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EMPLOYING BIOMIMICRY IN URBAN METAMORPHOSIS SEEKING FOR SUSTAINABILITY: CASE STUDIES

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Structured Abstract

Objective

The current study has aimed to develop the framework of biomimicry involvement in urban metamorphosis for sustainability. This research has engaged four objectives to achieve the aim. Objective one is to explore the rudiment interaction between human and nature through interrogating history, nature's design. Objective two is to excavate the biomimicry in emulating nature's genius. Objective three is to investigate the association between biomimicry and sustainable development, focusing on architectural features. Objective four is to develop the framework based on the biomimicry rules for human evolution and survival in the natural environment.

Methodology

To achieve objective one, the grounded theory method was applied for scrutinizing human development and human awareness about their natural environment. To achieve objective two, an evidence study was conducted on the biomimicry emulation of nature's genius. To achieve objective three, a critical literature review was conducted using content analysis method to identify the biomimicry focus and architectural features. Through matrix development method, the focus and architectural features were tabulated. To achieve objective four, the waterfall framework design method and case studies were conducted to plot this framework.

Conclusions

This research gained a better understanding of biomimicry-based on theories of the evolution of organisms, including humans in the urban context, as measurement against sustainable benchmarks. It followed the paths of ecological researcher and urban philosophers, such as Freya Mathews and Moore, by re-versioned the human relationship with nature and the surrounding environment and observing human actions and development about life principles.

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In particular, the research found out that biomimicry is an approach that recently becomes the focus of many researchers of different disciplines seeking a solution for human problems.

The biomimicry has been merged with sustainable architecture design through specific features; included, form and function, geometry, metaphor, movement, material, pattern, proportion, sustainability, and technology. Furthermore, biomimicry is an approach that involves nature as a model, mentor, and measure for inspiration, which converges law, principles, and strategies in the context of biomimicry-based on human evolution.

Originality

The findings allowed architects and urban designers to enhance people's awareness of their natural environment and provide a better perception of biomimicry in the application of human world, whether founded because of base instinct or a strategic view derived from the life's principles.

1. Introduction

Cities are the primary impulse and the first tools for human settlement. Ever since the discovery of fire, humans as distinctive organisms expressed their needs for independent settlement from the natural environment. Such needs are evidence in humanity's timeline of evolution, over the course which they learned to use various energy sources (Lamit *et al.,* 2013a; Keyvanfar *et al.,* 2014; Shafaghat *et al.,* 2016a). Separating themselves from the natural cycle led to changes in lifestyle and in development of urban layout, which have the limit association with their former natural lifestyle (Ranhagen *et al*., 2007; Salvador, 2014). Throughout the time, there has been an insignificant increment in consumption of natural resources up to the era of industries that severed societies from the dynamic human world, marking the beginning of human development (Goldstein & Johnson, 2015). The positive side of the equation is the stabilization of the human population, while the global overconsumption of natural resources raised a red flag of the consequence ranging from global warming to resource shortages (Lamit *et al.,* 2013b). It is currently posing major challenges to human development in the 21st century. In urban areas, the challenges mainly include the comprise ever-changing demographics, traffic congestion, supply reduction, the rise of water level, and ever-increasing climate heat (Buck, 2015). A desire to avoid a catastrophe of Malthusian proportions has led to an increase in calls for sustainable development (Robert, 1998). Accordingly, planners, scientists, and designers have prioritized sustainability with the primary objective of mitigating the effect of the human footprint on the natural and built environment, fewer humanity imbalances to the ecosystem and even itself. As a result, sustainable design has become a central pillar that requires instigating a guide to humanity toward appropriate participation in natural processes rather than applying new technologies that predict, manipulate, and even control the work of nature (Wackernagel & Rees, 1998; Majid *et al.*, 2012). As an outwork for sustainable urban solutions, biomimicry has become the target field.

Biomimicry field of research is increasingly attracting scientists to the importance of continuous learning from nature of 3.8-billion-years (Benyus, 1997). Nature acts as a rich sourcebook for several fields, including engineering (Pawlyn, 2011). There is a handful of educational institutes and research centers that have included this subject in their architecture and urban studies programs. The benefit of the biomimetic approach increases the demand for seeking an application driven from nature for a future sustainable city. It was declared in the recent OMICS International report released by 28 July 2014, "As per available reports about nine journals, five conferences and workshops are presently dedicated exclusively to biomimicry, and about 199 articles are being published on the current trends in biomimicry" (OMICS, 2014, p. 2). Recently, there are few major educational institutes, websites and research centers focus on biomimicry,

such as Biomimicry Institute, Biomimicry 3.8, Center for Molecular Design and Biomimicry, Ask Nature, Biomimicry Guild, and TED. One of the international conferences was the Sustainability Through Biomimicry Conference at Dammam University, Kingdom of Saudi Arabia in 2012. Frequent international gatherings are meant to focus on novel ideas that can be derived from natural species with illustrative applications in design and the development of future eco-cities.

Biomimicry is the basic science that looks at nature as the ampules of life's principles (Salas Mirat *et al*., 2018). Many scholars view nature as 'the ontology of the city,' urging the adoption of innovative and cooperative methods of urban infrastructure design and management that are supplemented by forward-looking paradigms such as the smart city *(Canizaro, 2012; Majid et al.*, 2012; Buck, 2015). Over 3.8 billion years, life has progressed a series of self-sustaining strategies based on the interrelated and symbiotic relationship between an organism and its surroundings. The organism is the concept is known as 'life's principles'- that is the design lessons from nature existed on earth and are inherent for many generations (Aziz, 2016). Different life's principals were evolved by the human that can be the means to different environmental problems. An understanding of these principles can make a basis for manipulating several features of human evolution, and thus make the sustainable development benchmarks. The developments would then follow the footsteps of many ecological philosophers, for example, Freya Mathews and Moore, to enhance people's awareness of their natural environment. Many profound ecologists have re-versioned human and humankind's relationship with other natural and the surrounding environment (Mathews, 2011). Also, observing human development about life's principles allows an examination of their application in the human world, whether founded because of instinct or a inspire derived from the biomimicry concept.

The current study has aimed to develop the framework of biomimicry involvement in urban metamorphosis for sustainability. This research has engaged four objectives to achieve the aim. Objective one is to explore the rudiment interaction between human and nature through interrogating history, nature's design. Objective two is to excavate the biomimicry in emulating nature's genius. Objective three is to investigate the association between biomimicry and sustainable development, focusing on architectural features. Objective four is to develop the framework based on the biomimicry rules for human evolution and survival in the natural environment. The research has engaged specific research methods to achieve the objectives. To achieve objective one, the grounded theory method was applied for scrutinizing human development and human awareness about their natural environment. To achieve objective two, an evidence study was conducted on the biomimicry emulation of nature's genius. Then, to achieve objective three, a critical literature review was conducted using content analysis method to identify the biomimicry focus and architectural features. Through matrix development tables, the focus and architectural features were tabulated. Finally, to achieve objective four, the waterfall framework design method and case studies were conducted to plot the framework of the human development for biomimetic civilization.

2. The Interaction between Human and Nature

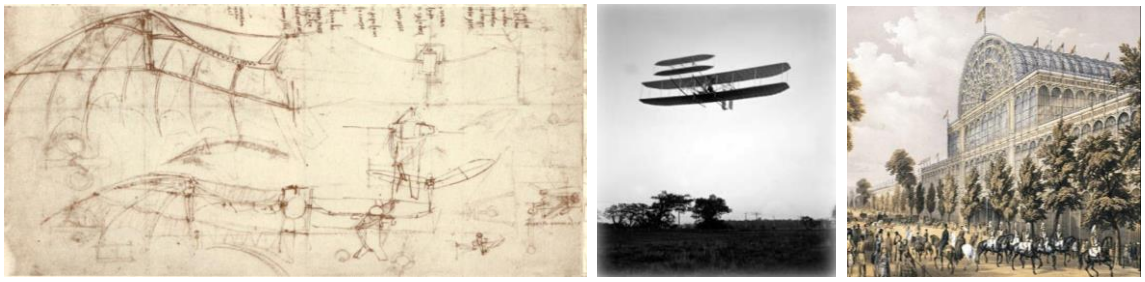
2.1 Human and Nature in History

Nobody would dismiss the fact that humans have been completely subject to nature throughout their history, but, Kellert added, humankind displays a central physical, passionate, and scholarly reliance on nature (Kellert, 1997). Hence, the start of the historical backdrop of the connection of humans and nature undeniably matches the start of humanity's history on the environment (Okhovat *et al.,* 2011). Regarding biophilia and conservation ethic, Wilson (2017) states that ninety-nine percent of people in history were associated with nature's history and

can be seen in two social orders; hunter-gatherer social orders and Agrarian social orders. Both orders were band tightly with other organisms.

