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The Emerging Discipline of Biomimicry as a Paradigm Shift towards Design for Resilience

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Abstract: The paradigmatic situation in which the design disciplines are immersed as part of the human-driven global crisis – environmental, social and economic – demands responses coming from innovation and radical change. In this context the discipline of Biomimicry emerges as a response and a new design paradigm, and can be a powerful tool for design for sustainability, and furthermore, for 'resilient design'. Biomimicry inspires designers to learn from nature rather than use it as resource for materials and disposal. Natural systems are the playground for an astonishing amount of living forms in perfect balance with natural forces, living in a network of mutualism and synergy, in a sort of perpetual cycling loop. We can learn from nature not only how to design better materials and artifacts, but also how to design better processes, systems and conducts that lead to better behavioral patterns. This paper explores the emerging discipline of Biomimicry as both an evolutionary and revolutionary step for design and a necessary path to a sustainable future, from an epistemological standpoint, within a paradigm model. It presents main points which make Biomimicry a substantial set of ideas that can lead to product and material innovation and a paradigm shift in design, and explores different perspectives to provide theoretical frameworks to the discipline. Finally, this paper discusses the prospect of biomimicry for building resilient and sustainable futures, linking biomimicry to the concept of 'resilient design'.

Keywords: Bio-inspired Design, Biomimicry, Nature, Design for Sustainability, Resilient Design, Design Epistemology.

Context

Design as a broad variety of disciplines has evolved from industrialization, and the early process of industrialization has proven to be detrimental to society, destructive to our natural resources and to our world (Montana-Hoyos, 2010). The current human crisis – environmental, social and economic– is clearly a consequence of the "dynamics of an ecological crisis" (Bateson, 1972). This situation demands responses that lead to innovation and radical change. It is imperative for designers to learn from life's lessons in order to change the course of the current practices (Fiorentino, 2012) and this leads to the next step in design evolution. *Living things have done everything humans want to do, without guzzling fossil fuels, polluting the planet, or mortgaging their future* (Benyus, 1997). From a designer's perspective, what better models could there be? Biomimicry embraces this concept and offers a path to design for sustainability and resilience. This is a paradigmatic challenge for design knowledge and an epistemological opportunity for biomimicry as an emerging discipline. In this context, an initial question arises: *In which ways can biomimicry as new knowledge paradigm contribute to building resilience and sustainability through design?* This paper builds around this foundational question.

Evidence over two decades indicates that biomimicry offers foundational principles that are useful to designers (Baumeister, 2013). Finding new ways to approach sustainable design –from biomimicry principles– provides a significant contribution to the theory and practice of design and it opens new perspectives within the disciplines of design. Not less important, through biomimicry, design disciplines turn truly interdisciplinary, integrating not only practitioners from different design fields but also from science –biologists, physicists, botanists, entomologists, ecologists etc.– and the social sciences –human ecology, anthropology, sociology, etc. If sustainability has influenced design to the extent of being considered the trigger of a design paradigm shift, then biomimicry has undoubtedly a role to play on this view.

Based on available evidence, we believe biomimicry is an evolutionary step for design; however, the evidence does not come from the traditional design epistemology but from an

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emerging change of mindset observed in bio-inspired design pioneers and new generations of designers embracing biomimicry. This paper explores this perspective and presents main points which make biomimicry a substantial set of ideas that can lead to product and material innovation. While exploring and defining the concepts, the paper also discusses the prospect of this emerging discipline as a design paradigm shift, which can be the basis for resilient design.

