

SUSTAINABLE SPACES WITH PSYCHOLOGICAL CONNOTATION: HISTORICAL ARCHITECTURE AS REFERENCE BOOK FOR BIOMIMETIC MODELS WITH BIOPHILIC QUALITIES

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Abstract

Biomimicry is a growing area of interest in architecture due to the potentials it offers for innovative architectural solutions and for more sustainable, regenerative built environment. Yet, a growing body of research identified various deficiencies to the employment of this approach in architecture. Of particular note is that: first, some biomimetic technologies are not inherently more sustainable or Nature-friendly than conventional equivalents; second, they lack any spatial expression of Nature and are visually ill integrated into it. In a trial to redeem these deficiencies, this paper suggests a framework for more sustainable strategy that combines this approach with the relative approach of "Biophilia", with reference to examples from historical architecture. Using pioneering strategies and applications from different historical styles, the paper shows that the combination of these two approaches may lead to enhanced outcomes in terms of sustainability as well as human psychology and well-being. In doing so, architects may go beyond simply mimicking Nature to synthesizing architecture in tune with it and bringing in bio-inspired solutions that is more responsive to human needs and well being.

Keywords: *Biomimicry; Biomimetic architecture; Biophilia; Biophilic design; Sustainable design*

INTRODUCTION

Architects have long taken inspiration from Nature. They borrowed the shapes and proportions of natural forms ever since as they strived to achieve aesthetic perfection. In Ancient Egypt columns were modeled on palm trees and lotus plants, so were classical orders modeled after Acanthus leaves, spiral shapes and human proportions.

Nature is also still an inspiration source for contemporary architects, who keep trying to connect with it and learn from it; taking different pathways, bio-mimicry, bio-gnosis, bio-philial, and bio-morphology all have the same concern, but with different priorities, weightings, and principles.

Biomimicry, as developed by Janine Benyus in 1997, is one of these approaches that encourage the transfer of functions, concepts and strategies from natural organisms or systems to create a resilient built environment and improve its capacity for regenerative systems (El Ahmar, 2011). A lot of buildings today started to incorporate such features in a pure functional format that, unfortunately, lack any natural expression and with components that mostly look displeasing.

As present in Nature, design is not a collection of parts, but a synthesis of a whole. To respect and care for Nature, people have to obey, not only its functions, but also its patterns and forms. Not surprisingly, this way of thinking may lead to buildings that are more sustainable, where sustainability goes hand-in-hand with a respect for Nature. In explaining this concept, Salingaros says: "*Part of humans' perceptive system looks for information, whereas another part looks for meaning.... By imposing an artificial meaning on the built environment, contemporary*

architects contradict physical and natural processes, and thus create buildings and cities that are inhuman." (Salingaros and Masden, 2008)

Therein, on the other part of Nature-based design spectrum, *Biophilia* or biophilic design stands as a way of integrating Nature's own characteristics, principles, and patterns into the immediate environment of human beings. Applicable to all kinds of buildings, where people live, work, or learn, Biophilia is referred to by S. Kellert, as "*the missing link in sustainable design*", which "*aims not only to reduce the harm that stems from the built environment, but also to make the built environment more pleasing, enjoyable and healthy*". (Kellert et al., 2008)

But, contrary to biomimetic design; in biophilic design the building itself does not necessarily function cohesively with Nature, although its architectural expression is derived from it. An exclusive focus on biophilic interventions is not also an automatic guarantee for a higher level of well-being, as long as it is to remain apathetic for ecological issues.

The origins of the theory of *Biophilia* lies in the 1980s-writings of Edward O. Wilson, but the earlier roots of this theory is to be traced in the works of Christopher Alexander. In his 1977-book *A Pattern Language*, Christopher Alexander and his colleagues tried to answer the question of "quality" in space by gathering examples of buildings and places throughout the world that evoke a sense of order, robustness, and comfort; identifying and explicating 253 physical qualities, or patterns, that they considered to be the essential ways to solve architectural basic design challenges. They called this "a language" because they form a type of grammar, where the patterns were linked to one another, showing which ones worked well together and arranged hierarchically from large to small. As Grabow explains, this "pattern language phase" centered on the "a particular quality of space that one can actually see as well as feel" (Grabow 1983).

In his 2002-05-four volumes of *The Nature of Order*, Alexander paid further effort to incorporate life-evoking geometry and step-by-step construction process that sustains environment and place well being in the architectural space.

In *The Nature of Order*, Alexander amended the mostly static patterns of *A Pattern Language* by more dynamic sequences. He advocates "wholeness", as the "source of the coherence" (Alexander, 2002). Wholeness, he says, is integrally related to other lived qualities like beauty, eloquence, good health, well being and -most integrally-vitality and "life". He attributes life in any system, to the wholeness of this system, identifying 15 properties of centers that contribute to achieving wholeness and life in architectural composition; these are: levels of scale, strong centers, clear boundaries, alternating repetition, positive space, good shape, local symmetries, deep interlock and ambiguity, contrast, gradients, roughness, echoes, voids, simplicity, not separateness (Alexander, 2002).

And despite Alexander did not directly talk about "Biophilia" or "biophilic design" in any of these writings, N. Salingaros, one of the most prominent theorists of Biophilia, used Alexander's rules and patterns as basis for his approach to biophilic design (Salingaros, 2014). Some recent works, such as R. Bhat's "Understanding Complexity Through Pattern Languages", M. Mehaffy's "Counting Urban Carbon", and J. Kalb, "Life In Design" gave some further insights about how Alexander's Patterns anticipated biophilic design.

This paper's argument is that the improvement of architectural performance, where the whole is greater than the sum of the parts, is in need to reach a balance between the tangibles and the intangibles to produce a stronger wholesome. It suggests an architectural design approach that puts the two sides of the spectrum together by supplementing biomimetic applications with biophilic qualities. To achieve this, it aims at finding architectural strategies that combines these two approaches together in resilient applications that achieve the functional targets of Biomimicry, while keeping the livable expression and the psychological qualities as proposed in Biophilia; i.e. what K. Harries describes as: "*the sheltering power of place and the indefinite promise of space*" (Harries, 1997). By bringing together science, geometry, humanities, and architecture, the paper aims at finding a design approach that holds both functional design and spatial expression in tension, neither privileged over the other. This approach allows, on another hand, a compensation of the initial costs of biomimetic technologies by the economic

benefits of biophilic architecture, which had proved to be very effective in terms of improving human productivity, reducing sick days in office workers, and therewith raising profits (Browning et al., 2012).

In quest of specific strategies and settings for achieving the twofold target of this approach, the paper's hypothesis is that historical architecture is a valid platform and reference book for simple, low-cost and clever methods and solutions for the suggested approach.