For the foreseeable future, the natural environment would be the main source of technological innovation and techniques that allow the global populace to securely settle in the sustainable natural environment (Dyson, 2007). Biomimicry as an approach to discover innovative solutions derived from nature. Figure 1 shows three examples of biologically inspired designs. Figure 1a shows the world-renowned Leonardo da Vinci's ornitottero wings (1452-1519), who looked to the physiology of birds in his quest for human flight. Figure 1b shows the Wright Brothers, who made da Vinci's dream reality in 1903, draw inspiration for their invention from their observations of pigeons in flight. Figure 1c shows Joseph Paxton the Great Exhibition at Crystal Palace in 1851, the principal international expo of fabricated items. The royal residence extraordinary engineering, which employs jumbled iron braces to help considerable water weight (Bar-Cohen, 2006).

Figure 1. **Interaction between Human and Nature**



(a) (b) (c)

Note: a) Leonardo da Vinci's ornitottero wings; b) Wright Brothers in Flight, c) The Great Exhibition Crystal Palace
Source: a) https://commons.wikimedia.org/wiki/File:Leonardo_Design_for_a_Flying_Machine,_c._1488.jpg
b) https://www.britannica.com/biography/Wright-brothers
c) https://www.theguardian.com/science/blog/2015/aug/28/how-the-great-exhibition-of-1851-still-influences-science-today

2.2 Humans as members of Earth's communal lifecycle

Human beings share a typical relationship with many other organisms through their roots in the evolutionary procedure that gave rise to all species, which is an outworking of the challenges they share merely by the environment. The human capability to construct culture is considered a little expansion in those attitudes that have seen humans nature compared to other organisms (Lents, 2016; Patel & Mehta, 2011). Additionally, it can be seen how humans confront inherent challenges as evidenced by their ability to transform their surroundings for settlement. Thus, humans can recognize themselves as part of the ecosystem. Humans action in the environment is whatever they may affect the ecosystem; hence, humans actions impose specific requirements for their survival and well-being.

2.3 Nature's Design

The life's principles encompass different aspects of life, from leadership behavior that draws on sophisticated psychological perspectives to the physical aspects that help lifeforms overcome and solve a range of issues (such as engaging in philological reactions). Regardless of when humans recognized the potential of biomimicry, life's principles have existed since Earth creation. It is the hallmark of life into eternity. The perception of biomimicry about the principles of life describe decades of nature's evolution, and the various changes describe that earth is in a condition of dynamic non-harmony, conditions on Earth constantly change. Only organisms that adapt and evolve can thrive in such a system.

Notably, instincts are a unique element that all living-beings share. Human intuition to survive is the most effective drive. Since the early periods of human presence, development has been guided by its capacity to enable us to survive. The nativist view assumes that all parts of human lead are natural, and individuals have inbuilt instinctive practices that are hereditarily decided (Spink, 2010). Blumberg (2005) portrays the nativists as the individuals who "intensely trust that we are conceived with certain center capacities and information that give the fundamental structure to a lot of what we keep on learning for the duration of our lives." The dependence on instinct indeed protected human lives, and reactions are the first shade to all evidence received.

3. Biomimicry and Urban Metamorphosis

3.1 Biomimicry Emulating Nature's Genius

Since we have exhibited the significance and propriety for biomimicry in considering nature along with its living organisms to be physis or being itself, we may turn our regard for the topic of how we may identify with nature to be comprehended in this way. The overall perspectives that have been reflected in the concept of biomimicry have been divided by Benyus (1997) into three perceptions: (A) nature as a model, (B) nature as a measure, and (C) nature as a mentor.

3.1.1 Nature as a Model

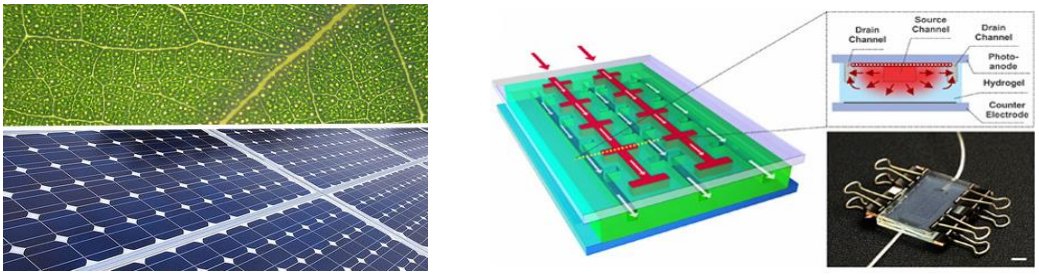
Mimicry implies copying something; however, bio-mimics recognizes that they are not by any stretch of the imagination engaged with impersonation in essence yet in any case in imitating. In this manner, they are not increasing while they are on any occasion grabbing on observations that might be helpful. Girard, the author of 'Things Hidden Since the Foundation of the World', discussed mimesis. He expressed the phenomenon of being human rejecting the imitation of avid behavior in which mimicking is the source of all conflict (Girard *et al.*, 2003). However, according to Henry Dicks (2016), while Girard offered a classical model noting that mimesis may include a non-reliable impression of human behavior, he looked at imitation and disregarded various types of non-explanatory aspects. For example, the imitation of beneficial strategies applied by different people - all the more imperatively to the extent concerned here - or the impersonation of nature's methods for delivering things (Dicks, 2016).

Our perception of the issue of CO_2 is a clear example. The law of human survival has influenced us to perceive CO_2 as a poison - for good reasons, biologically; nevertheless, life sees this substance as support. Observing plant's life reveals, without exception, that all plants on earth see CO_2 as a building block, collecting CO_2 and turning it into starches and then sugar into polymers. Also, looking at deep ocean creatures that comprise hard surfaces such as coral reefs and seashells, around 50% of them consist of CO_2. Normally, in our awareness of the harm that CO_2 can cause to humans, we try our best to avoid it and rid ourselves of it as much as possible. However, by using nature's path as a mentor and following its instructions, we will be able to use the surrounding materials that otherwise are not used and turn them into our building blocks.

This approach has been established by scientists who studied bio mineralization - the way corals and bones form - who focused on collecting the CO_2 out of smokestacks, bubbling it through seawater and transforming it into powdered limestone useful for making concrete into cement (Debs, 2009; Monkman *et al.*, 2016). With this approach, we have found a cure for global warming, thus checking one box on the list of sustainability goals. Additional case

includes the solar cells inspired by a leaf (Benyus, 1997). Leaves can restore themselves after being harmed by absorbing infrared light; they are thus able to heal themselves, continually creating new cells to replace those that have been harmed. Scientists and researchers have mirrored this system and recreated the natural methods using proteins, microorganisms, and water. This noteworthy beginning could lead to further enhancing artificial leaf-type sun-oriented cells to a significant degree (Sandru, 2010); and we will be able to mitigate manufacturing more solar cells which will approach us to the objective of biomimicry (Figure 2 a, b).

Figure 2. **Nature as a Model**



(a) (b)

Note: a) Solar Cell Self-repair Panel; b) Self-healing Solar Cell
Source: a) https://solarpunkwitch.tumblr.com/post/121376163130/solar-cell-self-repairs-like-a-plant-when-leaves
b) https://inhabitat.com/self-healing-solar-cells-mimic-plant-leaves-to-repair-themselves/

3.1.2 Nature as a Mentor

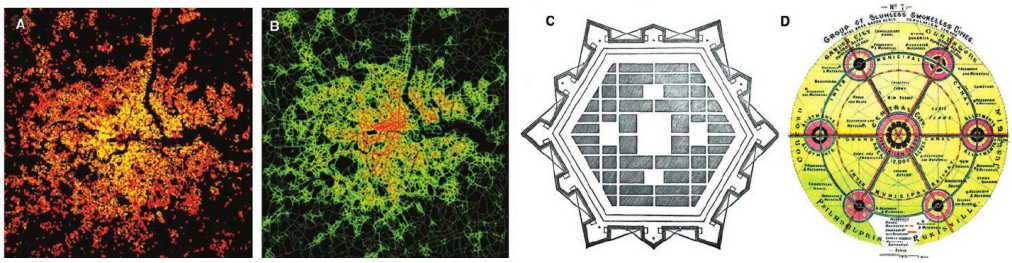
Benyus has defined biomimicry as a “method for review and esteeming nature. It presents a time that is not based on what we can extract from the natural environment, but on what we can gain from it” (Benyus, 1997, p. 2). Thus, nature can guide us toward building up our particular arrangements. While thinking about nature as an instructor, it turns out to be evidence that nature can be thought of as an educator in essential ways.

Benyus (2002) stated that nature should be regarded as our educator and the famous philosopher. Rolston (1979) discussed the theory of an ethical relationship between the human and the environment, and in his book ‘Environmental Ethics’ examined that we should follow nature as a mentor for our development. He stated that the cultural life of human beings within their nature is not completely subject to the laws of evolutionary nature. However, based on the concept of nature’s law, we certainly can see human beings are a subject to the process of the natural laws that we occasionally seem to surpass to achieve our dependency. There is no clear justification for why nature should exclude the human genre (Rolston, 1979). There are justified laws in any case applied in nature that we may violate, either in our biochemistry or in our psychology (Rolston, 1979). Thus, making us as any other organism, sharing the same qualification make us subject to nature’s law.

