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EXPLORING CREATIVITY IN THE BIO-INSPIRED DESIGN PROCESS

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Abstract: The growing interest in the of field bio-inspired design has been driven by the acknowledgement that inspiration from nature can serve as a valuable source of innovation. As an emerging approach, there has been a focus on building a principled methodology to address the challenges that arise in the application of the practice. This article investigates ways in which the understanding of creativity can support the application of bio-inspired design. By observing the bio-inspired design approach using a macro-orientational framework of creativity, we identify the role of creativity in bio-inspired design, as well as challenges currently faced by the approach in coming up with novel and appropriate solutions. Based on this, possible ways to address these challenges by applying elements of the design approach to the bio-inspired approach is suggested.

Keywords: *Bio-Inspired Design, Creative Performance, Creative Process, Creativity*

1. Introduction

As the effects of the manufacturing and IT revolution are starting to diminish, people are beginning to look to other areas for the technological breakthroughs that can cater to an increasingly complex world. Natural organisms has been brought forward as a promising source of new technological innovations - as the argument goes: nature has gone through 3.8 billion years of trying and failing, it would be silly not to learn from it. An emerging discipline, Bio-inspired design, seeks to develop a way to systematically transfer knowledge from the biological domain to the technological domain.

As there is yet to be formulated a high level theory of what bio-inspired design is (Vincent et al., 2006), to practitioners and researchers, bio-inspired design tends to be defined much along the lines of *bio-inspired design is what bio-inspired designers do*. Authors operate with different operations of what bio-inspired is and should be, but the base level assumptions tend to be the same. Some authors use the term bio-inspired design (or biologically inspired design) as a generic umbrella term for all the approaches, defined as using analogies to biological systems to develop solutions for problems (Benyus, 1997; Vattam et al., 2010; Vincent & Mann, 2002). While there are other terms, such as biomimicry, biomimetics, and bionics (Shu et al., 2011) this paper will use the 'bio- inspired design' term when referring to the process of mimicking natural models, systems, and processes to create solutions for human problems.

One of the biggest challenges in the application of bio-inspired design is the transfer of biological knowledge to the technology domain. Some perceive this step to involve long-term exploration and rigorous scientific experiments. There is also a perception that the "transfer" requires extensive biological knowledge. To address this challenge, much research and development within the discipline has been focusing on building information databases to make biological knowledge more accessible to bio-inspired design practitioners (e.g. AskNature.org). While making information more accessible is an important factor in facilitating the bio-inspired design process, we believe that there is currently a lack of focus on how to work with this biological information to produce novel and useful solutions. That is, the creative production in bio- inspired design is often black-boxed.

Creativity has been suggested as an important element in generating innovations (see Sawyer, 2012; Amabile, 1996; Brown, 2009; Bharadwaj & Menon, 2000). Understanding creativity, according to Sawyer (2012), can help us to respond better to the challenges facing modern society. Understanding the role of creativity in a bio-inspired design is thus of particular importance as the process involves new ways of solving problems. We believe that in deconstructing the elements of bio-inspired design using a creativity framework, we can contribute to a better understanding of the dynamics in the implementation of bio-inspired design, and the role creativity plays in the process of doing so.

This paper observes bio-inspired design from an individual, process, and environment point of view. Specifically, we are looking at (1) the individual and environmental elements influencing the *creative performance* in bio-inspired design; and (2) the process of bio-inspired design observed through the *creative process* perspective. By using creativity framework to better understand the dynamics in applying bio-inspired design, we identify some challenges and opportunities faced by the approach to produce novel and appropriate solutions.

2. Creativity in bio-inspired design literature

The complexity of the systems and the analogical nature of bio-inspired design have led various researchers to observe bio-inspired design from a creativity perspective. Creativity as a point of departure is likely to be chosen because of the importance of analogical reasoning in the bio-inspired design framework (see Vattam et al. 2010; Mak & Shu 2008). Vattam et al. (2010) argue that the practice of bio-inspired design is largely ad-hoc, with little systemization of the transfer process from biological examples to design challenges. Thus, there is a need to transform the paradigm of bio-inspired design into a principled methodology (ibid.). Such belief has led several of the researchers in bio-inspired design to focus on recommendations to minimize the challenges in the transfer process through the use of a principled methodology.