A qualitative methodology, with purposefully selected examples and case studies that typify certain characteristics, was employed in this paper in order to seek observed and illustrative support for this hypothesis. Other than the mere formalistic imitation, the selected examples show that ancient architects had always drawn inspirations from natural creatures around them, for both beauty and functionality, in early appearances of both Biomimicry and Biophilia, hundreds of years before these terms were coined. They demonstrate how historical architects made use, not only of the functional and structural efficiencies, but also of the patterns and cycles of life, in: honeycomb, cacti, termites, trees ...etc, to create an architecture that sprout, grow, and harmonize with surrounding environments.

The paper is structured as follows: an introduction, three main parts, and a conclusion. In the introductory part, an overall view of the notions of the paper is introduced. In the second part, a theoretical background about the two approaches is overviewed, while in the third part, certain strategies and settings, as obtained from historical architecture, are explored to show both the biomimetic applications and the biophilic qualities in each of them. The results of this analysis are then discussed in part four, and the findings of the research are summarized in the conclusion.

BIOPHILIA AND BIOMIMICRY: BEYOND SUSTAINABILITY, DESIGN FOR WELL-BEING

Biologist Stephen Boyden (1971) defines the optimum healthy environment as the conditions, which tend to "*promote or permit the optimal physiological, mental, and social performance in its natural or 'evolutionary' environment.*" Boyden's discussion of well-being raises two main concerns: (1) there is a mismatch between humans' evolutionary environment and current industrialized settings, and (2) this mismatch is detrimental to human well-being because current environments do not support the full range of evolved survival and well-being needs.

He argues that environments need to fully satisfy both "survival needs" and "well-being needs" and defines the criteria that should be addressed to satisfy these needs in the built environment as the following:

- i- Think beyond survival to well-being
- ii- Build on "primitive preferences" and connections to Nature
- iii- Design for the senses as well as the body (Boyden, 1971)

Biophilic architecture is a contemporary philosophy of architecture that supports these tendencies and seeks solutions for sustainability in Nature, not by replicating the natural forms, but by understanding the rules governing those forms. The origins of this approach lies in the theory of *Biophilia*, which contends that human health and well-being has a biologically-based need to affiliate with Nature (Wilson, 1993). Advocators of Biophilia believe that it has more to offer than simply making buildings look good. They believe that it is "*the missing link in sustainable design*" (Kellert et al., 2008) and that "*while reducing the energy use of buildings is essential for a sustainable future, it is equally important to improve the conditions in which humans live, work, play, heal etc...*". (Kellert, 2005)

It has been also proven that people depend on the presence of these qualities in the environment not only for the sense of belonging and wellbeing, but equally for existence, as a primal source of the so-called "*neurological nourishment*" (Salingaros and Masden, 2008). The mechanism for this nourishment was discovered in neurological studies, from which it has been concluded that humans have an innate craving for certain type of information that is associated with the brain's pleasure centers, which also control the reduction of pain (Biederman and Vessel, 2006).

Biophilic design, as developed by E. O. Wilson, acknowledged the advantages of forms inspired by biological structures, but in a more profound way than simple mimicry. Wilson's original idea was extended and applied to architectural design by Stephen R. Kellert in his book, in association with J. Heerwagen and M. Mador, "Biophilic Design", which is considered to be the bible of this discipline. In this book, several models had been developed by different theorists, such as Salingaros, Kellert, Hildebrand and others, to suggest qualities and characteristics of spaces that may fulfill humans' needs to affiliate with Nature. The most prominent, and the simplest, of these models is the one suggested by Kellert himself, as developed from studies by the Psychologists Judith Heerwagen and Betty Hase. In this model he defined the following qualities as basis for the Biophilia-effect in the built environment (Kellert, 2008):

- Prospect: brightness, wide horizons, or ability to see into a distance
- Refuge: sense of enclosure and shelter with canopy effect or branch-like forms overhead
- Livability and movement: with real moving water or reflecting surfaces
- Biodiversity: vegetation elements or symbolic representation of them (trees, plants, or flowers)
- Sensory variability (or ephemeral qualities of space): changes and variability in environmental color, temperature, air movement, light, texture...etc.
- Fractals: self-similarity, natural patterns or cycles, hierarchal characteristics
- Sense of playfulness: elements that aim at delight, surprise, or dazzle
- Enticement: complexity and richness of details to be seen, or gradual openness of views.

Empirical findings on psychological advantages of natural environments, and environments mimicking their geometrical qualities, on human wellbeing were documented in several studies by Salingaros (2003), Salingaros and Masden (2008), Biederman and Vessel, (2006), Joye (2007), Kellert, (2005), Hagerhall, Purcell, and Taylor (2004), Purcell, Peron, and Berto, (2001), Taylor, (1998), Harris (2012), and Browning et al. (2012). (See (N. Ramzy, 2015) for full overview of these empirical findings). However, despite of these empirical evidences that show the positive effect of biophilic design on individuals, tracking and measuring efficacy of biophilic patterns and parameters or metrics is still challenging. This is due to the high number of variables, shifting baselines, the unpredictability of the built and natural environments, as well as the highly invasive nature of some data collection techniques (Ryan, et al., 2014).

However, this concept is sometimes misunderstood and commonly confused with *Biomimicry*, which promotes copying functional systems and processes of flora, fauna or entire ecosystems in Nature to find efficient solutions to design problems or to provide cooling, generate energy, desalinate water...etc.

The term *biomimetics* was coined by Otto Schmitt in 1982 (Vincent et al., 2006), but nobody tried to actually apply it until it was re-discovered by Janine Benyus in her 1997-book, *Biomimicry: Innovation Inspired by Nature*, where she advocates looking to Nature as a "Model, Measure, and Mentor" and emphasizes sustainability as the main objective of Biomimicry (Benyus, 1997).

This concept is also often misrepresented as creating a building that looks like something natural, i.e. a building shaped like a pinecone, which is another different approach in design called *Biomorphology*. Mimicking natural systems or processes would sometime have an effect on form as well, but that is not the main point in Biomimicry (Biomimicry 3.8, 2012).

The most obvious and common type of Biomimicry is the emulation of Nature's **function**. Emulating Nature on the process level is another form of Biomimicry, which involves learning from the way Nature produces things or evolves. The third variety of Biomimicry looks at Nature's systems; this area examines how Nature deals with things like waste and regeneration inside closed-loop lifecycles. There are, hence, three levels of mimicry; organism, behavior and ecosystem. Buildings on the organism level mimic a specific organism. Working on this level alone without mimicking how the organism participates in a larger context may not be sufficient to produce a building that is more sustainable than a non-biomimetic building (El Ahmar, 2011). On the behavior level, buildings mimic how an organism behaves or relates to its larger context. On

the level of the ecosystem, a building mimics the natural process and cycle of the greater environment.

Within each of these levels, further five possible dimensions to the mimicry exist: form, material, construction, process, function (fig. 1). Table 1 demonstrates the different levels of Biomimicry with the five dimensions within each level (El Ahmar, 2011). These levels are not mutually exclusive and some overlap between them is always expected.