The fractal arrangement offers an example that exhibit nature as a practical advisor for human development at various levels (see Figure 3). This normal strategy has been adopted as a method for arranging development from the base upward or detail starting from the top. For example, the logarithmic winding of a snail's shell did not originate from the fact that it is pretty but rather claiming it considers unending development without evolving shape. At the point when the snail expands to twice size, it does not need to tear down dividers to grow its home, as most engineers would; instead, it merely continues to add more shell in a similar shape. Likewise, the significant complex state of different types of trees is produced by a fundamental

fanning calculation. Fractal frameworks do not require distinctive arrangements for various scales, while they are all the same. Fractals do not frequently look precisely indistinguishable at different scales, yet at the same time, they possess self-similitude (see Figure 4).

Figure 3. **Nature as a Mentor**



Note a) Population density of London, b) London transportation network, c-d) Two idealized geometric cities
Source: Batty (2013)

Figure 4. **Nature as a Mentor**

Note: from left to right: a Computer model of the human lungs; Romanesco broccoli; Aerial view of a river valley
Source: Winter et al. (1988)

3.1.3 Nature as a Measure

Nature as a measure has been considered as the strength of biomimicry concept. Biomimicry applies the ecological standards to criticize technological innovations (for examples, sustainable buildings using the idea of self-cooling mounds of termites). Also, biomimicry applies a natural standard to judge the maintainability of our advancements. Life's standards and principles urge us to see our plans as a feature of the unpredictable and versatile frameworks of a particular area. Also, nature gives us models from which we derive inspiration; it also approves and provides principles that restrict us in terms of what we are or are not designed to do. According to what mentioned earlier about self-generation, we noticed that a basic part of self-creation is finding boundaries of limits. Without a doubt, self-creating creatures define themselves based on the conditions in which they exist. Nature taps the power of limits, and these limits should not be unfortunate boundaries affecting our liberty to develop, but rather as powerful foundations of creation and, as such, ultimately generative of different types of freedom. Offering these limitations will obligate us with the necessity of creativity. In other words, applying the principle of nature, ‘nature curbs excesses from within,’ will subsequently lead and impose bounds our current excesses (e.g., greenhouse gas discharges, overfishing, food waste, etc.).

Moreover, biomimicry makes nature integrity and embeds with nature’s harmony, which is such a standard of ecological ethics. Following the natural systems and entities in technological designs, biomimicry can adhere to bio-inclusive ethics; then the technological design can be adjusted to the ecological principles of nature (Blok and Gremmen, 2016). According to Benyus’ (2002) bio-inclusive ethics, it is important to interpret and translate the natural problem-solving and transpose them to human problem-solving. Mathews (2011, p. 373) states that “we must

allow our ends as well as our means, our designs, to be shaped by who and what is out there in our environment''. Notably, biomimicry has found the weaknesses in questionable presuppositions (Benyus, 2002), since the "natural principles are assumed to be principles that conduce to ecological health and integrity of the ecosystems of planet earth, biomimetic technology and innovation can claim to be ethically right" (Blok and Gremmen, 2016, p. 2).

3.2 Biomimicry, Biomorphism, and Sustainable Development

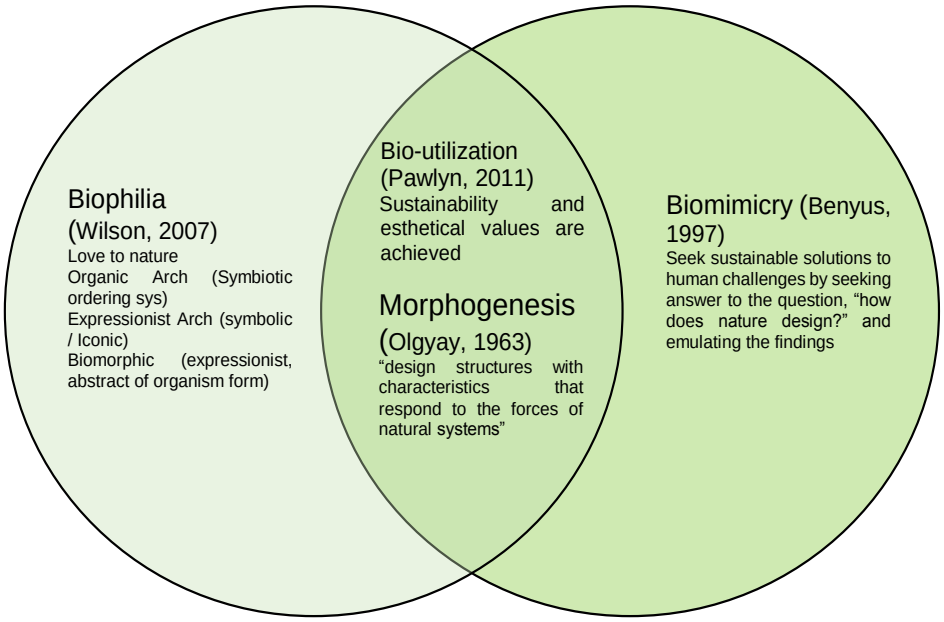
Since an early time, people around the world have emulated nature in their buildings. It is an expression of biophilia and love of nature. The fluted shaft in the classic Corinthian Order mimicking the form of the cactus stem is a good example found in Roman architecture. Biophilia has been approached under different titles. In modern architecture, we come across the terms like, expressionist design, symbolic design, and iconic design that can be exemplified by John F. Kennedy Airport that abstracts the shape of a bird and Sydney Opera House that recalls the form of open seashells. Michael Pawlyn (2011) called the duplication of natural elements in design 'Biomorphism' that is synonymous with the term 'iconic design.' Organic design is another title that goes under biophilia. It is mostly characterized by linear soft edges of the building and by curvilinear streets. Creating the possibility to live with nature is another way of achieving organic architecture as the case of the traditional Arabic inner courtyard houses where residents are in continuous contact with plants, natural light, air flow, sun, and water.

On the other hand, in 1967, Ian McHarg examined the variation of adaptability of nature concerning different locations, geography, and climate (Mcharg, 2006). His approach initiated the need for advanced analytical methods to study natural organisms. His research was followed by some researchers, as one of the famous researchers is Janine Benyus, who called a scientific approach to explore natural organism for novel appropriate design solutions for sustainable architecture. She referred to this approach as biomimicry (Benyus, 1997). Employing the biomimicry in designs, coincidently morphogenesis approach takes place. Morphogenesis is an approach that was applied in architecture and urban design, inspiring ideas from nature. Morphogenesis falls between bio-utilization and bio-mimicry. Victor Olgyay, in his book titled 'Design with Climate,' has introduced a biological approach to architectural thought based on the design of structures with characteristics that respond to the forces of natural systems (Olgyay, 2015). The resulting architectural form then becomes the product of this complex design process. A morphogenetic approach in architecture is possible with digital technology.

Consequently, digital architecture can become synonym with morphogenesis. The digital architecture utilizes "Computationally-based processes of form origination and transformations" (Kolarevic, 2006, p. 13). While the biomimetic approach is about seeking responsive design solutions to the built environment challenges, morphogenesis seeks the emulation of species to organize their forms based on self-organization and responsiveness to natural forces.

Regarding the scientific examination of plant and its adaptation to local ecosystems, a paradigm shift was occurred. It is a shift from an unempirical approach of biophilia to the quantitative discipline of biomimetics. To put the recent application in a clear context, Figure 5 shows the relationship between biophilic and biomimetic approaches. By definition, other applications (i.e., organic, expressionist, iconic, and biomorphic) are related to biophilia as they are limited to the expression of human love to nature. Partially, biomimicry overlaps with biophilia, while it largely separates itself as a purely scientific approach. The overlap often occurs as a result of the multi-function of natural elements; for example, trees are planted to provide a townscape while at the same time they filter out the dusty wind and protect pedestrians from the hot sun. The overlap area is called bio-utilization (Pawlyn, 2011); referring to a situation when plants are used in buildings for saving energy or other specific benefits (Shafagaht *et al.,* 2016b).

Figure 5. **Bio-inspired Design in the context of duplications, utilizations, and forms**



Source: Authors

The researchers follow biophilia, bio-utilization, morphogenesis, or biomimetic approach for different applications. It is believed that the mimicry does not seek slavish duplication of organisms, but rather an interpretation, adaptation, or derivation of ideas from nature. Hence, when we face a problem, instead of asking the question, how does nature look like in such climatic conditions? The question should be, what would nature do? In response to this question, discovering new solutions for human challenges becomes possible. Flowers and leaves, for example, were the base for the novel idea of deployable structures (Guest & Pellegrino 1992), while the surface of the lotus helped develop the self-cleaning surfaces (Barthlott & Nein-huis 1999). Plant adaptation is a source of numerous advantageous ideas. Barthlott and Nein-huis (1999) have defined eight advantages coherent with ecosystems: integration, optimization, multi-functionality, details, use of solar energy, implementation of temporary limitation, recycling, and development by trial and error (Eleftheriadis, 2012). These advantages require a scientific investigation. For instance, integration means that complex systems tend to be self-organizing and distributed while details mean fine adjustments of its features with respect to the environmental adaptation (Zari and Storey, 2007).