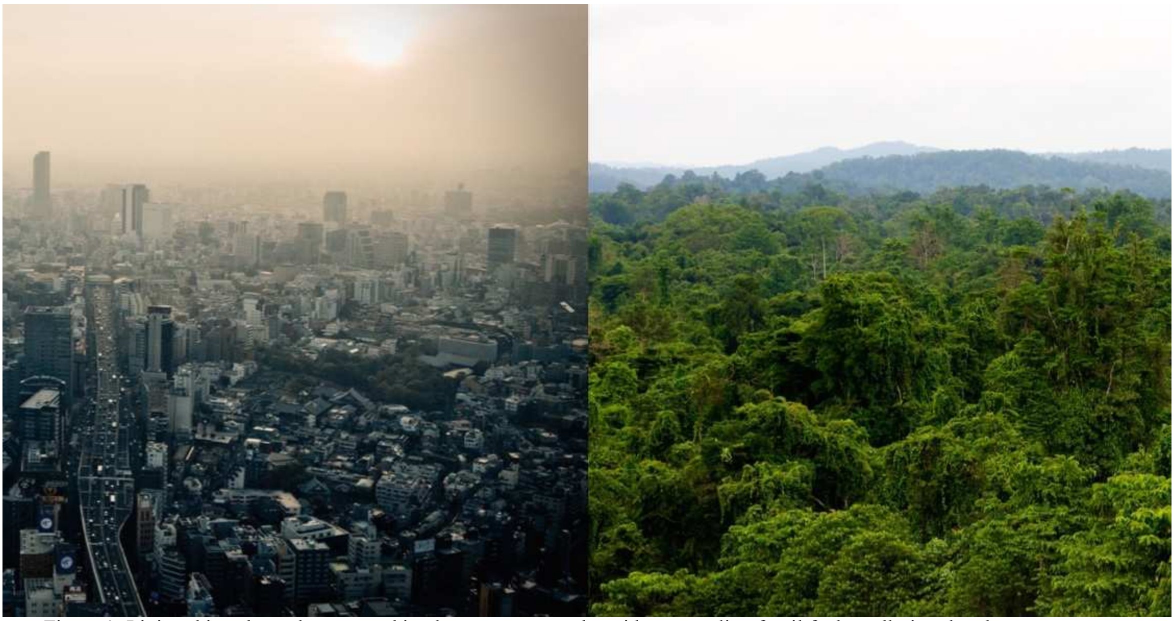

Figure 1: Living things have done everything humans want to do, without guzzling fossil fuels, polluting the planet, or mortgaging their future (Benyus, 1997). Biomimicry proposes learning from nature how to design better, resilient and sustainable systems.
Source: Images retrieved from royalty free photo sources.

Biomimicry: A Contemporary Approach to Bio-Inspired Design

The concept of bio-inspired design (or design inspired by nature) has existed since early times, perhaps with first attempts by Leonardo Da Vinci in the XV century, engineering artifacts that imitated animal functions, such as the flying machine. Diverse movements in arts, architecture and design have shown strong influences and inspiration from nature. Some of these important movements were the *Modernism* (1880-1910), the *Aerodinamism*, *Styling* and *Organic Design* styles of the mid-twentieth century, to today's *Blobjects*. Architecture is also full of examples of inspiration in nature, in a wide range of proposals that go from Modernist and Biomorphic sculptural works from the late 1800's, to *Organic Architecture* in the 1930s and *Metabolic Architecture* in the 1960s, just to name a few (Montana-Hoyos, 2010). In the fields of design, in the 1950s Buckminster Fuller introduced the concept of synergetics[1] and the design of the geodesic domes[2] inspired in natural functions, geometry and patterns (Edmondson, 2007); and Victor Papanek in the 1970s, studied the natural relationships between forms-functions in his

[1] Synergetics is the empirical study of systems in transformation, with an emphasis on total system behavior unpredicted by the behavior of any isolated components, including humanity's role as both participant and observer. Fuller coined this term long before the term synergy became popular.
[2] Fuller introduced the geodesic dome in 1949: a spherical shell based on a network of great circles (geodesics) on the surface of a sphere. Fuller used an energetic-synergetic approach to geometry observed in nature, e.g. the eyes of some insects like dragonflies or spiders.

seminal book *Design for the Real World* (Papanek, 1971). In the fields of engineering design and technology, diverse bio-inspired approaches have generated some of the most important inventions in the last three centuries of human history. Fields of research such as *biomechanics*, *bio-engineering*, *bionics*, *robotics*, and *biomimetics* had their origin mainly during the mid-twentieth century and are today widely explored fields.

However, it was not until 1997 when science writer Janine Benyus published her seminal book *Biomimicry: Innovation Inspired by Nature* that the concept of Biomimicry became consolidated and the "*biomimicry movement*" was initiated. At the same time period biologist Steven Vogel played a fundamental role in further defining the concept of biomechanics through his seminal book: *Cat's paws and Catapults* (1998). Almost two decades later, the biomimicry movement is growing exponentially[3] and it starts differentiating from biomimetics, biomechanics and other "bio" approaches. While the boundaries of the diverse bio-inspired approaches are still unclear as many of these disciplines overlap, we believe that one of the main differences between Biomimicry and other bio-inspired design approaches is its focus in sustainability and nature conservation. Biomimicry not only tries to emulate form or function from nature (as biomechanics or some fields of robotics, for example), but rather imitates behavior, processes and systems, with a strong focus in solutions which are conducive to and respectful of life.

Biomimicry (from *bios*, meaning life, and *mimesis*, meaning to imitate) is an emerging discipline that studies "nature's genius" and consciously emulates life's principles of adaptation and survival, mimicking form, process and ecosystems (Benyus, 1997). Biomimicry is bio-inspiration not only as form, function or structure, but in a deeper systemic sense. Benyus prescribes biomimicry as a sustainable mean for design by suggesting: "life teaches us a clear lesson: after 3.8 billion years of research and development, failures are fossils, and what surrounds us is the secret to survival" (Benyus, 1997). Living organisms have evolved as a set of strategies that sustain natural systems over time, and there are many lessons to be learned from them. Biomimicry considers the complex living networks we find at every level of biology—between and among genes and cells, proteins and polymers, organisms and species—as the playground that resulted from evolution. These systems have been shaped by natural selection over billions of years into the densely intertwined collaborative web of "mutualism" that we call Life (Woolley-Barker, 2013). Organisms and environments integrate and optimize strategies ***to create conditions conducive to life***. The *Anthropocene* (which many believe started with the industrial revolution) has proven to be detrimental not only for human survival but also threatening to many species and the environment (Crutzen, 2006).