While we believe that the construction of a principled methodology has significant merit to address the challenges in the transfer process within bio-inspired design, a principled methodology in itself may not fully address the whole spectrum of challenges faced by bio-inspired design. Just like any other design process, the methodology has to be supported by the understanding of the mindset and tacit knowledge involved (Fulton Suri & Hendrix, 2010).

A well-built principled methodology can help address the search for biological analogies, but may still face a challenge in translating the analogies into a set of relevant, feasible outcomes. In addition, creativity involves more than analogical thinking – it may serve as a framework for the understanding of how people produce original and useful solutions. Thus, by observing the interplay between creativity and bio-inspired design, we can identify the prerequisites that have to be in place in order for bio-inspired design to generate creative outcomes.

3. Creative performance in bio-inspired design

The study of elements within an individual that influences the practice of bio-inspired design is rare. These elements within individuals are not restricted to only ways of thinking (e.g. the way we approach problems), but also other factors like *expertise* and *motivation* (Amabile, 1998). In a discipline like bio-inspired design, the understanding of the range of skills needed in exercising the approach is of importance. The quality of the outcome in such a specialized discipline is influenced by the expertise of the individuals responsible for the task. In addition, as bio-inspired design approach

spans different domains, the discipline might face challenges in motivating individuals to familiarize themselves with new fields.

3.1. Domain relevancy in bio-inspired design

Amabile (2012, p.2) argues that creative production is dependent on the individual's ability to *"combine the elements of their skills to create possible combinations of responses or use their expertise against which the individual will judge the viability of response possibilities."* Thus, it is important to first understand which skills are needed in applying bio-inspired design. The understanding of biology has been argued to be a crucial skill in bio-inspired design. However, the extent of Biology needed when applying bio-inspired design depends highly on the context of the approach. The perception that bio-inspired design requires expertise in biology may hinder the growth of the discipline, especially in industries that do not require extensive technical knowledge. Renowned design consultancy IDEO, for example, worked with biologists and designers to redesign the organizational structure of US Green Building Council based on principles adopted by natural organisms (Walker, 2010).

Furthermore, it requires a range of skills beyond biology to commercialize a feasible and viable bio-inspired concept. Biologists may play a role in transferring biological examples into the context of the problem, as well as decoding the functional parts of the natural phenomena. In addition, engineers and designers play a crucial role, as they are the ones assessing the feasibility and translate the biological analogy into the final solution. In summary, the journey from concept to commercialization requires different skills to be tied up together.

The interplay between technical domains in bio-inspired design is not without challenges. It is a dilemma to combine the rigidity of science and the flexibility of design. A key skill that is largely nurtured within the design discipline is abstraction, or the ability to see beyond the literal concept of the observed object. In contrast, science has predominantly been about specialized expertise in a specific domain. Amabile (1988) argues that a specific knowledge in a certain domain enhances creative production, as one obtain more expertise about the domain. However, such specialized skills may also have a detrimental effect on creativity, especially when it alters one's ability to look at a more holistic perspective. Wickelgren (1979) argues that the more specific a concept or proposition is, the less capacity we will have available to learn general principles and questions that crosscut different areas and perspectives. In light of this, we argue that to better support creativity in a bio-inspired design setting, there has to be a way to find the right balance between the designer's and the scientist's mode of reasoning. Both the deep expertise valued in science and the innate ability to abstract in design can contribute to a better creative production within bio-inspired design.

3.2. Task motivation in bio-inspired design

Creativity is believed to be appearing in conditions of intrinsic motivation – a motivational state generated by the individual reaction to intrinsic properties of the task, and not generated by the extrinsic factors (Amabile, 1998). It is common for practitioners in bio-inspired design to have a strong interest in sustainability issues, and many bio-inspired solutions emulate nature in a way that promotes sustainability (e.g. the cradle-to-cradle approach to waste management and the Biomimicry 3.8 focus on 'ethos' and 're-connect').