Dayna Baumeister, developer of 'The Biomimicry Guild,' and Taryn Mead, developer of the FIT (Fully Integrated Thinking) project at HO+K have documented fifteen sustainability realism clustered into triple-bottom lines of sustainability (i.e., economic, environmental, and social) (see Table 9). Accordingly, they documented the function and goal of each realm in the biomimicry perspective (from the assembly, storage, strain, and dispensing water to emerging and assigning energy and directed an over-all investigation into biological representations for every task). Referring to FIT (2011) "the Life's Principles encourage us to view our designs as part of the complex and adaptive systems of a specific location. The FIT matrix can reveal the latent potential of 'place,' including site selection, available ecological services, potential partners and opportunities for new industries".

Table 1. **The FIT Matrix, realms of Sustainability**

Aspect	Realms	Functions	Goals
Environmental	Eco-Structure	Provide ecosystem services	Maintains and fosters the health and integrity of the native physical and ecological landscapes
	Water	Manage water	Protects and enhances water quantity and quality
	Atmosphere	Protects air	Protects and enhances air quality
	Materials	Manage materials	Fosters closed material loops and eliminate wastes
	Energy	Provide energy	Provides safe, clean, abundant, reliable, consistent, free energy for all inhabitants in perpetuity
	Food	Provide sustenance	Provides safe, clean, abundant, reliable, consistent, free energy for all inhabitants in perpetuity
Social	Community	Foster community	Fosters integrated, connected community identity for all inhabitants
	Culture	Support cultural exchange	Reflects a vibrant exchange of historical and modern identity, food, art, music, and science rooted in place
	Health	Promote health	Ensures health and well-being for all citizens and universal access to quality health care
	Education	Provide education	Fosters world-class, life-long learning opportunities for all citizens
	Governance	Provide comfort	Maintains responsive, accountable stewardship
	Transport	Provide mobility	Provides congestion and pollution free mobility
	Shelter	Provide comfort	Protects inhabitants comfortably from biotic and abiotic factors
Economic	Commerce	Foster commerce	Fosters the balances exchange of goals and services
	Value	Provide value	Sustains value for investors

Source: Adopted from The Biomimicry Guild, 2011

Furthermore, reviewing the literature shows that the researchers are increasingly considering biomimicry for a sustainable future. Table 1 presents six main references published by the most well-known researchers who expedited the biomimicry applications and development in architecture and urban planning. Their viewpoints are more or less a proposition of ideas, new applications, or possible research approaches. For example, Benyus (1997) and Helen (2006) have proposed the design strategies for sustainable urban development by capturing the solutions form nature. Some researchers have specifically studied the biomimetic approaches applicable to sustainable architectural design (such as Zari (2012) and Zari (2014)). Notably, some of the researchers do not differentiate between morphogenetic and biomimetic approaches such as Michael Pawlyn (2011).

Table 2. **Biomimicry Concept in Sustainable Architecture and Urban Development**

Citation	Title	Focus	Comment
Benyus (1997)	Biomimicry - Innovation Inspired by Nature.	Benyus's book sets out nine basic laws underpinning the concept of biomimicry.	She proposed design strategies for solving human urban problems. Nature contains the answer. This book comprehends the topics in general visions.
Helen (2006)	Techniques and Technologies in Morphogenetic Design.	Helen compiled twelve articles on a recent study in morphogenetic design. The publication focuses on "theoretical and methodological foundation within a biological paradigm for architectural design, …"	Limited to form and its construction. So, climate consideration was not considered.

Olgyay and Chan (2010)	Embracing forces of nature: Environmental morphology as an influence on ecological architecture.	"Form integrates forces of natural systems in design structures."	This study is concerned with form and structure, a topic related to morphogenetic architecture.
Pawlyn (2011)	Biomimicry in Architecture.	"Explores how these ideas [species' adaptations] can be applied in the real world – form, structure efficiency, material manufacture…:"	Pawlyn presents designed forms that derive from species such as plants with a focus on form. His study falls into the overlap area between biomimicry and morphogenesis.
Bejan and Zane (2012)	Design in Nature	"How the constructal law governs evolution in biology, physics, technology, and social organization."	General presentation of design in nature. Examples of various species to support the application in architecture. There was no analysis of the flora.
Zari (2014)	Can Biomimicry Be a Useful Tool for Design for Climate Change Adaptation and Mitigation? and Biomimetic Approaches to Architectural Design for Increased Sustainability	Zari proposes approaches for sustainable biomimetic architectural application.	Zari's researches highlight new design applications ideas derived from species. She does not focus on plants, in particular.

Source: Authors

3.3 Biomimicry Features in Architecture

Recently, and especially within the past decade, biomimicry has been the subject of intense interest, a trajectory established in 1997 when researcher Janine Benyus distributed her groundbreaking work entitled 'Biomimicry Innovation Inspired by Nature' which discussed "new science that studies nature's models and imitates these designs to solve human problems" (Benyus,1997, p.10). She expressed that the aim of biomimicry is sustainability. According to Aziz (2016), biomimicry has been applied in almost every modern design, from textiles to building mechanisms. Reviewing the literature shows that biomimicry has nine features. The following briefs each feature by proving the most well-known examples from famous architects and urban designers (see also Table 3);

i) *Form and Function:* Physical external forces (i.e., function) play a role in an organic body (i.e., form) which facilitates the better expression of architecture (Mumford, 1989). For instance, Antoni Gaudi's designs have an inseparable aesthetic form and practical function. Gaudi committed to Vitrivius style, which is highlighted in his Sacra Familia Cathedral (Figure 6a) as the symbol of the combination of structural load and structural appearance in a tree-like building with irregular shapes. Or, in Calatrava's design, the structural forces are shown with the physical shapes as well. For instance, in his TGV station (Figure 6b) descending pointed arches work for functional requirements of the building, and in Stadelhofen (Figure 6c), the structural elements merged with the anthropomorphic forms.
ii) *Geometry:* Calatrava states that geometry is the function of architecture, and the structure is build based on geometrical rules (Shafaghat et al., 2016c). Some architects believe that nature does not have straight lines, while the surfaces follow non-straight and curved surfaces (such as hyperboloids, hyperbolic paraboloids, helicoids).
iii) *Metaphor:* There are three types of metaphor; structural, isolated pictorial, and textural, which deal with intellectual, visual sensitivities, and poetic (Antoniades, 1990). Abel (2012) states that metaphor can be clustered into three classes; tangible, intangible, and combination of both. For example, Antoni Gaudi borrows from natural phenomenon in his designs; such as, Sagrada Familia which has a tree-like columns and skylights with glasses that reflect the light, Parc Guell which is surrounded by a wave-like serpentine bench and

terraces, or Casa Mila which is similar to sandy halls around Barcelona (see Figure 7). Calatrava has inspired from deep ocean plants (such as, leaves patterns) and bird skeleton in his architecture and urban monuments (for example, Valencia Science center, Cathedral of Saint John, and Heritage Square) (see Figure 8).

Figure 6. **Form and Function Features of Biomimicry**

(a) (b) (c)

Note: a) Sacra Familia Catherdral, b) TGV station, c) Stadelhofen.
Source: a) https://en.wikipedia.org/wiki/Sagrada_Fam%C3%ADlia
b) foto-klub.ch/01_Mitglieder/Mona/kollektionen/calatrava/slides/Bahnhof%20Stadelhofen%20-%2003.html
c) https://www.pinterest.com/pin/659214464176035100/

Figure 7. **Metaphor Feature of Biomimicry in Antoni Gaudi's Designs**

(a) (b) (c)

Note: a) Sagrada Familia, b) Parc Guell, c) Casa Mila.
Source: a) https://www.casabatllo.es/en/antoni-gaudi/park-guell,
b) https://www.webarcelona.net/architecture-barcelona/casa-mila-pedrera-antoni-gaudi
c) https://www.viator.com/Barcelona-attractions/La-Sagrada-Familia/d562-a845

Figure 8. **Metaphor Feature of Biomimicry in Calatrava's Designs**

(a) (b) (c)

Note: Valencia Science center, b) Cathedral of Saint John, c) Heritage Square.
Source: a) https://en.wikipedia.org/wiki/City_of_Arts_and_Sciences
b) http://www.nyc-architecture.com/HAR/HAR002.htm
c) https://www.flickr.com/photos/88017382@N00/8710439955

iv) *Material:* The architects and urban designers are using a variety of materials from nature as some choices are warm and ebullient while some choices are homogenized and abstracted. Calatrava states that the materials should be matched with the environment and respond to different functions. For example, Gaudi has used traditional materials in his designs, such

as stone, motor, glass, and ceramic, while Calatrava has confined to concrete, ceramic, and glass (like Montjuic Tower).

v) *Movement:* Architecture is a tool to motivate progress and growth through a movement, which can create spaces to enlighten the movements (Dupré and O'Malley, 2009). Antoni Gaudi believes that the building should imitate the alive and animated movements, and the growth should be shown in the architectural design thoroughly. For instance, in his Sagrada Familia cathedral and Parc Guell, the structures show the growing trees. Calatrava has also represented the nature-inspired moving structure in his design (such as Milwaukee Art Museum).

vi) *Pattern:* Natural pattern is considered as the core of bio-inspiration (Zarsky, 2017). Zarsky (2017, p. 48) states that "nature uses patterns and gradients to optimize interactions and benefits." For example, Gaudi has used very colorful tiles and mosaic patterns in his Parc Guell.

vii) *Proportion:* Numbers of architects have worked on the proportion; such as, Gaudi, Wright, Otto, Maillart, and Nervi who have applied the tree proportion in their tree-inspired structures. Gaudi has followed the same size of natural creatures in his bio-inspired architectural elements, while Calatrava has designed the architectural elements very huger than the real size.

viii) *Sustainability:* Brebbia (2012) states that biomimicry is the "mimicking the functional basis of biological forms, proves, and systems to produce a sustainable solution." Mazzoleni (2013) states that biomimicry merges the environment to the design forms to achieve sustainability principles. The quantitative aspect of natural geometry incorporates with the regulation and order of shapes and forms (Imani 2017). Some architects merge them forms with the urban context (e.g., Calatrava) which are equipped with sustainable technologies (such as, energy saving, waste disposal reusing, etc.).

ix) *Technology:* Structural engineering has learned a lot from nature. For instance, the computer-aided design tools are helping engineers and architects to create complex structural morphologies inspired by nature's structures (Yeler, 2015).