The term Anthropocene relates to the current geological age, viewed as the period during which human activity has been the dominant influence on climate and the environment. Because human activities have also grown to become significant geological forces, for instance through land use changes, deforestation and fossil fuel burning, it is justified to assign the term "anthropocene" to the current geological epoch. This epoch may be defined to have started about two centuries ago, coinciding with James Watt's design of the steam engine in 1784 (Crutzen, 2006). Humans are the dominating species that lead to the current conditions far from being conducive to life. If, as a fundamental principle, *life creates conditions conducive to life,* another fundamental question for designers arises: *How can design create conditions conducive to life? Can biomimicry be the missing link?* The contribution from biomimicry can be essential in this matter; framing the incidence of biomimicry as a new knowledge paradigm, the role that biomimicry plays in design innovation for creating the conditions in which humans can give a positive input to the ecosystems that sustain the planet.

We must not confuse *bio-inspiration* with *bio-utilization* or bio-assisted technologies. For example, using bacteria to clean water, genetically modified food, or any kind of life-form domestication are all ways of bio-utilization. Unlike bio-utilization, biomimicry uses the

[3] The Biomimicry 3.8 Institute was initiated in 1998 and conforms today an educational hub and a global network extended to regional independent representations worldwide. http://biomimicry.org/

blueprints from nature to inspire design ideas: it is not just about using it or replicating it, but about learning from it. **Biomimicry sees nature as a model, as a measure and as a mentor. As a model**, because it imitates nature's master pieces –such as photosynthesis, self-assembly, natural selection, self-sustaining ecosystems, eyes and ears and skin and shells, talking neurons, natural medicines, and more– to be applied in design and processes to solve human problems (Benyus, 1997). **As measure,** because it uses an ecological standard to judge the rightness of our innovations, what works, what is appropriate and what lasts (ibid). **As a mentor,** by proposing a new way to view and value nature; it introduces an era based not on what we can *extract* from the natural world but on what we can *learn* from it (ibid). Biomimics –the biomimicry specialists– believe that nature is the atlas from which design and designers can learn. Life –plants, animals and microbes– has been patiently perfecting its ware for 3.8 billion years since the first bacteria. In that time, "life has learned to fly, circumnavigate the globe, live in the depths of the ocean and atop the highest peaks, craft miracle materials, light up the night, lasso the sun's energy, and build a self-reflective brain" (ibid).

An Epistemological Opportunity for an Emerging Change of Mindset

To frame biomimicry from an epistemological perspective, basic questions like "*what can we know from biomimicry?*" and "*how can we know it?*" are crucial steps to understand past, present and possible future of this emerging design discipline. This also involves analyzing the context in which biomimicry aligns as a response to the overarching and dominant paradigms.

Ergon Guba (1990) in *The Paradigm Dialog* defines paradigm as "a set of basic beliefs that guide actions." Benyus proposes through biomimicry not only basic beliefs –in nature's genius, in natural selection and life's evolutionary power– but also new lenses to understand our biological existence and to re-shape our role as species and as a harmonious part of our ecosystems. The change in lenses proposed through biomimicry is guiding to a change in mindset, and therefore to a design paradigm shift. As introduced at the beginning of this paper, the preceding era of industrialization from which design has evolved has led to the current global crisis –climate change; inequality; energy, food and water security; among other planetary problems. Design has been an instrument of progress and an instrument for current models of development based solely on economic growth. All the systems, artifacts, products, buildings, cities, all the material man-made world that surrounds us has been purposely designed. Natural resources are being depleted. Materials created, the manufacturing processes needed, and the energy demanded is consequence of this human-designed world. This reality makes designers highly responsible of the state of things and influential stakeholders at the time of changing. Therefore, the post-industrial, post-carbon world of the 21st century demands evolutionary responses from design that lead to innovation and radical change. This is the context in which biomimicry is placed today, at the verge of change where only two options arise: *change by design or by disaster.*

Figure 2: In this image artist Nickolay Lamm illustrates how the AT&T Park in San Francisco, California would look like under 25 feet of seawater. This is part of a series of images titled "What Could Disappear? Published by *The New York Times*. Many articles and studies have tried to describe the scenarios of coastal cities affected by water levels rising, based on scientific modeling using data provided by the Intergovernmental Panel on Climate Change in 2007. Today even conservative scientists say sea levels are rising 60 percent faster than what the IPCC predicted seven years ago. *Source: Nickolay Lamm (2013) Retrieved from: http://mashable.com/2013/07/03/8-new-cities-climate-change-gifs/*

> To see life as a whole - to observe what all life has in common - requires a shift in the way we normally look at things. We must look beyond the individual insect or tree or flower and seek a more panoramic perspective. We need to think as much about process as we do about structure. From this expanded viewpoint, we can see life in terms of patterns and rules. Using these rules, Life builds, organizes, recycles, and re-creates itself. (Hoagland and Dodson, 1995).