However, sustainability alone is not necessarily sufficient to ensure intrinsic motivation, and there should to be other mechanisms in place to better encourage creativity in the process. Koestler (1964), Rogers (1954), and Crutchfield (1962) in Amabile (1988) argue that creativity is generated under the condition of freedom of control, and that self-perception of personal freedom is necessary for creative thought and expression. Thus, the ability of an individual to exercise control over their actions is a factor that can support motivation.

It can be a challenge for non-biology practitioners to familiarize themselves with the bio-inspired design process. Some suffer from lack of motivation because they have little or no knowledge of biology, as well as the experience in applying bio-inspired design. Amabile (1988) argues that the presence or absence of extrinsic constraints, the factors that are intended to control or could be perceived as controlling individual's performance on the task in a particular instance, largely impact

motivation. A possible way to minimize extrinsic constraints as a result of unfamiliarity is through, simply put, making the unfamiliar, familiar. Establishment of ownership is thus a key variable in bringing intrinsic motivation to life, especially in the context of creating familiarity in a new domain. Kelley and Kelley (2013) argue that vernacular influence attitudes. Behavior and language play a key role in influencing dialogue around new ideas. Thus, phrasing the design challenge in familiar language can be a way to establish ownership for non-biology practitioners in bio-inspired design. *"Thoughts become words, and words become deeds. If you get the language right, it affects behavior"* (ibid., p. 220).

4. The creative process in bio-inspired design

A review of bio-inspired design processes usually involves an observation of different methodologies of bio-inspired design (e.g. Sartori et al., 2009; Badarnah Kadri, 2012). It follows a sequence of steps that describe the activities undertaken, from recognition of problem to the emulation of natural principles. A review of methodologies is useful to draw some level of generalization of the different frameworks of bio-inspired design. However, just like the understanding of other design approaches, a methodology on its own is not enough to explain the complexity and the depth of a discourse, as argued above.

The elaboration of the creative process, as explained by Sawyer (2012), describes the sequence of stages of not only activities that lead to generation of creative solutions, but also the *mental models* involved. These mental models encompass identifiable cognitive principles that have been known to influence creativity. Thus, a review of bio-inspired design, using a creative process perspective, may explain the process in terms of both methodology and the associated mental models.

4.1. Problem finding in the bio-inspired design process

The source biological system or -entity can be found through an extensive informed search for a solution to a predetermined human problem, an approach that is mainly problem-driven (Helms et al., 2008; Badarnah & Kadri, 2014). Alternatively, in a solution-driven approach, the principles of a biological system or -entity is uncovered first, and then a search for appropriate problems is performed (ibid.). Here, practitioners discover natural phenomena, often serendipitously, with principles he/she believes can be translated into solving human problems. To our knowledge, examples of bio-inspired design are normally skewed more towards a solution-based approach; hence, these examples might leave some wondering on how to apply bio-inspired design in a problem-based setting.

As most creativity occurs when people are working on complex problems (Sawyer, 2012), we argue that creativity plays a key role in a problem-based bio-inspired design approach. Thus, we turn to the problem formulation stage in the creative process to describe the pattern of problem finding in bio-inspired design. In a problem-based approach of bio-inspired design, the problem finding poses a challenge as the process involves a two-tiered approach. First, just like any other design discipline, the initial step is directed at discovering the root of the problem. Second, the problem has to be translated in to a biological language in order to assist the search of natural model.

The two-tiered model of problem finding is not something that all bio-inspired design practitioners agree upon. Many tend to directly "biologize" a problem (Helms et al., 2009). This means that there is a tendency to directly formulate the problem in biological language without taking a closer look on what the *real* problem is. Such practice is prone to hindering the effectiveness of bio-inspired design, as it may hamper the ability to abstract, which is essential to analogical thinking (Mak & Shu, 2004).