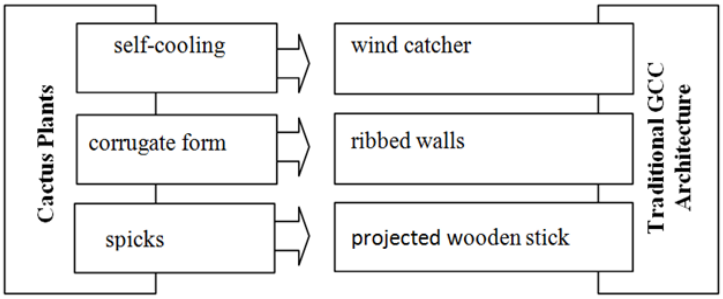
Table 3. **Biomimicry Features in Architecture and Urban Design**

Features	Levels of Mimicry	Natural Elements in Design	Description
Form and Function	Organism, Behaviour, Ecosystem	Building elements	Form follows function
Geometry	Organism	Curves, Mountains, Plants, Simple organic geometry (i.e., Conical and Cubical forms)	Geometry is in nature in both forms of qualitative and quantitative.
Material	Organism, Behaviour, Ecosystem	Concrete, Brick, Stone, Steel, Colourful tiles, Warm/White, Cold colors, Glass	
Metaphor / Analogy	Organism	Waves, Ornaments, Ribs, and Body	It is an illustration of an idea using another idea.
Movement and Growth	Organism, Behaviour	Dynamic building elements, Controlled movements, Mechanical movement	Movements are attributed mainly to human and animals, but plants also have slow movements during the growth process,
Patterns	Organism, Behaviour	A lot of different textures	Patterns have different scales and characteristics that can be simulated as trees, shells, blood vessels, seeds.
Proportion	Organism	Trees and Human Body	The human body is the source of design, and nature is the source of harmony in proportion.
Sustainability	Ecosystem	Considering site characteristics, climate, harmony with nature,	
Technology	Organism, Behaviour, Ecosystem	Limitations in Construction, Exhibition of Construction technologies.	The nature-oriented structures exhibit the structure technology and engineering in architecture and construction.

Source: Authors

For instance, Qatar's urban planning and development have mainly been undertaken by local and international companies based on design principles and strategies that have roots in western practices (Rizzo, 2014). It has produced a contemporary development pattern that raises questions regarding appropriateness in adaptation to the climatic environment. Traditional built environments, on the other hand, are a product of years of trial and error of adapting and balancing built environment with nature, and to produce sustainable settlements. Currently, the researches in Qatar are focused to understand technical lessons from traditional settlements as a mean to improve contemporary development patterns. These researches are often focused on physical characteristics, semiotic presentation, and the functionality of the wind-catcher and inner courtyard. A question was 'how much do we know about the traditional built environment and bio-inspiration?' There are assertions that some of the adaptations in traditional environments are a direct translation from nature, while this association was lost in many cases. Pawlyn (2011, p.1) notes that "the lesson from nature which informed many vernacular approaches to design and manufacturing were largely lost from our collective memory." In 2013, Ferwati (2013) hypothesized that traditional mud architecture has an identifiable construction system that resembles the ecosystem of tropical flora. His approach opened the door to further investigation in traditional built settlement and bio-inspiration. He developed his argument shown in Figure 9. Referring to Figure 9, traditional Qatari buildings simulate barrel cactus with three climatic solutions. In general, there is a growing recognition of the potential of nature to supply sustainable solutions for use in the built environment in a biomimicry approach. In particular, the findings of this study would help in suggesting design principles for passive solutions. Ferwati (2013) states that the biomimicry approach focuses on using nature as an inspiring source for innovative solutions and principles for human problems. Ferwati's hypothesis can be rephrased by saying that, the more we know about flora adaptability, the more we will recognize the architectural solutions embedded in a sustainable traditional settlement. The flora has been evolving for thousands of years and adapted itself to the harsh hot-arid zone, thereby providing many ideas for application.

Figure 9. **Three main characteristics of barrel cactus resembled in traditional architecture in Qatar**



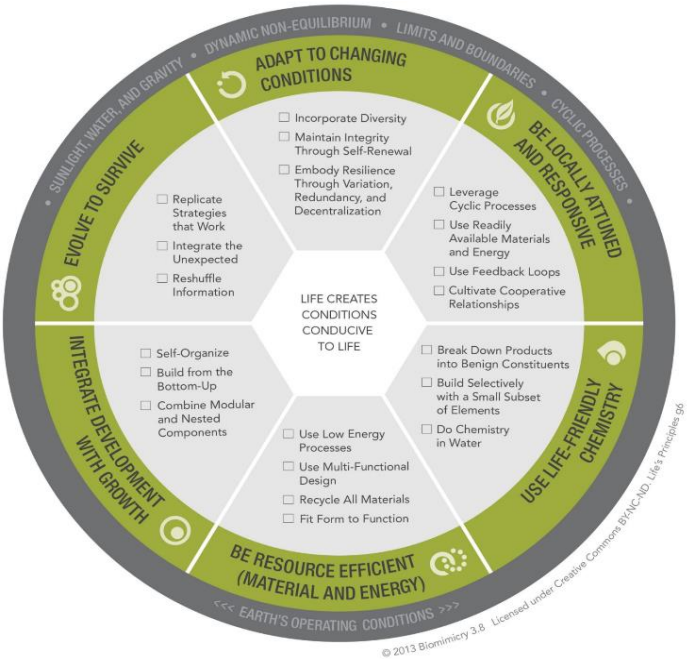
Source: Ferwat (2013)

4. Biomimicry Life's Principles

The development of the concepts of biomimicry has drawn inspiration from natural organisms that embody solutions to problems grounded in life principles, which may be identified as the foundation for designs in natural environments (Benyus, 2002). According to Benyus's six laws of nature, these principles are powerfully the focus of many of her literature which argues that each property must be of vigorous deliberation to any truthfully biomimetic design (Marshall & Lozeva, 2009). Besides, the biologist Mahlon Bush Hoagland (2001) has developed the sixteen (16) Life's Principles, which are proof that biomimicry perception parallels to other sects of development (see Figure 10). His sixteen (16) Life's Principles are; 1. Life builds from the

bottom up, 2. Life assembles itself into chaos, 3.life needs an inside, and outside, 4.Life uses a few themes to generate many variations, 5. Life organizes with information: 6. Life encourages variety by recombining information, 7. Life creates with mistakes, 8. Life occurs in wáter, 9. Life runs son sugar, 10. Life Works in cycles, 11. Life recycles everything it uses, 12. Life maintains itself by turnover, 13. Life tends to optimize rather tan maximize, 14. Life is opportunistic, 15. Life competes within a cooperative framework, and 16. Life is interconnected and interdependent.

Figure 10. **The Sixteen Principles of Life**



Source: Adopted from Hoagland (2001)

5. Biomimicry Rules

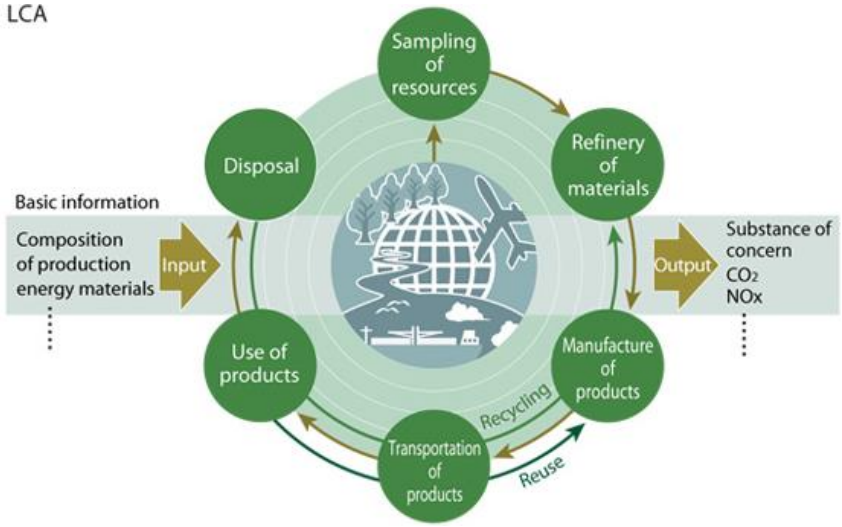
The way strategies and rules connected to individuals from the Stone Age to the hunter-gatherer time will not work in the 21st century. We may ask, for what reason may the standards that served humankind so well for so long will not work now? The appropriate response lies in the expanded many-sided quality of life that has advanced since humanity wound up understanding its capacities and became more humanized, bringing about creating new ways of survival based on technological advancements and changed humanity's social perception of life, leading to the Industrial Revolution (Taylor, 2012).