As described above, we can see in life and nature certain patterns in the way life works. These patterns repeat themselves in different scales, from microscopic organisms and their parts to large ecosystems. Using nature as an inspiration, and from a systems point of view, we can draw analogies for our designs based on these patterns (Montana-Hoyos, 2010). We have compiled the 16 patterns proposed by Hoagland and Dodson (1995) in combination with the 9 principles proposed by Benyus (1997), in order to provide a comprehensive list of some of the characteristics of life and nature that can be mimicked for the design of the artificial environment. As such, after discarding repeated ideas, we end up with 22 patterns or principles, as follows:

1. Life Builds from the Bottom Up
2. Life Assembles Itself into Chains
3. Life Needs an Inside and an Outside
4. Life Uses a Few Themes to Generate Many Variations
5. Life Organizes with Information
6. Life Encourages Variety by Reshuffling Information

7. Life Creates with Mistakes
8. Life Occurs in Water
9. Life Runs on Sugar
10. Life Works in Cycles
11. Life Recycles Everything It Uses
12. Life Maintains Itself by Turnover
13. Life Tends to Optimize Rather Than Maximize
14. Life Is Opportunistic
15. Life Competes Within a Cooperative Framework
16. Life Is Interconnected and Interdependent (Hoagland and Dodson, 1995)
17. Nature runs on sunlight.
18. Nature uses only the energy it needs.
19. Nature fits form to function.
20. Nature demands local expertise,
21. Nature curbs excesses from within.
22. Nature taps the power of limits (Benyus, 1997)

In order to validate biomimicry as a relevant discipline and as an important element in recognizing a paradigm shift in design, it is necessary to study the epistemology of biomimicry, this is, understanding the circumstances that lead to the principles summarized by Benyus and her recent predecessors, as well as its source of rationality and empiricism. The generation of thinkers –writers, scholars, scientists, and philosophers– that precede Benyus in understanding how nature works and how this can be applied to human ingenuity, can be found as far as in the Aristotelian interpretation of the universe and the natural forces. In the words of Aristotle: "Nature does nothing uselessly," which aligns with many of the principles considered by biomimicry and mentioned above. However, it is the generation of environmentalists and ecologists who emerged in the twentieth century what inspired Benyus to build an epistemological standpoint for biomimicry, among them Rachel Carson and her seminal book *Silent Spring* (1962); Amory Lovins from the Rocky Mountain Institute; Biologist E.O. Wilson, author of *Biophilia: The human bond with other species* (1984); Hazel Henderson, and her seminal works *Redefining Wealth and Progress: New Ways to Measure Economic, Social, and Environmental Change* (1990), *Paradigms in Progress* (1991), and *Beyond Globalization* (1999); and Paul Hawken, author of *The Ecology of Commerce* (1993) in which he coined the term "restorative economy" in clear reference to nature's resilience applied to human economy. All these influential thinkers are mentioned in the book *Biomimicry*, and all of them share the compounds for a common vision that defines the paradigm of sustainability acknowledged in our days by designers and design researchers.

Biomimicry has been predominantly understood and evaluated only from an objective approach, part of the dominant worldview evolved from positivism-modernism (Guba, Nielsen, 1990). This is a utilitarian approach seen in the sciences, engineering and technology. Looked from other angles, less conventional and perhaps more subjective, biomimicry, biomimetics and the overall spectrum of bio-inspired design can reveal new spaces for speculation. For instance, from a human ecological perspective biomimicry can be related to the *Theory of Affordances* (Gibson, 1977), which is particularly appealing to the idea of bio-inspired design. Gibson's *Theory of Affordances* reflects on how the quality of objects and environments allow humans to perform actions, framed on the relationship between natural and human environment (ibid). Affordances are widely used today in product and interface design, and are defined as "properties in which the physical characteristics of an object or environment influence its function" (Lidwell et. al 2003). It is interesting to note that Gibson formulated his theory of affordances while studying nature and living species. This ecological approach opens up an opportunity to apply the theory to bio-inspired design. Based on new perspectives, basic epistemological questions of *what can we know* from biomimicry and *how can we know it*, can be addressed from both objective and subjective views.

Situating Biomimicry Within the New Knowledge Paradigms: Building Resilient and Sustainable Futures by Design

According to Thomas Kuhn (1962) a paradigm shift is a change in the basic assumptions within the dominant theory –predominately ruling by science. Kuhn's approach suggests that there are certain conditions that need to be filled in order to recognize when a paradigm shift is complete, and this is linked to his proposed structure of "the three phases of a paradigm shift: a *pre-paradigm* phase, a *normal science* phase and a *revolutionary* phase" (ibid). Kuhn proposes this structure as a cycling or closed loop idea. Science eventually may go through these cycles repeatedly, although Kuhn notes that it is a good thing for science that such shifts do not occur often or easily (ibid).