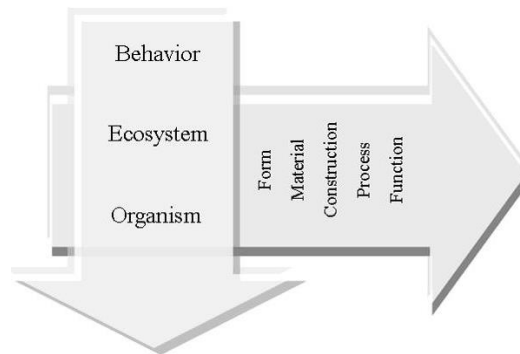


Figure 1. Levels and dimensions of Biomimicry (Source: Author)

Table 1: The applications of Biomimicry (after El Ahmar, 2011)

Behavior level (Mimicry of how an organism behaves or relates to its larger context)

- Form* looks like it was made by an organism.
- Material* made from similar materials that an organism builds with.
- Construction* made in the same way that an organism would build in.
- Process* works in the same way as an organism mound would.
- Function* functions in the same way that it would if made by organism.

Ecosystem level (Mimicry of an ecosystem)

- Form* looks like an ecosystem (an organism would live in).
- Material* made from the same kind of materials that (an organism) ecosystem is made of.
- Construction* assembled in the same way as an (organism) ecosystem.
- Process* works in the same way as an (organism) ecosystem.
- Function* able to function in the same way that an (organism) ecosystem would.

Organism level (Mimicry of a specific organism)

- Form* looks like an organism.
- Material* made from the same material as an organism; exoskeleton / skin for example.
- Construction* made in the same way as an organism or goes through similar growth cycles.
- Process* works in the same way as an individual organism.
- Function* functions like an organism in a larger context.

In these classifications, the shapes and patterns of Nature do not come anywhere and are not a priority at all. So the user for this kind of architecture will probably not have the chance to actually experience any features, qualities, or relations with natural environment as suggested in the biophilic design approach.

BIOMIMETIC APPLICATIONS WITH BIOPHILIC QUALITIES IN HISTORICAL ARCHITECTURE

While the terminology of these two disciplines is relatively new, the actual practice of both Biomimicry and Biophilia has been going on since very old times. Mankind has learned many lessons by observing other creatures and adapting their behaviors for human's own needs, while artists and philosophers have always looked to natural organisms as offering perfect models of harmonious balance and proportion, as synonymous with the classical model of beauty. The

qualities of wholeness, integrity, and unity in structure are central concepts in the Aristotelian view both of living beings and of the best works of art.

In the same direction, architects and designers have always looked to biology for inspiration since the beginnings of the science. They have sought not just to imitate the forms of plants and animals for their beauty and gracefulness, but to find methods in design analogous to the processes of growth, evolution, and structural stability in Nature.

In the following the 'biomimetic' dimensions in some models from historical architecture are discussed and compared with some prominent contemporary biomimetic models, showing that the former are not only equally efficient in terms of biomimetic functionality, but also have the additional privilege of Biophilia-effect.

On behavior level

On the behavior level, the building mimics how an organism interacts with its environment via a structure that can fit in without resistance in its surrounding environment, or a specific type of behavior that the organism does or replicates on a regular basis to survive or adapt with its context.

Mashrabiya screens

The Qatar Cacti Building is one of the prominent applications of biomimetic approach in architecture, where the sun shades on the windows open and close in response to heat, just as the cactus undergoes transpiration at night rather than during the day to retain water.

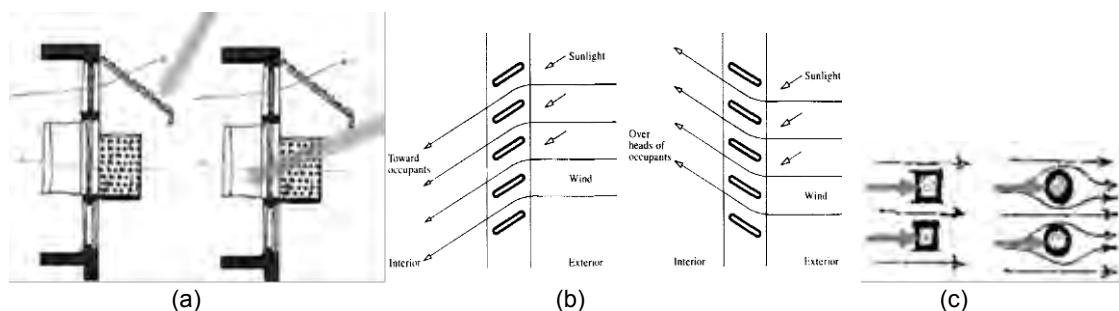


Figure 2. (a) Operable windows permit the low-angled winter sun to penetrate, while giving protection from the high-angled summer sun. (b) Difficulty of adjusting straight blinds (after Fathy, 1986). (c) The curvy surfaces of latticework obstacle sunrays, while permitting airflow

When the suitable sensors-technology is to be added to it, the 'smart' design of *Mashrabiya* screens (window-screens that were used in traditional Middle Eastern architecture), would provide more efficient model, with the following advantages: The operable windows in *Mashrabiya* screens permits the low-angled winter sun to bring daylight and warmth to the interior spaces during the cooler months of winter and gives shade and protection from the high-angled hot summer sun, while allowing the cool air from the street to flow through it (fig. 2-a). Latticework, with smaller opening in the lower part and larger openings in the higher parts, causes the draft to be fast above the head and slow in lower parts, providing a significant amount of air moving in the room without direct uncomfortable draught on the users' level (fig. 3). Furthermore, the curvy surfaces of this latticework help to overcome the difficulty of adjusting straight blinds, where the position for the optimal direction of air movement is undesirable with regard to sunshine and vice versa (fig. 2-b). These curvy surfaces also have the advantage of being able to obstacle the sunrays, while allowing the largest amount of air to enter the space with the least obstruction (fig. 2-c).

On another hand, and unlike the system in the Qatar Cacti Building, *Mashrabiya* screens would add the following biophilic qualities to the building: The patterns of the latticework would

add the fractal quality to the space, while the projection of the Mashrabiya would add the quality of refuge with its alcove-like form (fig. 3) providing also a place for water features (it used to be a place for cooling water-jars). With air coming from three sides, it has the ability to capture natural ventilation, even if the draught outside was parallel to the house façade, providing air movement and sensory variability as well as prospect through a wider horizon with three-sides-view. A row of projected Mashrabiya screens would also provide shelter and refuge for those in the streets.

Further advantage of Mashrabiya screens is sustainability, as it gives the producer the capability to make use of the smallest pieces of wood, which helps reducing the loss in rough materials to the lowest level and enables using low-quality local woods in its fabrication.