According to Taylor (2012), the idea of survival and how best to promise it has changed fundamentally since the soonest days of humanity. It will never again be tied with staying alive by fighting or escaping despite a clear and present danger. Survival no longer focused solely on shelter, clothing, and sustenance. These fundamentals have not changed much and are still a major aspect of life, but how to provide these fundamentals has been changed (Taylor, 2012). As a result, human life became more powerful and more complicated, and scholars repeatedly reestablished the principles of biomimicry. However, it does not mean that importance of imitating or reinterpreting the operating models offered by nature have been diminished by the biomimetic principles.

According to Fryer et al. (2001), the concept of biomimicry can be taken into a much deeper context or philosophy by dividing it into three main components; 1) laws, 2) principles, and 3) strategies as explained in following;

i) ***Law:*** It is defined as the special procedure in which a specific action or thing dependably prompts a specific outcome. For example, the laws of nature are absolute (Hanks, 1986). The 'balance of nature,' which reflects this concept, rests in harmony, and disturbing one component will affect the entire system. The natural condition of any framework is the favored state, and that is the best to leave it undisturbed the 'balance of nature.' This idea is reflected in numerous procedures, for example, the life cycle which has been taken into account for multiple advancements beginning in the 1960s and has been recognized as the life-cycle assessment (LCA) (Figure 11). This approach is defined as cradle-to-cradle assessment of processes and methods, including direct, indirect, and supply chain effects (Alissa, 2012).

Figure 11. **The Biomimicry Law: Life Cycle Assessment**



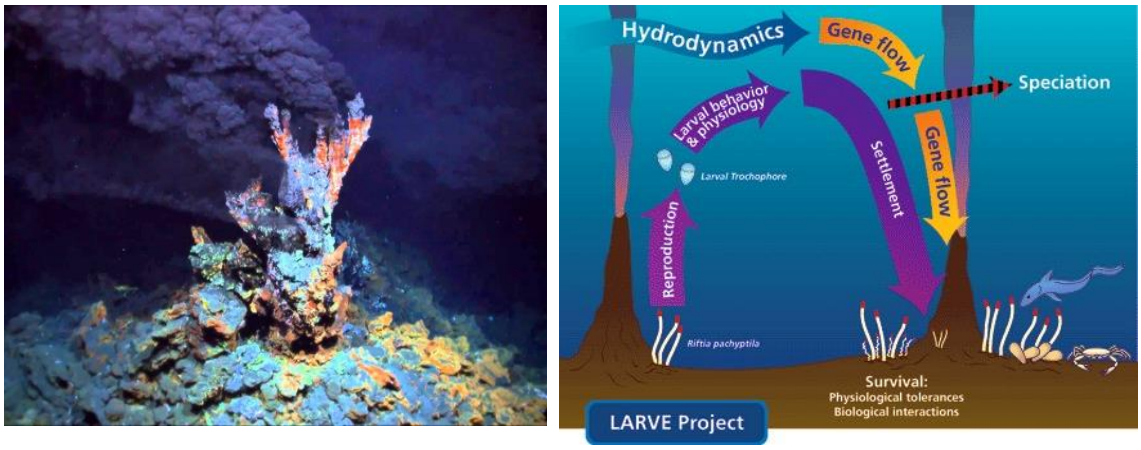
Source: Sianchuk (2016)

ii) **Principles:** Principles do not convey the powers of law. Discipline and punishment are not required if these principles are broken (Moore, 2017), thus, making them applicable to urban design and planning, in which it can easily be adjusted, changed, and broken through human development. However, the definition differentiates depending on the field that represents it. In the case of urban development, it is about biological inspiration and, in many instances, imitation. Indeed, the most acknowledged standard may be that nature keeps running on sunlight.

Although this is a revelation for some, age is viewed as a law in fundamental science and undoubtedly is precise as a rule that emphasizes urban innovation. In any case, it does not have any significant bearing for all living beings. For example, some remote ocean creatures live close to the depths of the sea, where sunlight never enters. Up to this point, all life on Earth was purportedly reliant on the sun. In any case, in the last couple of years, the revelation of new remote ocean environments have changed this discernment. It has been found that these living beings employ an elective wellspring of vitality: Rather than sunlight, they depend on hydrogen sulfide, which is lethal to most land-based life, to create natural

material using chemosynthesis (Mullineaux, 1998). In this manner, when unintended utilization of sun-powered the vitality (e.g., wind, hydro, biomass) is figured in, the case that 'nature keeps running on daylight' is not a law-even though it is the primary technique for vitality acquiring embraced by life on Earth (see Figure 12).

Figure 12. **The Biomimicry Principles**



Not The life cycle of Riftia pachyptila with the complexity of factors; involving biology, chemistry, geology, and physical oceanography. Source: Mullineaux (1998)

Another example is presented by William McDonough about the concept of biomass. He pointed out that the biomass does not always depend on the size of the organism, giving the example of an ant colony (Mathews, 2011). Ants' biomass is larger than the total biomass of humans[5] on earth, but no pollution or environmental ruin is resulting from their activities because their activities respond to the ecosystems that support them-a give intake relationship (Braungart et al., 2007). In other words, the size of what humans ingest is not the subject.

Thus, the decrease of the industrial input is not an answer in this situation, but the key can be looked at by how humanity produces output that regenerates nature instead of draining it (Mathews, 2011). Hence, the principles of biomimicry are discussable and always constant based on its situation.

***iii)* Strategies:** They are somewhat sequences of actions which is normally the base unprejudiced of any urban mission. Biomimicry is often unplanned. Nature is perceived as far from the outline methodologies of specific plants and creatures and their life frameworks, and we are asked to match those systems in our plan rehearse. The nine rules that Benyus specifies are expressive but not engaging (Daly, 1990; Mathews, 2011).

Conversely, it still agrees with Garvin et al. (2015) as logical and vigorous as they seem to be financially encouraging as they show up, entrancing, and regularly perfect. They try not to appear to tap profoundly enough into life's principles in which they periodically miss the primary purpose of biomimicry, which is to create life-perfect, and even life-regenerative (Jedlicka, 2008; Garvinn et al., 2015). For example, a noteworthy part of urban improvement

[5] "If we were to weigh all the ants in the world, they would weigh as much as all of the people," This claim was originally made by Harvard University professor Edward O Wilson, and the German biologist Bert Hoelldobler, in their 1994 book Journey To The Ants.(Hölldobler & Wilson, 1994)

today involves discovering approaches to diminish the human footprint or the chance for a net zero effect.

Then he asks if humankind can manufacture urban areas in a similar way. Consider the possibility that, in New York City, when it rained, the water that went into the East River was cleaner than when it fell. Furthermore, imagine another scenario in which, when woodlands burst into flames, the flares could be stifled by implies that didn't rely upon dangerous substances (Jedlicka, 2008). Nature makes fire retardants that are nontoxic, and then she concluded by asking, “Why can’t we?!” (Vanderbilt, 2012).

6. Case Studies

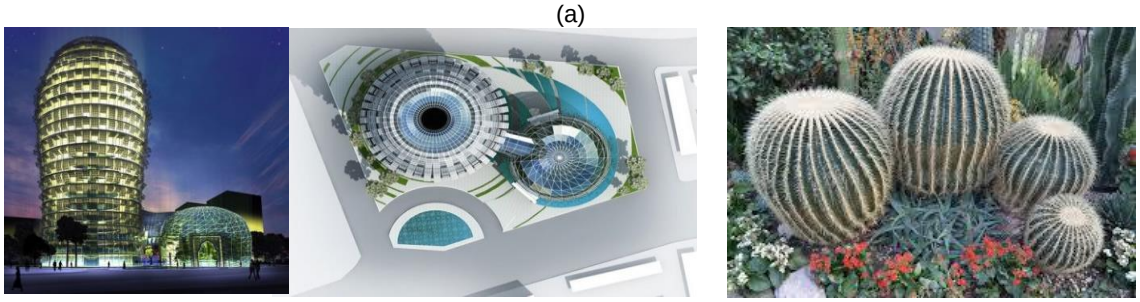
The research in the field of biomimicry devotes resources to creating sustainable architecture and urban settlements. The current research has studied a few cases that employed the biomimicry concept in sustainable architecture and urban development.