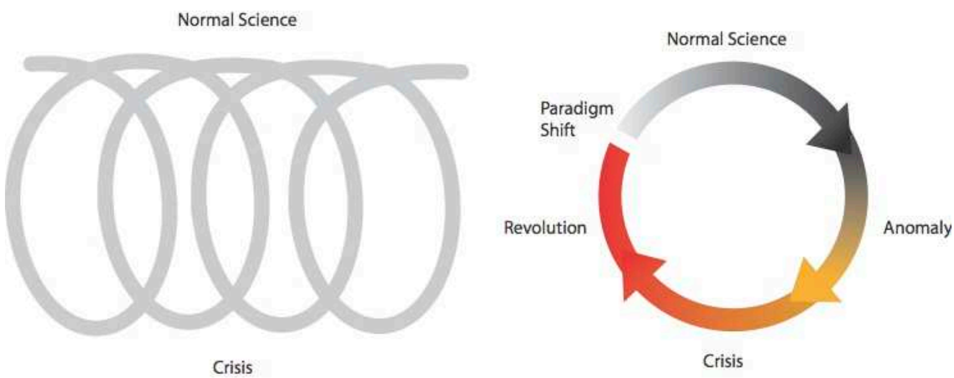

Figure 3: This diagram shows the cycling structure of a paradigm shift process proposed by Kuhn.
Source: Fiorentino, C. (2013)

In trying to place sustainability in a broader sense –or sustainable design and biomimicry as problem-solving paradigms in particular– under this cycling structure, it seems that we should start situating the context from which biomimicry emerges in the revolutionary phase rather than the pre-paradigm phase, since biomimicry can be understood as a revolutionary step in design history. According to Kuhn, *revolutionary science* implies a change in the basic assumptions within the ruling theory or *normal science* (ibid). Being the normal science the current systems in place that have lead to an unsustainable world, sustainability fits Kuhn's idea of a revolutionary phase. Biomimicry comes after as a response for sustainability, between the revolution and the pre-paradigm. The earlier stages of both ecological consciousness and contemporary bio-inspired designs, initiated by pioneer intellectuals and designers –Leopold, Carson, Lovins, Papanek, Wilson etc.– were responses to the emerging planetary crisis, responses to the anomalies shown in the dominant paradigm –the positivist-modernist worldview inherited from the industrial revolution and accelerated by the post-world war order. These anomalies show contradictory values and behavior. For the first time in the history of the planet, one species threatens all ecosystems that make its and other species' survival possible. In the name of positivist-modernist progress, humankind is heading self-destruction by destroying the environment it depends on. The paradigm shift manifests in different interpretations, for example, according to Iroquois Peacekeeper Oren Lyons "we face a period of enlightment"[4] in which we as a species we have realized that drastic change is the new normal and that we have to act accordingly to our nature.

[4] Quote retrieved from an interview to Oren Lyons included in the documentary *The 11th Hour (2007).*

As stated more than 3 decades ago, others believe we face a “tipping point” or “turning point” in human evolution (Capra, 1982), anticipating big changes after a period of deep crisis. There is sufficient and overwhelming scientific evidence that proves that humanity can no longer continue doing “business-as-usual” without facing terminal problems, read climate change and its consequent social, political and economic instability. The question is not *if* but *when* and *how* and *for how long* these changes will happen, and what we need to do in response to prevent major problems. We are still in between the old and the new paradigms, with influential thinkers from the dominant paradigm on one side “debating” (or denying) climate change in order to continue the dominant ideas, and on the other side advocates towards new paradigms pushing to act in response to “the fact” of climate change, through mitigation and adaptation. Applying Kuhn’s paradigm model, climate change could be seen as an *anomaly* that creates tension between *normal science* (accepted knowledge, or business as usual) and *competing theories* (sustainability), allowing new emerging disciplines like biomimicry to play a role in a pre-paradigm phase and set the terrain for future normal science.

Approaching research on biomimicry from a positivist-modernist paradigm would mistakenly focus the findings on perpetuating the model from the past that has driven to the problems we face today. This is the way the word *sustainability* has been mislead and misused by the dominant paradigm’s speech: to *sustain* business-as-usual, the current order and the status quo. This can be interpreted as an *epistemological error* (Boehnert, 2011). It is worth remembering what sustainability means at this point. Sustainability is a controversial term, semantically and etymologically, complex in all its possible interpretations. It is a “young word” that has quickly evolved in its very short life (Fiorentino, 2012). The most accepted definition of sustainability does not exactly address sustainability. Instead, it is a definition about sustainability applied to another concept: development. In fact, the word *sustainability* was not present in traditional dictionaries until very recently, and has been added to user-based public databases like Wikipedia. The most accepted definition of sustainability was introduced in 1987 by The World Commission on Environment and Development to the United Nations (the Bruntland Commission) and coined the term of *Sustainable Development,* which defines sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Bruntland et al, 1987). For instance, an industry based on the use of fossil fuels may meet our short-term needs but will compromise future generations’ needs. Despite this, in Canada we hear in mainstream news and in corporate and governmental speeches interesting statements like “oil-sands sustainable development” (http://www.energy.alberta.ca/Initiatives/3214.asp).

Research on biomimicry as a way towards sustainability must be framed instead in the context of a paradigm shift in design. Following Kuhn’s line of reasoning, design can play a significant role in provoking a shift from one paradigm phase to another. Applying Kuhn’s model, research on biomimicry is situated between the context of a revolutionary phase already initiated in mid 20th century (in response to the industrialism) and a pre-paradigm phase where knowledge is still fragmented but in process to be unified.