The second-tier in the problem-finding phase involves the translation of a problem into a biological question. This does not mean that once a problem has been defined, one can jump directly to biological solutions. Prior to solution generation, it is important to correctly frame the question in a biological language. *Framing of the question* becomes important in bio-inspired design, as the solution space of biology is vast, making it easy to get lost in the complexity and to oversimplify the search process. In bio-inspired design, *problems that are nebulously defined are either too vague to yield to a functional description, or result in a too large a search space* (Helms et al., 2009, p.617).

We argue that the two-tiered approach can be used to balance the gap between the problem- and the solution-driven approach. The first tier, where one identifies the core problem, should be a process mainly driven by abstraction and exploration. The second tier, however, needs to be addressed with a straight to the point, "biologized" framing of the question. A potential avenue for practical experimentation can be done by applying BID & a human centred design process in parallel. The collaboration between IDEO and USGBC (Walker, 2010) provides an example of how the such parallel approach is applied in a real life context. The workshop was kicked-off with an inspiration exercise, where the designers brought examples from nature that they found relevant to the project brief. The inspiration exercise also entailed designers sharing an example of extreme or inspirational organizations stories, and an interview session with the stakeholders in order to get understand the user's needs in the project. The findings were then converged: while the designers synthesized their findings by defining various people-centered problem formulations, the biologist provided examples where similar problems in nature has been solved. The co-creation between designers and biologists produces more problem formulations, from which biologists generated more biology-oriented questions to be explored in the nature domain. The parallel process ensures coherence between the people's needs, as translated by the designers, and the relevant natural examples based on the innate understanding of the people's needs. This methodology allows both designers and biologists to build an understanding how each other work and think, a key prerequisite in creating a condition conducive for a multidisciplinarity approach to bio- inspired design.

4.2. Idea generation in bio-inspired design

The current perception of the idea generation process is that it involves a divergent mode of thinking (Smith, 2003; Fink et al., 2010; Fasko, 2001). While much of the creativity literature stresses the importance of divergent thinking in idea generation, the process cannot be purely divergent (Cropley, 2006; Persaud, 2007). A challenge in bio-inspired design is to craft feasible connections between the problem, the model of the natural organism(s), and the solution. In bio-inspired design, ideas are mostly generated through the use of analogies (Mak & Shu, 2004). Analogical thinking encourages radical ideas, as practitioners are "forced" to see things outside of its literal context. However, the complexity of analogies poses challenges in the idea generation process. The awareness of the implications and the connection between an idea and the problem may aid in minimizing the complexity in "diverging" within the bio-inspired design process.

A major effort in bio-inspired design research has been aimed at addressing the complexity in gathering relevant information used to support the transfer process (for example Gramman, 2004). The complexity of the search process is often addressed through the establishment of search databases (e.g. BioTRIZ, Sapphire, AskNature.org). While the approach help address the simplification of the search space, some bio-inspired design projects call for more than a *direct translation.* As an example, taking the cleaning properties of the lotus leaf to address the problem of making a better detergent is problematic: *While the function "cleaning" is similar, the lotus leaf relies on the structural details of the structure to be cleaned, which a detergent cannot manipulate* (Helms, et al., 2009, p.617). Cross (2007) argues that the difficulty in computational modeling based on analogy is in abstracting the appropriate behavior features of an existing design. Thus, while databases may aid in identifying appropriate source organisms, the ability to abstract and build connections in the information gathered is pivotal in generating bio-inspired solutions, where reciprocation occurs between the natural model and the initial problem formulation. In BID practitioners tend to make connections based on superficial similarity, which are according to Helms et al (2009) commonly made through: (1) using *off-the shelf* biological solutions, or using biological entities to solve the problem without any abstraction, (2) improper analogical transfer where one transfers functions that are critical to the source biological phenomenon, but not necessarily relevant to the problem, and (3) misapplied analogies, where the solutions cannot be traced back to the original biological phenomenon.