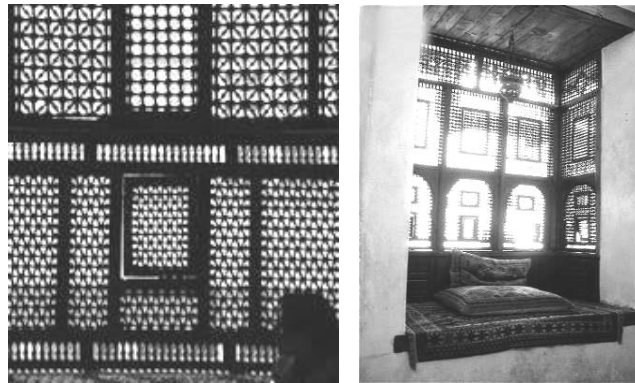


Figure 3. Mashrabiya screens from the House Al-Sohaimy, Cairo: (Left) Fractal patterns of Latticework with smaller opening in the lower part and larger openings in the higher parts. (Right) alcove-like arrangement (Source: Author)

Gothic towers

The biomimetic approach for the proposal of Mark Sarkisian for China World Trade Center began by investigating the cross-section and the growth patterns of the bamboo. It was found that its most important attributes are: a high strength-to-weight ratio, elasticity, long-term endurance, and a highly efficient form that resists loads and maximizes stability. These qualities are achieved in bamboo by organic bracing that is capable of fragmenting forces by sharing loads more uniformly within the structure and transferring them into the roots (Sarkisian, 2011).

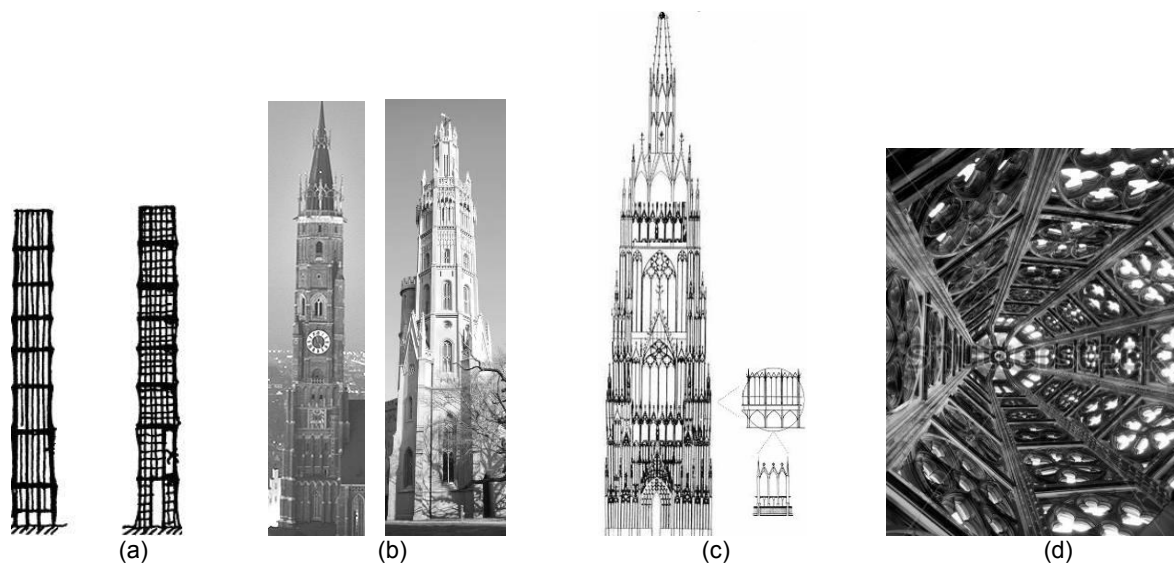


Figure 4. Bamboo concept for tall building: (a) The inter-nodes spacing and the overall frame of bracing, (b) Gothic towers, (c) fractal patterns in Gothic towers, and (d) tracery bracing at the tower of Cologne cathedral (Source: Author)

In the bamboo, the nodes or diaphragms, as seen in rings over the height of the stack, are positioned to prevent buckling of the thin bamboo-walls. They are also not evenly spaced; they are close at the base, further apart through the mid-height, then close again near the top (fig. 4-a). These diaphragm locations are not random, but rather mathematically predictable; it was found that the spacing between them depends on a ratio that is close to the Golden Ratio (Sarkisian, 2011). But, again, by looking at the design models of this proposal, any hint to its Nature-based inspiration cannot be realized, and it lacks therefore any biophilic qualities.

By exploring the design of Gothic towers, it is easy to realize that they have the same rules of the bamboo-growth (which is probably the growth patterns in plants in general) and the features of its structure in terms of height, bracing, articulation, and spacing (fig. 4-b), in addition to the qualities of Biophilia-effect. The most obvious one of these qualities is the fractal patterns (fig 4-c); the combination of the growth pattern as seen in the bamboo- structure and the fractal patterns is very logical because fractal patterns are also kind of growth-patterns governed by hierarchy of scales.

Gothic tracery, which provides an outer structural frame of these towers, replicates the strong mesh of the bamboo's outer organic bracing. Furthermore, with the comparatively large cross-section of these tracery, it acts as an integrated self-shading device controlling excessive heat gain and glare in the summer months (when sun angles are high), while the spacing between them permits low winter sun angles to bring daylight and warmth during the cooler months (fig. 4-d). And while acting as shading-device to add the quality of shelter and refuge, these tracteries are also shedding the qualities of biodiversity via their floral/foilage shapes and the quality of enticement through their complexity and richness of details.

On ecosystem level

Building on the ecosystem level involves mimicking how the components of an organism work together as a multiple-elements-system rather than a solitary element.

Traditional Arab houses

A prime example in biomimetic architecture is the Eastgate Centre in Harare, Zimbabwe, which adapts the termites' mounds ecosystem as an analogy for climate-control (Elmahdi, 2008) (fig. 5).

A termite mound was studied by architect Mick Pearce to solve the complex problem of heating and cooling a large structure. He found that termites' mounds are self-regulating systems, where hot air rises and flows out through vents at the top of the building and cooler air is drawn in at ground level (Manlutac, 2007). To stimulate induced flow, the Eastgate Centre makes use of fans to draw cool air into the atrium. Connected to these fans is a centralized duct distributing air to each floor (Benusa and Friend, 2008). The heat generated from thermal mass, occupants and machinery drive the thermosiphon flow (Chimney Effect) upward toward the ducts and chimneys (Turner and Soar, 2008).