In order to address the initial question on *how biomimicry as new knowledge paradigm contributes to building resilience and sustainability through design,* it is necessary to decipher where exactly in the process and where in the pre-paradigm phase biomimicry is situated. What is clear is that in an imaginary timeline biomimicry today is still far from the normal science phase. Still, the short-term prospect is optimistic. The sole idea of changing from a linear way of doing things to a closed loop idea is a big transformation to the way modern industry fabricates products, and it changes the role of designers at a paradigmatic level. This same principle is widely explored by the cradle to cradle approach (McDonough & Braungart, 2002). Michael Pawlyn, an architect who has widely used Biomimicry, gives an example: “the way we tend to use resources is extracting them, turning them to short life products and disposing them. Nature works very differently: in an ecosystem the waste from one organism becomes the nutrients to other organisms of the ecosystem" [5] (Pawlyn, 2010).

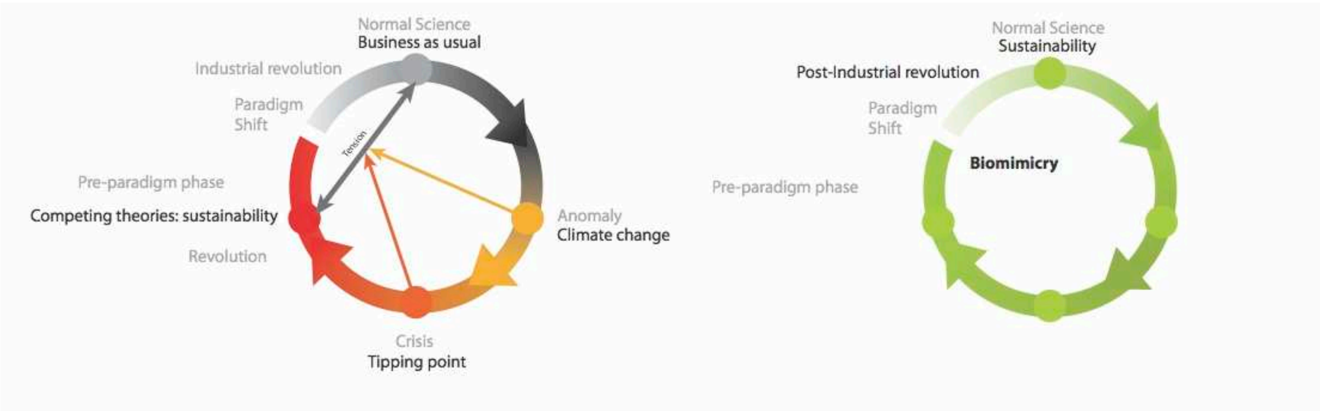

Figure 4: Applying Kuhn's paradigm model, climate change seen as an anomaly, creates tension between normal science (business as usual) and the competing theories emerging as a response to the crisis (sustainability). This situation allows new emerging disciplines like biomimicry to play a role in a pre-paradigm phase and set the terrain for a paradigm shift first, and the future normal science.
Source: Fiorentino, C. (2013)

Guba and Nielsen (1990) suggest that our current worldview is dominated by three overarching knowledge paradigms: post-positivism, critical-idealism, and constructivism[6]. It is not a simple task to place either sustainability or biomimicry within the boundaries of these suggested paradigms, nor classify biomimicry or sustainability under any disciplinary label (environmentalism, eco-design, etc.). Instead, the idea of playing a role within an open "paradigm dialog" in which commensurable or blending knowledge paradigms can be pragmatically applied to multiple disciplines (Lincoln & Guba, 1996), seems to fit better to the realms of sustainability and biomimicry. This standpoint can be perhaps described as part of a *post-"*post-modernism" view, as some authors suggest.

The emergence of biomimicry might be seen as part of the transition to a pre-paradigm phase in which "there is no consensus yet on any particular theory, nonetheless the research being carried out could be considered scientific in nature" (Kuhn, 1996). This phase is basically characterized by the fragmentation of ideas and approaches, and the combination of incompatible and incomplete theories. Again, it is hard to determine when this phase will end, if we are now in a transition period to the normal science phase or how far we are from it. The conditions to the normal science phase are when ends connect and puzzles are solved within the context of the

[5] This quote was extracted from Michael Pawlyn's TED Talk "Using nature's genius in architecture" in London 2010. In 1999 Pawlyn was one of five winners in "A Car-free London", an ideas competition for strategic solutions to the capital's future transport needs and new possibilities for urban spaces. In September 2003 he joined an intensive course in nature-inspired design at Schumacher College, run by Amory Lovins and Janine Benyus. He has lectured widely on the subject of sustainable design in the UK and abroad. The authors met him personally when presenting keynote speeches in the *Sustainability Through Biomimicry Conference* 2012 in Saudi Arabia.