Case Study 1: In Qatar, biomimicry is still in the stage of recognition as an essential approach. A few star designers and international consulting companies come out with biophilic or morphogenesis design concepts in architecture; such as, Qatar National Museum that follows the desert rose form (Figure 12a) and the Qatar Ministry of Agriculture which echoes the barrel cactus form (Figure 12b).

The Qatar National Museum is concerned with biophilia and place identity, and Jean Nouvel’ design was inspired by both Bedouin culture and a microscopic phenomenon that occur in the desert, sand crystallization, and the desert rose, while the Qatar Ministry of Agriculture has biophilia and sustainable morphogenetic structure.

Figure 12. **Sustainable Architectural Design Employing Biomimicry Concept**

(a)



(b)

Note a) Qatar National Museum, b) Qatar Ministry of Agriculture
Source:
a) https://www.architecturaldigest.in/content/national-museum-qatar-doha/
b) https://www.designboom.com/architecture/aesthetics-architects-go-group-minister-of-municipal-affairs-agriculture-building-doha-qatar/

Case Study 2: Traditional Qatari settlements, like those of other traditional settlements in the GCC (Gulf Cooperation Council), are characterized by an integrated organic pattern of growth. They represent a lesson of adaption to the harsh hot climate. This is in contrast with modern cities which display order and geometry in their gridded streets, segregated character of development, using free-standing buildings and sprawling urban forms. These modern urban forms display a rational process of development and growth compared to the organic pattern of traditional settlements that is consistent with microclimatic realities and their cultural and spatial identities.

Currently, the efforts in studying the sustainable development patterns are globally directing research towards passive solutions. Nature and natural forms, particular biotic forms are increasingly viewed as sources of ideas for generating sustainable development solutions in Qatar. In this research, we found a relationship between the barrel cactus plant and traditional building designs and the application of spines, ribbed elevation, thick stem and folded surfaces as a means of wind regulation and surface shading.

Case Study 3: The team of authors has also conducted another research on biomimicry and urban development entitled “Towards an Eco-Districts Strategy for Sustainable Urbanism in the Gulf Region, Greater Doha as a case study” (Ferwati, 2013). The research was based on the main question: “Does traditional Qatari architecture mimics the natures and resembles plants?” The research has analyzed the relationships between architectural design and biomimicry in Qatar’s urban and neighborhoods to provide a validated model for current and future cities.

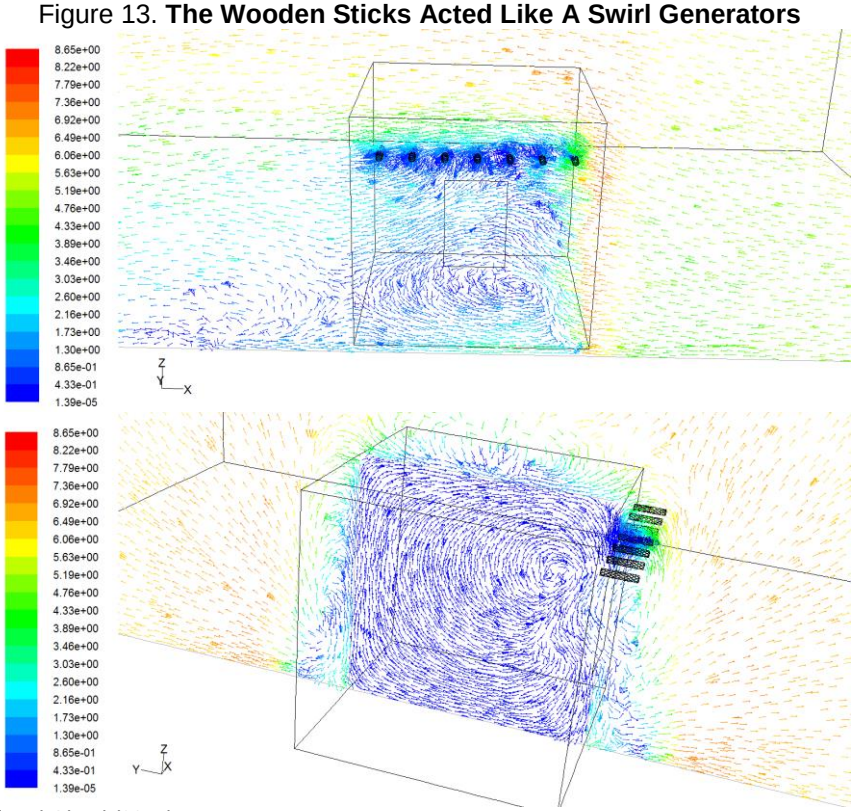
The research has sought sustainable solutions for buildings and urbanity to mitigate urban heat, from both theoretical and experimental approaches. Initially, the research followed a down-up approach with the assumption that GCC traditional architecture resembles plants in tropical regions. The research has carried out a descriptive analysis of both traditional Qatari architecture and barrel cactus.

The study concluded that there are three similarities: 1. Plant spines and projected sticks from wind towers, 2. The corrugated plant surface and the ribbed wall, and 3. The thick plant seems the mud wall (Ferwati, 2013). Extending this research to the experimental level, the research questioned the purpose of the projected wooden sticks.

The research has set a hypothesis that when the wind passes the building at various angles, it hits the projected wooden stick, creating a local vortex forcing air to penetrate the side or underneath nearby windows. Next, the research has built a virtual model and came out with a positive result (see Figure 13). Figure 13 shows that “the wooden sticks acted like swirl generators. The generated areas of wind swirl created lower pressure areas leading to an overall depression zone on the wall.

This depression area induced more air towards the wall and the window leading to a better ventilation rate” (Ferwati and Ghani, 2015, p.3). Indeed, this research would be extended further in the future, to explore the best possible ecosystem ideas that could be derived from the 270 native Qatari plants and trees.

Figure 13. **The Wooden Sticks Acted Like A Swirl Generators**



Source: Ferwati and Ghani (2015)

This research has investigated the field of biomimicry at two levels; integrative system and detail applications, to optimizes the sustainability of the built environment in Qatar. The research indicated four main advantages to Qatar's urban development:

1. Obtaining lessons from Flora of Qatar for eco-integrated-systems regarding adaptation to climatic challenges. For example, the patterns of land-covers of native plants will be a sustainable, responsive design and passive cooling, structural systems for eco-district development.
2. Knowing the similarities between native plants and the traditional Qatari settlements, its earth architecture (micro scale) and the urban layout (macro scale).
3. Need of biomimicry database for Qatar flora with adaptive features that can be referred to as a suitable responsive design system to the climate challenges.
4. It has conducted three models (a set of design principles and strategies) related to self-shading, wind channeling, and eco-urban density. These models will be referenced for the present and future developments while at the same time keeping the door open for further research for innovative biomimicry solutions.
5. The fully sustainable city includes three perspectives: environment, economy, and society. The biomimicry advantages to Qatar is anticipated to promote a sustainable built environment. The application of biomimicry application leads to passive architecture and eco-urban density that consequently will reduce the energy consumption that affects on the economy. Additionally, deriving solutions from the local flora offer a development that pertains to local identity. Hence, the passive biomimicry solution is an environmental, economic, and societal sustainable application.

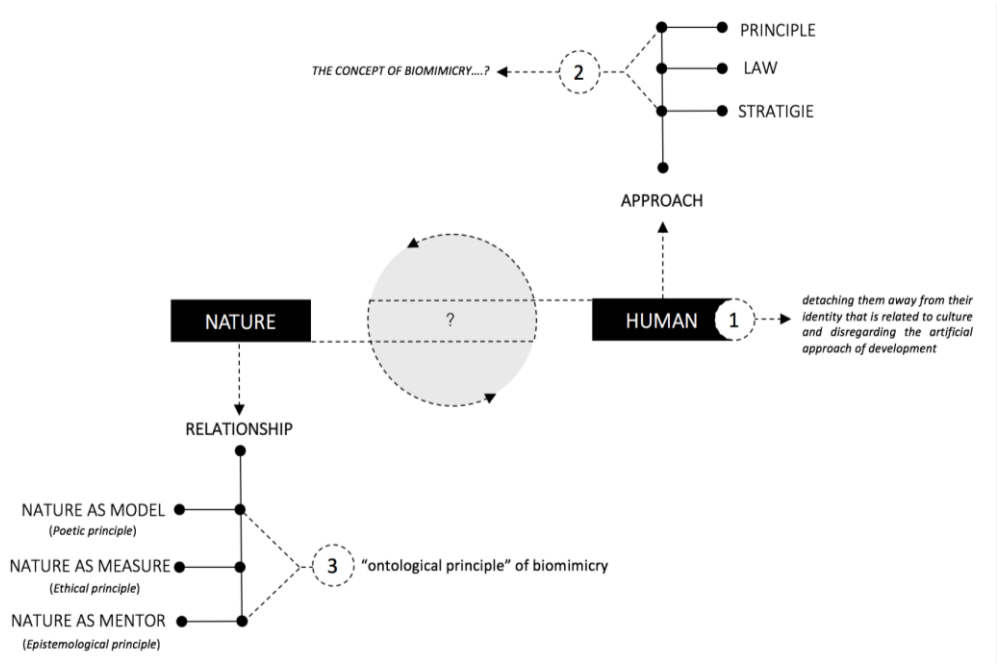
7. Discussion

The research refers to Freya Matthews's approach that prompts the view nature is 'being itself' by examining the three key dimensions of humanity's relationship to nature; nature as a model, measure, and a mentor. Synthesizing what investigated, understanding the relationship between human beings, biomimicry, and natural environment can be clustered into three steps as following;

1. Replacing humans inside nature as a way of enhancing people's awareness of their natural environment (Lents, 2016).
2. Identifying the differences between laws, principles, and strategies approaches while analyzing human actions (Mathews, 2011).
3. Examining the three key dimensions of humanity's relationship to nature through biomimicry (Mathews, 2011).