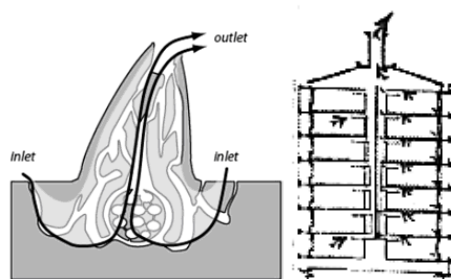


Figure 5. Termite mound temperature regulation and section through Eastgate Centre showing how temperature is regulated (based on: Manlutac, 2007 and El Ahmar, 2011)

Similar ideas, which depend on passive ventilation, were recognized as early as 450 BC by Socrates (US Department of Energy, 2014). The Pantheon design is one of the earliest buildings that employed this strategy.

In this building, air interacts with the oculus through both convection (*Stack, or Chimney Effect*) and *Venturi Effect*. The oculus, in addition to being the 'eye' of the building that brings natural daylight into it, creates a vacuum as air rises by natural convection and the portico entrance is the inlet for cool air at the bottom of the building creating an upward-moving air current (fig 6-a). Air enters the space on the ground level and as it warms up it rises and escapes the structure from the opening (Stack Effect) just like in the termite mound, while the domed shape forces air passing over the oculus to increase in velocity, resulting in a decrease in pressure (Venturi Effect). Near the portico, the air is slower, which increases the air pressure. The difference in air pressure creates airflow from high to low pressure -- from the portico to the oculus.

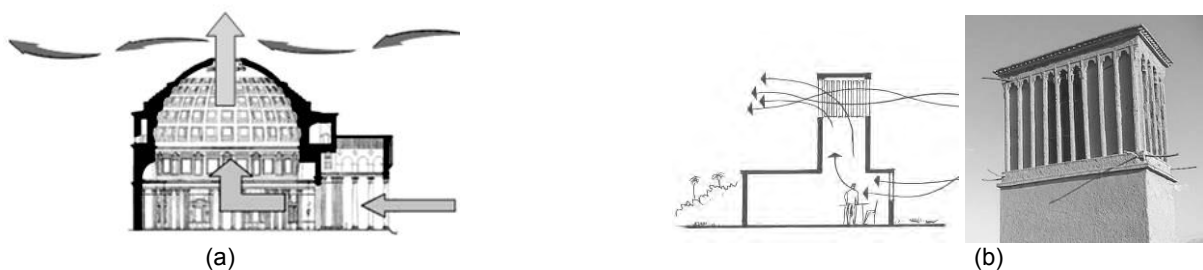
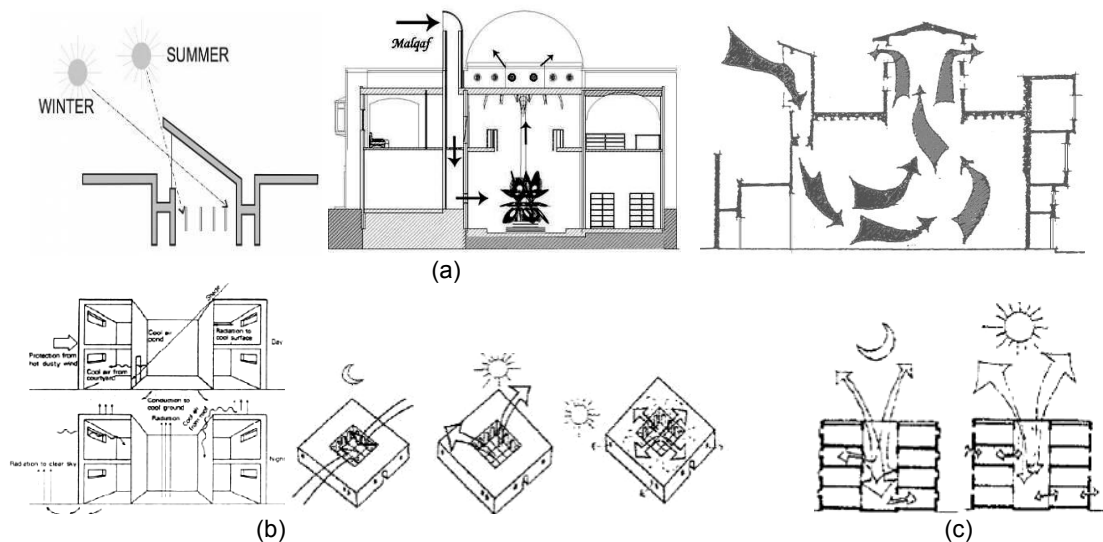


Figure 6. (a) The oculus opening and domed shape allow for both Chimney Effect and Venturi Effect. (b) The Badgirs in the teahouses in Kerman, Iran (Source: Author)

A later application of passive ventilation from historical architecture is the *Badgirs* (Farsi) or *Barajeels* or *Malkaf* (Arabic), which are wind-catchers that catch the wind from different directions with two to eight openings (fig 6-b); the air is then cooled as it travels down the tower, and cools the rooms below. When there is no wind, the hot air in the tower rises up, which draws cooler air from any other openings into the house (Chimney Effect).



(a) Climatic regulator system in medieval Islamic houses, (b) thermal mass behavior and the climatic cycles in courtyard-buildings (c) The atrium in multi-story buildings as ventilation shaft.

Figure 7. Natural ventilation in medieval Islamic houses through a system of Malkaf, dome/lantern and courtyard (Source: Author)

In the medieval Islamic houses these two elements (the dome and the wind-catcher), were employed, together with other elements (e.g. the courtyard), in a unified eco-system that kept the temperature in these houses moderate. Wind catchers in these houses are oriented to catch fresh breeze from the north and lead it into the house and court (fig. 7-a). On the other side, they lead away the warm air, maintain steady ventilation and thus by low air pressure trace fresh cold air into the buildings. Here, the courtyard functioned as a temperature regulator. When there is no wind, hot air in the tower rises and draws cooler air from the courtyard into the rooms (Chimney Effect). The dome or the lantern, over the central part of the house or the court, increase the velocity and result in a difference in pressure that creates airflow from high to low pressure (Venturi Effect), where the opening(s) in them acts as an outlet for hot air. A water fountain is often added at the middle of the court for more refreshing effect. Water tanks or food containers were also put under the wind-catchers as a method to cool drinking water and store food.