[6] In its broadest sense, **positivism** is a rejection of metaphysics. It is a position that holds that the goal of knowledge is simply to describe the phenomena that we experience. From a positivist standpoint he purpose of science is simply to stick to what we can observe and measure. Knowledge of anything beyond that, a positivist would hold, is impossible. Positivism was strongly embraced by the industrialism in the 20th Century. **Critical realism** is one of the most common forms of post-positivism. A critical realist believes that there is a reality independent of our thinking about it that science can study. Positivists were also realists. The difference is that the post-positivist critical realist recognizes that all observation is fallible and has error and that all theory is revisable. The critical realist is *critical* of our ability to know reality with certainty. Another form of post-positivism is **constructivism.** Constructivists believe that we each construct our view of the world based on our perceptions of it. Because perception and observation is fallible, our constructions must be imperfect. (http://www.socialresearchmethods.net)

dominant paradigm. At this stage of the process (the paradigm shift) our current worldview seems far from reaching a "sustainable world view" as a *normal science* phase implies, and design's worldview in particular seems far from sustainable design as *normal science*.

We have started to recognize the value of nature's wisdom and started to develop inspired solutions –new materials, new artifacts and systems– but we are still far from applying the concepts universally as Benyus describes. Nevertheless, a process of change has already started in this direction and the emergence and consolidation of biomimicry as a discipline is proof of this.

The Theory of Resilience Applied to Biomimicry

In addition to the conceptual framework given by biomimicry, and as a response to the human-driven crisis, the concept of *resilience* comes into play as a major role in the context of biomimicry and sustainability. Building resilience is perhaps the most fascinating feature that life can teach us, in concordance with nature's laws, strategies, and principles, as summarized above. The Resilience Alliance (www.resalliance.org) defines resilience "as the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes" (Resilience Alliance, 2010). A resilient ecosystem can withstand shocks and rebuild itself when necessary.

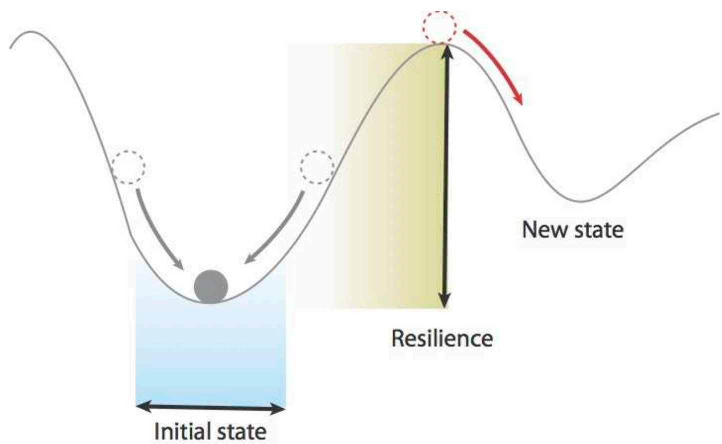

Figure 5: The "Ball in a basin" metaphor explains how resilient systems work. If the ball is pushed a little bit, it will return to the bottom of the basin, i.e., to its initial state. If the ball is pushed hard enough, it will leave the basin and eventually settle somewhere else, i.e., in an additional state. The height of the basin thus corresponds with resilience capacity: the higher the basin, the harder of a push the ball can withstand and still return to its initial stage.
Source: Fiorentino, C. (2013)

Humans are part of the natural world. We depend on ecological systems for our survival and we continuously impact the ecosystems in which we live on a local to global scale. Resilience is a property of these linked social-ecological systems. Resilience, applied to ecosystems or to integrated systems of people and the natural environment, has three defining characteristics:

- A system is resilient when it can undergo certain amount of change and still retain the same controls on function and structure
- At a certain degree, a resilient system is capable of self-organization
- A system is resilient when it possesses the ability to build and increase the capacity for learning and adaptation (www.resalliance.org).

Figure 6: "The Fish School Exercise" is an activity practiced at HECOL 493 Design for Sustainability course (University of Alberta) that provides a practical demonstration of self-organization patterns and behavior (idea retrieved from: http://www.icosystem.com/labsdemos/the-game) The exercise demonstrate that simple rules of individual behavior can lead to surprisingly coherent system level results while intuition can be a particularly poor guide to prediction of the behavior of complex systems above a few levels of complexity. Supported by a computer simulation, this exercise is a powerful tool for understanding the dynamics of complex systems, and applying the concept to build effectiveness and resilience to human systems.
Source: Fiorentino, C. (2013)

In contrast to the young word *sustainability*, the word *resilience* is an old one, originated in the 17th century, and evolved from the Latin *resiliens*, which means "*leaping back.*" Resilience is closely related to other two key concepts: flexibility and restoration. In modern physics, resilience is intrinsically present in the second law of thermodynamics, which introduces the idea of *entropy* or transfer of energy as a permanent condition for *negative equilibrium* and decay. In contrast to classical physics, modern theories demonstrate that natural systems are *thermodynamically open systems* and exhibit properties of self-organization far from thermodynamic equilibrium. In biological terms, life on Earth, seen as a whole system, is resilient to entropy. While living forms are affected individually by the passing of time (from birth to death) they are also part of a cycle that can reach permanent equilibrium. Time scale and the speed of changes also affect the capacity of a system to be resilient. Some scientists go into further speculations, proposing that the idea of *time* itself is a product of entropy. That is, the universe expands and makes the time *exist* or *move* with it. The way living forms and systems adapt to this idea is a way of being resilient to natural forces (Fiorentino, 2012).

