me generate new concepts	5.92	8.84
	Design Complexity	Multi-layering of design	6	I discover new layers of design	5.32	8.68
		New design method	7	I develop new design methods	5.2	9.08
		Design process	8	I focus on design process more than product	5.3	8.12
		Understand building lifecycle	9	I realize that buildings have lifecycles like humans	3.16	8.88
		Influence of nature	10	I understand the influence of nature on design	5.16	9.28
		Significance of flexibility	11	I understand the importance of flexibility in design	5.48	9.12
		Motion contribution	12	I realize the role of motion in architecture	4.08	8.52
	Advancement	Futuristic	13	The design method will be dominant in future	4.88	9
		New horizon in architecture	14	This method opens new horizons in architecture	4.04	9.28
	Personalization	Customization	15	It helps me reflect my personality on design	7.2	7.12
		Character	16	It helps me add individual character to design	7.08	7.78
	Knowledge integration	Nature/architecture link	17	Helps me link natural solutions to architecture	4.68	9.56
		Link technology to architecture	18	Helps me link technology to architecture	5.18	9
		Link science to art	19	Helps me link science to art	5.36	8.96
Pre-Design	Research	Research integration	20	Makes me do lots of research	5.66	9.56
		Information role	21	Makes me realize the importance of information to design	6.34	9.48
	Presentation	Multi media	22	Encourages me to employ Multi Media to express my thoughts	5.48	9.08
		Time impact	23	Adds information about the impact of time on design	4.52	8.04
		CAD role	24	Employs CAD/animations to express new concepts	5.6	9.24
Post-Design	Assessment	Evaluation	25	Helps me evaluate my design	7.12	8.44

2. The level of contribution of each approach to enhance innovation in design thinking. This questions how each approach helps to foster creativity, enrich imagination, and provide new concept generators and derivation method.
3. Cognition of the design complexity. This category consists of seven questions about the multi-layered nature of design. They highlight the various design methods and the possible design processes. They emphasize the life cycle of buildings, the impact of natural and environmental forces on buildings, and the consideration of flexibility in the interior and exterior of buildings. They particularly examine the influence of integrating the time element and motion into the design of building structures to accommodate different settings and scenarios of the inhabitants' lifecycles.
4. The contribution and enhancement of each approach to the advancement of design knowledge. This part examines the futuristic potentials of each approach to grow and continue as a pedagogical methodology of design instruction in Higher Education. It also prompts for the predictability of whether the questioned approach may open new horizons in architectural designing.
5. The reflection of individual customization and personalization in each approach. This examines the extent to which the personal touch of the designer can be reflected on design, and to which the individual character of each building can be expressed.
6. The networking aspect of each approach. This tests how each approach helps bridge different areas of knowledge together to enrich design quality. It includes the linkage between: built environment and nature, technology and architecture, theory and practice, biology and engineering, and art and sciences.
7. The contribution of each approach to the integration of pre-design research into design. This emphasizes the significance of information and knowledge to the design reasoning and processing in all phases of designing.

8. Enhancing the communication and presentation skills in each approach. This tests how each approach encourages designers to employ new multi-media techniques in order to express their ideas. Furthermore, it examines how each approach enhances the employment of time and motion animations and computer aids to visualize and communicate thoughts.
9. The development of evaluative skills. This part examines if the given approach helps designers to evaluate their alternatives, and to assess their strengths and weaknesses by testing the performance of design products

As illustrated in Table 1, responses of the participants ranked the Biomimetics approach higher than the conventional in all aspects. The exception was recorded for the personalization element of both approaches. In this regard, the reflection of a designer's personal touch on the designed product seems almost similar in both approaches. This aspect may represent one of the limitations of the bio-inspired approach that needs more development and research.

Based on the results of the structured questionnaire and the jury discussions, it was clear that this method added more challenge and stimulus which encouraged the students to derive new unpredicted solutions. In particular, responses to questions 3-7 reveal that the innovation ingredient of designing was improved in this project. The resultant designs were creative and different from other previous and concurrent designs in equivalent studios.

6.Conclusion

Using a multi-disciplinary and inter-disciplinary framework for designing, a 4-stage strategy and 6-step process for design management is developed in this research to introduce a new Biomimetics-Driven Design (BDD) approach to architectural designing. The BDD approach uses new resources of inspiration that are tailored to digital studio settings. It is developed, described, implemented, reflected on and discussed. It is based on the application of principles of Biomimetics on architectural design using various points of departure. Within this approach, three Biomimetics-based methods are proposed, developed, discussed, applied and tested in this paper. These are the BBD, OBD, and ABD that vary according to their source and destination stations. The approach was developed to enhance imagination, creativity and innovation by exploring new sources of inspiration. Its implementation is described as an action research where an experimental digital architectural design project was applied in real life studio settings. The project entitled "BioTecture" was concerned with the design of an autonomous adaptive house that changes its structures according to inhabitants' needs. The house was also supposed to respond to climatic changes, and to mutate during its lifecycle as the size of the family residing in it grows and shrinks.

Reflections and feedback about the approach and the project implementation are measured by structured questionnaire. Feedback about the project implementation suggests the success of this approach as an addition to conventional design approaches. It achieved its goal of enhancing innovation in design which was clear in the products that were different from all previous and concurrent results. However, the new design approach has some limitations as its participants pointed out. One of these is that it limits expressing the designer's personal touch in the generated design.

A future extension of this research is the automation of databases that are relevant to biosystems and that may be matched to artificial artefacts through computer-aided software. Such software may help in the external and internal referencing between entities and in the knowledge linkage and networking between data resources from different disciplines.

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