A further element in this passive system is the *thermal mass*, which refers to materials that have the ability to store thermal energy for extended periods of time such as stone, mud, brick, water and ceramic tile. The walls of traditional Arab houses were mainly made of brick and were very thick. During the day, the walls absorb daytime heat, reducing the amount of heat that reaches the interior space, and resulting in a cooler interior air temperature. The thermal energy absorbed by the thick walls is then negated at night through the airflow of the passive ventilation system (fig. 7-b) (Hein, NA). Marble or glazed floors were also part of this passive design system together with the above mentioned effect of Mashrabiya-screens (3.1.a); they all contribute to the overall effect. The application of this system on a multi-story building is illustrated in (fig. 7-c)

In addition to these biomimetic-climatic potentials, the passive system in Arab houses has also several biophilic qualities that are not found in the system of the Eastgate Centre. The form of the dome is believed to have been inspired by the shape of the egg (Pawlyn, 2011), and, in this sense, it provides a sense of shelter to the inhabitants. Its canopy-like structure is factor of the biophilic quality of refuge. The central dome is also an element of the *Theory of Centers*, which is one of Nikos Salingaros's strategies of complicity and order (Salingaros, 2010). The dynamic light obtained through the openings in the base of the dome or lantern travels from one place to another in the space, which is, together with the air movement resulted in by the dome-*Malkaf*-arrangement, features of the sensory variability (Ramzy, 2013). The courtyard is one of the prominent strategies for the biophilic quality of prospect and with its vegetation elements it also provides biodiversity, where water elements and glazed surfaces provide livability and movement. Hence, this system actually provides an almost full biophilic system that fulfills most of the biophilic qualities included in Kellert – Heerwagen model of Biophilia.

Gothic arcuated system

In his 2009-book *Bio-Structural Analogues in Architecture*, Joseph Lim emphasize that every form in Nature is essentially the product of the diagram of forces acting, or have acted, on it. Based on this diagram, he put his so-called *biotectonic-model* of structure (Next Nature, 2013 & Lim, 2009).

Other studies in biomimetic structures by Henry Coe State Park, suggested the turtle's bone structure as a biological model that offers great possibilities of structural hybrids. The analogy drawn from the turtle's bone structure is that it provides protection strategy that differs from that of running animals with stronger support of the heavy body and smooth gradient and transitions between the different elements of the structure, offering possibilities for differentiated spatial qualities (Regenerative Leadership Institute, 2012).

Searching for a structural system that combines the qualities of these both systems (Park's turtle and Lim's biotectonic-system), it had been found that Gothic structural system is a perfect model, where "each component is a product of the force's diagram acting on it", and while giving "strong support to the heavy body", these elements are "composed in perfectly smooth skeleton" that competes with that of the turtle's bone structure (fig. 8).

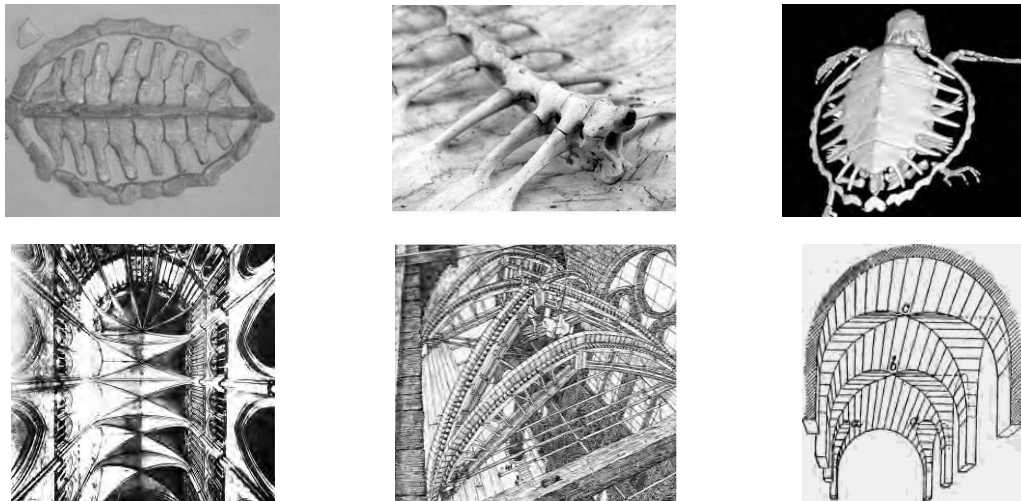


Figure 8. The analogy between Gothic vaults and turtle's bone structure (Source: Author)

Before Gothic era, architecture was defined with the formation of three elements: floor, wall and roof (Thiis-Evensen, 1990). These terms have been exchanged by gothic builders with an innovative 'biomimetic' trend of skin-and-skeleton structure. Gothic techniques produced truly skeletal structures that were composed of arches, ribs, piers and flying-buttresses, where forces are adequately balanced and neatly channeled towards the buttresses and foundation with minimum material consumption.

Gothic pointed arch carried combined strength and elegance almost as far as it could be carried, but the concept of unlimitedly growing architecture is to be attributed to the different variations of Gothic ribbed vault, which -very much like the turtle shell, and unlike all previous types of vaults- does not systematically crack (Lourenço, 2009).

The skin/skeleton analogy here is drawn from two natural principles: the first of these was the *concentration of strains* upon isolated points of support, which was made possible by the substitution of groined/ribbed for barrel vaults. This led to a corresponding concentration of the masses at these points; so that the building was as if "upon legs" (Thiis-Evensen, 1990) (fig 9).

The second principle was that of *balanced thrusts*. In Gothic architecture thrusts were as far as possible resisted by counter-thrusts from the flying-buttresses that were further weighted by pinnacles (Thiis-Evensen, 1990). So, the wall and the roof became a mere filling-in (skin) between piers, ribs, and the buttresses (bones).

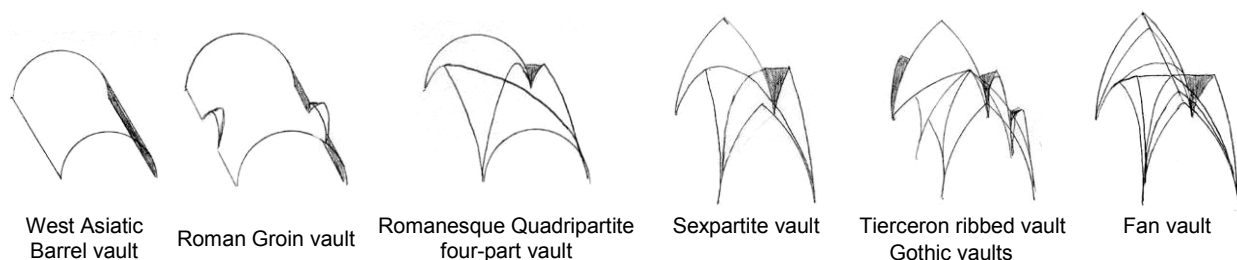


Figure 9. The evolution of Gothic vault (Source: Author)

Furnished with this system, Gothic architects actually competed with Nature in terms of structures; unlimited heights and spans were available, while splendid materials were not anymore necessary. As birds and bees build their nests, medieval architects did not have to quarry marbles or stone and did not have to transport expensive materials from far countries or colonies; they worked rather with poor quality bricks, mortar, and all kinds of materials available

in their local environment. Shabby and scrappy materials were able to attain amazing results and the smallest piece of materials was able to function somewhere.