Connecting the concept of resilience with sustainability, John Lyle wrote the book *Regenerative design for sustainable development* in 1994, suggesting, but not yet using, the term resilience explicitly. Years later David Orr in his book *The Nature of Design* wrote an insightful definition while describing ecological design or eco-design–the closest relatives to Design for Sustainability: "... [eco-design] is an art by which we aim to restore and maintain the wholeness of the entire fabric of life increasingly fragmented by specialization, scientific reductionism, and bureaucratic division" (Orr, 2002), in clear reference to change the dominant positivist-modernist worldview. In this definition, Orr (as Lyle), uses the concepts of restoring and maintaining as a part of an integrated process of design. A chronological order is implicit in this statement. Design might be able to restore things first –products, systems and behavior, in order to later maintain a wished balance. In order to design for sustainability, we must first design for resilience. Resilience is both a conditional and a conducive factor to sustainability (Fiorentino, 2012).

Although the idea of resilience is implicit in the principles of biomimicry, Benyus does not emphasize the concept as Lyle and Orr do. Even though, Lyle and Orr do not refer to the concept as *resilience*. It was not until very recently that the term resilience started to resonate in papers and articles related to sustainability and bio-inspired design. A few years after Orr's paper, Carl Folke wrote in an article: "the resilience perspective is increasingly used as an approach for understanding the dynamics of social–ecological systems" (Folke, 2006), and more recently Walker & Salt's book *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function* coins the idea of *resilience thinking* aligned with Folke's interpretation (Walker & Salt, 2012). Still the link between bio-inspired design, or biomimicry, and resilience is not explicitly present. In 2013 The Resilient Design Institute posted a short article in its website (http://www.resilientdesign.org) named *Biomimicry and Resilience,* which comments on another article published in The New York Times: *Will Biomimicry Offer a Way Forward, Post-Sandy?* More recently in the Biomimicry First Global Conference (University of Massachusetts, Boston, June 2013), where Janine Benyus was keynote speaker, after being asked on how biomimicry could help to prevent the aftermath of climate change disasters, like rising level of oceans and city waterfronts affected by flooding, Benyus answered: "go to the shore, take a walk in the beach, all the answers are there. All you can see there survived erosion and adapted to changing conditions for eons."[7] This is an example of how biomimicry thinking can be articulated and applied with integration in mind. Designers suffer not from lack of information but from the lack of integration. Biomimicry helps to address this deficiency, for instance by integrating resilience thinking and design for sustainability thinking. The case of waterfronts is a good example of this integration. While traditional design thinking proposes building dams and sandbag walls to keep water out, biomimicry thinking proposes "replicating strategies from humble grasses rebuilding dunes, and oyster beds acting as reefs, sheltering the land from impact." [8] Natural waterfronts and beaches are resilient to changing conditions, they respond to these conditions after billions of years of adaptation in a sustainable way. Design can learn from examples like this and provide more effective, long term solutions in contrast to short term mitigation.

Figure 7: Rising level of oceans and city waterfronts affected by flooding will be increasingly common. In contrast to usual reactive responses to disaster, Biomimicry proposes preventive pro-active measures of change and adaptation, by observing and mimicking the strategies that build resilience in nature.
Source: Images retrieved from royalty free photo sources.

[8, 9] These statements were part of personal notes by the first author when attending the keynote lecture at the Biomimicry Global Conference in Boston, and taken during the round of questions to Janine Benyus on June 22, 2013. There is not record of this conversation being published up to date.

Conclusions

The reflections presented in this manuscript emphasize the relevance of the emerging discipline of biomimicry as part of the new paradigms of design. In this context biomimicry can be a powerful tool for design for sustainability, and furthermore, for ‘design for resilience’. Biomimicry inspires designers to learn from nature and offers a model based on mutualism, synergies, and cycling loops observed in ecosystems and living organisms. Biomimicry not only tries to emulate form or function from nature (as other bio-inspired design disciplines do), but rather imitates behavior, processes and systems, with a strong focus in solutions which are conducive to and respectful of life. It offers too a set of conceptual tools to enrich the design process, as well as clues to develop better materials and artifacts, improve systems and create conditions that lead to better behavioral patterns. From an epistemological standpoint, biomimicry seems to fill the transitional gaps between paradigm phases (as proposed in this paper and based on Kuhn’s paradigm model), and in the process it collaborates to achieve more inclusive and conciliatory ways of thinking and knowing for design disciplines. The emergence of biomimicry might be seen as part of the transition to a pre-paradigm phase in which “there is no consensus yet on any particular theory. This phase is basically characterized by the fragmentation of ideas and approaches, and the combination of incompatible and incomplete theories. This can open new spaces for speculation and knowledge generation, and an example of this can be the inclusion of theories like *affordances,* as described in the paper. The integration of biomimicry in fields such as human ecology and design for sustainability provides theoretical and methodological direction to the discipline in a holistic and interdisciplinary manner. Sustainability is a controversial term, complex in all its possible interpretations. In contrast, the word *resilience* is an old one, closely related to other two key concepts: flexibility and restoration. The idea of resilience is implicit in the principles of biomimicry. As a final remark, the emerging discipline of biomimicry can play a vital role in the paradigm shift conducive to sustainability and resilience.

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