The research states for merging human and nature it is necessary to, first, detach humans from their identity and culture, then apply the biomimicry approaches (i.e., laws, principles, and strategies), and afterward construct the relationship with nature through ontological principles of biomimicry (see Figure 14). The ontological principles of biomimicry include Poetic principle, Ethical principle, and Epistemological principle.

Figure 14. **Merging Human and Nature through Biomimicry concept**



Source: Authors

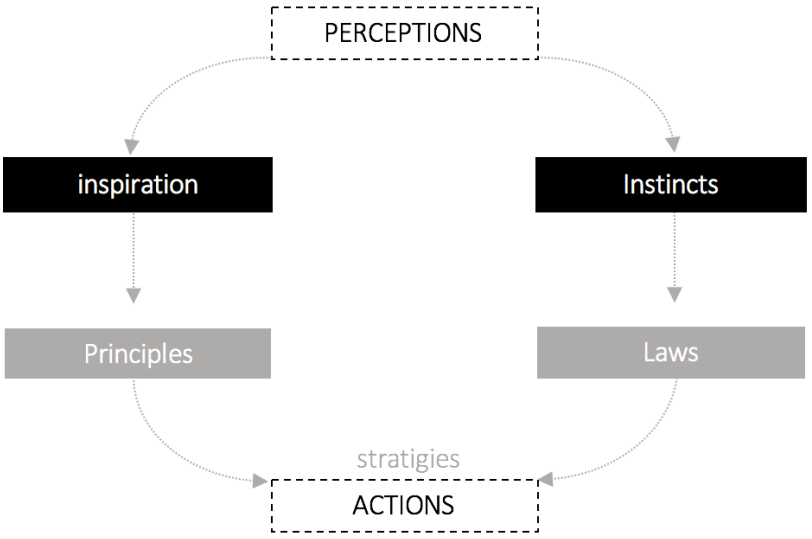
Human combines two functions for survival; instincts and inspiration, which have been major powers in civilization. The idea of sustainability did not exist during the time of hunting gathers, although this fact had later contradiction due to the clan is exposed to other civilizations. They had to follow their instincts and focus on the fundamental characteristics of survival. In this way, crude individuals applied the standards of life vigorously. These basics have not been changed much through time, but how to offer these basics has been changed along with other needs that grow parallel to human evolution. Substantially. Life's principles and biomimicry have developed into a substantially harder test of an urban setting.

Humankind has undoubtedly recognized movements with convoluted procedural and overflowing thought given to the souls of nature. Even when humans became socialized and moved into cities, they were again reliant on nature (for example, through agriculture), assumed to be a vital part of the civic establishment. If we evaluate evolutionary movements of human development, we may understand that the human instinct is inherited deep inside the human perception of life and human inspire, which both lead to human survival.

It is believed that human's instinct and strategic vision are the main sources of survival in which the ethical relationship with the natural environment is essential, and the laws of nature need to be followed but without preconception and prejudice. Although this approach of survival has less effect on the natural environment, it has a positive limit effect on human evolution. Also, it is believed that human inspiration and wisdom and intelligence develops its own set of principles that can be adjusted for innovative ways of survival (see Figure 15). Indeed, human instinct and human inspire are the consequence of each other for human survival along with the biomimetic civilization. However, the problem is to know 'how to channel these approaches with wisdom,' which is the key to biomimetic urban metamorphosis. For example, on the microclimatic scale, use of solar radiation in a linear space to create a draft in urban space on a calm day or to increase the velocity of the wind flow. In literature, there are enormous researches on solar chimney system and the urban canyon. The former is related to the application of a cooling and ventilation system for building using solar radiation to heat air that as a result move up which cause in pulling air through the building (Ong and Chow, 2003). The latter is related to study wind flow and sun exposure to create self-shading open spaces, reduce polluted air. These studies present the building biomimicry in a simplified geometrical form (Erell et al., 2011).

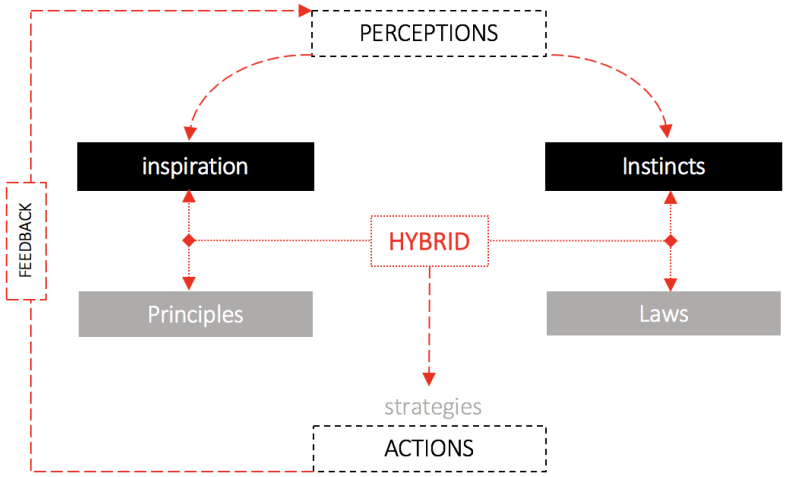
This approach has been altering for generations but on the expense of other organisms and environments. Even when applying the principles of biomimicry, we still are not looking at these approaches as a whole. Thus, there will be no sign of balance between human development and the natural habitat. Improvement and instincts are direct systems that alter the response to risks, which is coded into our qualities and cannot be immediately removed from the human mind. Indeed, in a couple of hundred years, human's fight-or-flight has been probably developed to improve actions, and of course, perceptions, to future demands (see Figure 16).

Figure 15. **Involving Human Instinct and Inspiration in Biomimetic Civilization**



urce: Authors

Figure 16. **The Framework of Human Development for Biomimetic Civilization**



Source: Authors

However, those who counter with 'old school' fight-or-flight instincts nowadays will not likely sustain. Indifference, those who control and direct the primeval natural responses (Instincts) and balance it with the innovation of nature's actions (inspiration) to develop hybrid solutions for human survival. Their genes will start the manifest a loop and a journey to a ground-breaking and more adaptive solution to today's threats and challenges. This approach is to continue gaining from nature to ensure our senses of survival that is mindful of our innovative thinking. And it is to generate looking at the inspiration that is taken from nature principles. Therefore, biomimicry becomes a trustable method for taking a human at nature. It will turn into a fight and a safeguard for both humankind and the natural environment.

8. Conclusion

The human stabilization and civilization, even though the global overconsumption of natural resources raised a red flag of the consequence ranging from global warming to resource shortages. The planners, scientists, and designers have prioritized sustainability with the primary objective of mitigating the effect of the human footprint on the natural and built environment, fewer humanity imbalances to the ecosystem and even itself. As a result, urban sustainability has become a central pillar that requires instigating a guide to humanity. Employing a biomimicry concept in the built environment has facilitated considerably to achieve sustainable architecture and urban designs. Accordingly, this research has gained a better understanding of biomimicry-based on theories of human evolution and civilization, particularly in the urban context, as a measurement for sustainability. It followed the paths of ecological research and urban philosophers, such as Freya Mathews and Moore, by re-versioned the human relationship with nature and the surrounding environment and observing human actions and development about life principles. In particular, the research found out that biomimicry is an approach that recently becomes the focus of many researchers of different disciplines seeking innovative solutions for human problems. Human as a part of the ecosystem confronts natural challenges to transform their surrounding environment for settlement. Human uses his instinct and intuition to adapt and evolve the natural environment to thrive in such a system and living sustainably.

Moreover, biomimicry emulates the natures' genius where nature is extended as a model, as a measure, or as a mentor. It is for human inspiration which converges law, principles, and strategies in the context of biomimicry-based on human evolution. Also, biomimicry has been merged with sustainable architecture design through specific features; included, form and function, geometry, metaphor, movement, material, pattern, proportion, sustainability, and technology.

Indeed, generating a sustainable urban form for future development requires an understanding of the application of adaptable elements found in nature for an innovative organizing concept of biomimicry that can be made to adapt human to the natural environment. That leads enhanced collaborations between urban development and architectural form to ensure livable and environmentally sustainable urban; such as, the Eco-urban development which is a product of the biomimicry approach that calls for the low-carbon city with next-generation infrastructure, cultural and climate-sensitive public spaces, and high-energy-performance buildings. Observing human actions and development in relation to life principles is followed by emulating nature's genius.

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