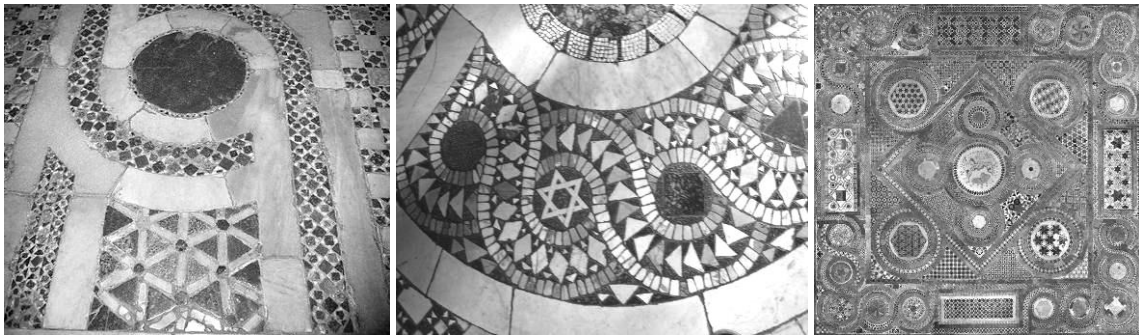
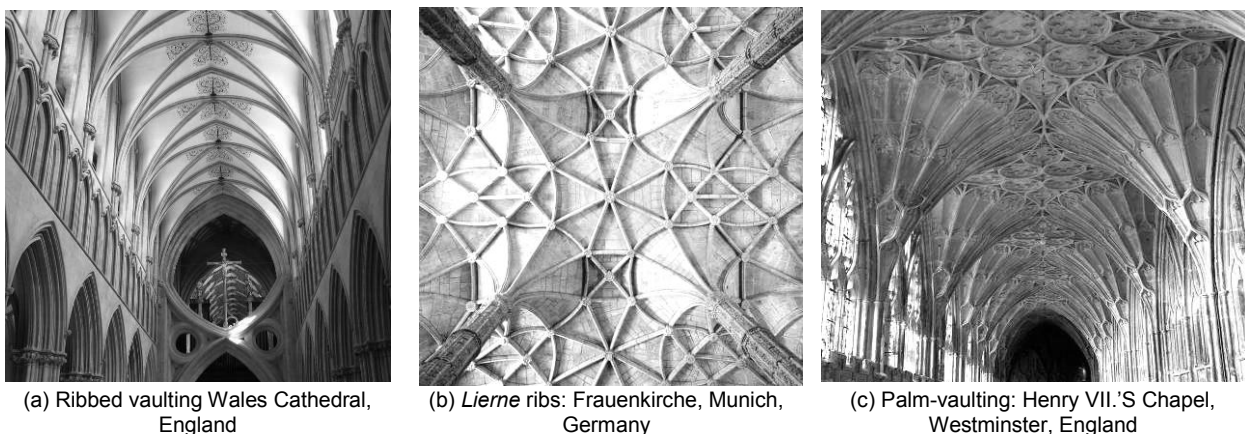


Figure 10. Cosmati floors: Santa Maria in Aracoeli- Vatican Museum - Westminster Abbey (Source: Author)

Sustainable use of building materials did not concern only hidden structural elements, but also visible ornamentations. For example the Cosmati style of decoration (fig. 10), which was used in the most prestigious churches (e.g. the Westminster Abbey) was a technique, where the smallest piece of materials could be used. Without strict patterning, it allows easier matching of tiles, minimum discards and flexible choices, all ultimately resulting in waste reduction. Stained glass is another application in the same direction, where small pieces of glass were used to cover large areas of openings.

In addition to this Nature-based biomimetic structure, Gothic style has the ability to offer another almost full biophilic system that fulfills the following qualities: prospect and refuge via high ceiling in the main area flanked by lower aisles on the sides with canopy and tree-like forms overhead; fractal patterns in the self-similar patterns all over the building (Goldberger, 1996); biodiversity through ornamentation and symbolic representation of all kinds of vegetation and elements of Nature, livability and movement in reflecting surfaces, light reflections and stained glass; and enticement in the complexity and richness of ornaments and details (fig 11).



(a) Ribbed vaulting Wales Cathedral, England

(b) *Lierne* ribs: Frauenkirche, Munich, Germany

(c) Palm-vaulting: Henry VII.'S Chapel, Westminster, England

Figure 11. Biophilic qualities of Gothic vault: high ceiling flanked by lower aisles; fractal trees; canopy like; complexity and richness of ornaments and details (Source: Author)

On organism level

This level refers to mimicking a specified organism. On this level, the building or part of it, mimic a specific organism or part of a whole organism.

Velarium

Spider's web is a tarpaulin-like load-bearing system that lets the spider spread its web wide, while still making no concessions as to its strength. This marvelous technique has been mimicked in many contemporary structures; Munich Olympic Stadium, the Sydney National Athletic Stadium, and Denver Airport in Colorado are allegedly some of them.

The *Velarium*, which is a retractable, canvas-like paneled system of ropes and masts that shielded the spectators at the Colosseum in ancient Rome from sun and rain, is a much older and cheaper application of this technique. In addition to providing shade for the spectators, its sloping design was meant to create a ventilation draft. It consisted of two hundred and forty mast corbels that were positioned around the top of the attic to support a net-structure, carrying a retractable awning (fig. 12) that sloped down towards a hole in the center to catch the wind and provide a breeze for the audience (fig. 13). When it was not in use, the shades were pleated back on themselves, much like modern Roman shades (Bay of Screens & Shades, 2014).



Figure 12. A Model of the Velarium in the exhibit of Roman artifacts in the Colosseum and a line engraving of it by Carlo Fontana (1725).

In addition to the functional biomimetic privilege of this web-like structure that allowed the ancient Romans to cover such huge area with only a system of ropes, providing them with shelter and refuge, the Velarium had biophilic qualities that are not found in most of the modern structures that employ web-like structure, where the air movement resulted in by its sloping design provides sensory variability, while the retractable structure provides a sense of playfulness. A recent suggestion by Mathew Tucker to improve the acoustic problem in the Albert Hall was to linen the dome with a suspended Velarium (Orpheus Complex, 2010), which is a further possible utility of such light structure.

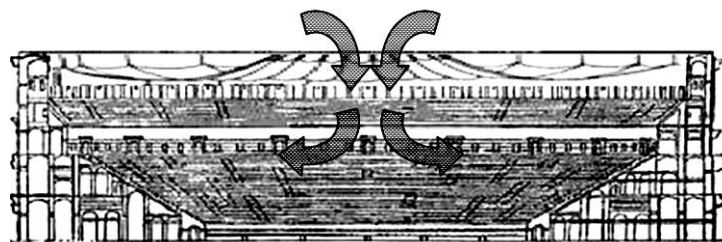


Figure 13. The Velarium as wind catcher (Source: Author)

Stalactite-works and Honeycombs

In biology, modularity refers to the construction of a cellular organism by joining together standardized units to form larger compositions. One example of this modularity in Nature is the cells in a honeycomb (El Ahmar, 2011).