While abstraction is essential to the BID process, in the context of creative ideation, examples from nature that is used in bio-inspired approach have the possibility to disrupt conventional thinking, because it allows one to see things outside its literal context. It is common for creativity practitioners to gather inspiration by immersing in a new environment, be it a physical space, an unfamiliar culture,

or new knowledge outside the context of the research. One might also argue that examples from nature in itself can be a good way of exploring unexpected associations. Mednick (1962) argues in creative thinking process, *The more mutually remote the elements of the new combination, the more creative the process or solution* (p. 221). When one turns to nature and ask, "what would nature do?" it serves as a way to disrupt the linear mode of thinking, by looking at distant associations to things.

4.3. Incubation in bio-inspired design

Many of world's exceptional creators are known to get their best ideas from an unguided, unconscious process (Sawyer, 2012). The process is often referred to as a *creative leap*, which is defined as a *sudden perception of a completely new perspective on the situation previously understood* (Cross, 2007). Often, a creative leap follows an incubation phase - *"the effects of break and fresh context"* (Smith, 2000, p.20). Incubation is often seen as a mysterious and less-understood aspect of creativity (Mac Crimmon & Wagner, 1994) and the process of incubation is somewhat counter-intuitive, in the sense that instead of working on the problem, the value lies in the time *away* from the problem (Smith, 2000). The saliency of the creative leap is a likely explanation to why people tend to see creativity as a serendipitous process. While we do not deny the serendipitous nature of the creative leap, we still argue that the incubation process may contribute to the generation of creative leaps in idea generation (e.g. Smith, 1995).

In the context of bio-inspired design, such a creative leap is crucial, as the process requires the ability to abstract and build connection through the use of analogies. In addition, fixation is a common challenge in the bio-inspired design process (Mak & Shu, 2008). To resolve fixation, Weisberg and Alba (1981) suggest a complete restructuring of the problem, while Smith (2000) proposes that the value of incubation is that it helps avoiding fixation issues, where the break effect leads to different path of idea generation. We thus argue that the understanding of incubation is important to address the challenges in the connection-making and fixation in the bio-inspired process. For example, some bio-inspired approaches, like Biomimicry (Benyus, 2009), incorporate excursions in nature as part of the early stage of the process. As incubation is essentially about the effect of *fresh and breaks* from the common setting, excursion to nature or immersion in a topic like biology can be a way to promote incubation and thereby insights in the creative process.

5. Conclusion: the role of creativity in bio-inspired design

By examining the process of bio-inspired design using the *understanding of creativity* as the observational lens, we identify some of the key challenges currently faced by bio-inspired design that might potentially impede the production of novel and useful solutions. The creative performance in bio-inspired design rests on two key factors. First, successful implementation of a bio-inspired approach relies on the interplay between different the modes of reasoning and technical expertise of different domains involved in the process. Second, engagement through means of using familiar language plays particular importance in establishing ownership for non-biology practitioners.

We argue that in order for bio- inspired design to systematically deliver feasible solutions that are novel, useful, and applicable, bio-inspired design should be seen as a part of a bigger design space and adopt the tools and mindsets that is often associated with creativity. Such mindsets and mental models are nurtured in the design process of other design fields. Thus, we argue that *the understanding of creativity* can act as the glue that establishes bio-inspired design as part of a bigger design space. The nurturing of such mental models can be fostered by being exposed to, and working with, practitioners from other design disciplines within the bigger design space. We argue that the understanding of bio-inspired design as a part of the bigger creative space can set the right expectation for practitioners. It entails the understanding that a collaboration between biology and design (or "creative disciplines") is needed throughout the whole bio-inspired design process.

The creative process in bio-inspired design relies on the ability of practitioners to connect problems, natural models, and solutions in a coherent way, using not only search databases, but also the awareness of the different cognitive modes involved - e.g., that of abstraction, connection-making, and fixation. In addition, our understanding of creative process uncovers that examples from nature used in bio-inspired approach have the potential of disrupting conventional thinking. Thus, we

conclude that creative outcomes can be fostered *through* bio-inspired design approach by two means: utilization of natural models to disrupt thinking, and in capitalizing on the incubation effect of excursions in nature.

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