The construction of honeycombs offers a great many important advantages, including stability. As the bees in the hive give directions to one another, they set up vibrations that, in a structure of such small dimensions, can be equated to an earthquake. Nature magazine stated

that architects could use this superior structure in designing earthquake-proof buildings (Yahya, 2006).

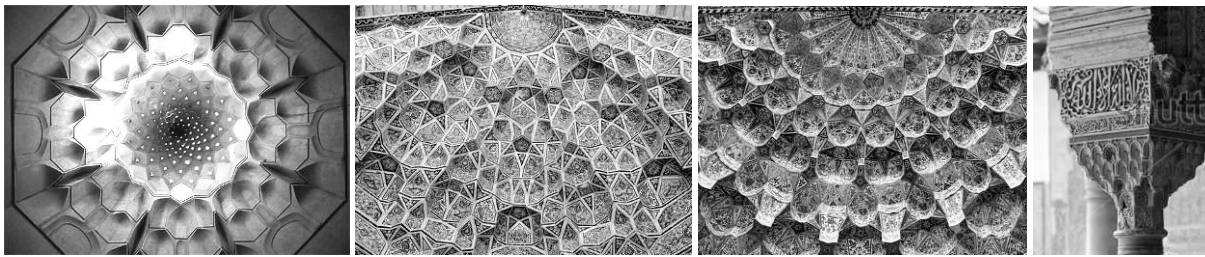


Figure 14. Different stalactites works in Alhambra palace in Spain (Source: Author)

-like Islamic architectural ornamentation (fig. 14) appeared in the early 12th century to overlay the transitional zone between domes and the squinches or brackets under them. Later on, it became also a usual decoration for door heads, niches, and the bracketing under cornices and minaret galleries.

In addition to these functional aspects, the fractal patterns of the stalactites and the enticement in their complexity and richness of details evoke the biophilic character on them. It was also found that they can function as acoustic baffles to decrease echo sound reflection (Harmony of the Spheres, NA).

Eiffel Tower and structure of bones

In the early 1850s, the anatomist Hermann von Meyer saw that the inside of the thigh bone, which is capable of withstanding a weight of one ton when in a vertical position, consists not of one single piece, but contains an orderly latticework of tiny ridges of bone known as *trabeculae*.

In 1866, the Swiss engineer Karl Cullman visited von Meyer's laboratory, where the latter showed him a piece of bone he had been studying. Cullman realized that the bone's structure was designed to reduce the effects of weight load and pressure. The trabeculae were effectively a series of studs and braces arranged along the lines of force generated when standing. As a mathematician and engineer, Cullman translated these findings into applicable model that was later developed by Gustave Eiffel in the design of the Eiffel Tower, where a lattice of studs and braces are used to support the curved structure of the tower (Yahya, 2006) (fig 15). So, it could be said that this tower is in fact the earliest actual application of Biomimicry in architecture.

Thanks to this design, the tower also required fewer materials (sustainability), and made for a building framework that is both strong and flexible. The fractal geometry of the design together with the enticement evoked by the complexity and richness of its details granted it also a biophilic dimension.

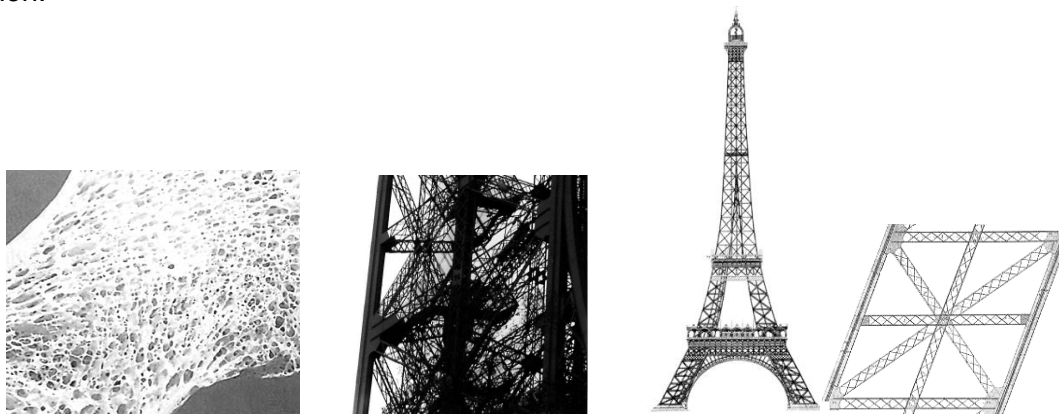


Figure 15. Eiffel Tower: (left to right) thigh bone structure, construction patterns of the tower, and the fractal geometry of the tower (Source: Author)

RESULTS

The results of the discussion in the previous chapter are summarized in table 2, which shows that, although the terminologies were still unknown, biophilic qualities were strongly present, side by side, with biomimetic functional/structural applications in all the above mentioned examples, where the three levels of Biomimicry, with variations of the five dimensions included in them, were all applied and the whole spectrum of biophilic qualities was covered.

Biophilic qualities:

The most prominent biophilic quality that was present in almost all of these examples, except for the *Velarium*, is the fractal patterns. Prospect, refuge and sensory variability were also strongly present. With six out of eight qualities for each of them, the Biophilia-effect as defined in Kellert-Heerwagen model has very strong presence in the two examples of "medieval-ecosystems": the medieval Islamic house and the Gothic arcuated system.

It is worthy here to mention that these examples also cover the three categories of Human-Nature relationships: Nature in the space, Natural analogues, and Nature of the space (Ryan et al., 2014). The first refers to the presence of elements from Nature, such as plant life, water bodies, etc. within the built environment, which is found in the model of Traditional Arab House; the second refers to objects, materials, colors, shapes, patterns and algorithms that evoke Nature, such as seen in the Stalactite-works; and the third refers to spatial configurations and associated psychological and physiological responses associated to natural environment such as prospect and refuge, such as seen in the Gothic arcuated System.

Biomimetic/Sustainable Applications:

Compared with the contemporary applications in biomimetic projects, models and applications from historical architecture show that they are not only equally efficient in terms of biomimetic functionality and more considerate to the Biophilia-effect, but -furthermore- they are **more sustainable**. In Mashrabiya screens, the smallest pieces of wood could be used, reducing the loss in raw materials to the lowest level, while the arcuated system in Gothic style brought the buildings on legs with a sustainable construction approach that makes use of the smallest piece of building 'local' materials, even those which are shabby or scrappy, for both structural and ornamental elements, with no need for expensive non-regenerative or exported materials. The fractal design of Eiffel tower also enabled economic use of materials.

The discussion in 3.2.a shows also that the contemporary biomimetic climatic treatment in the Eastgate Centre is almost typical to that of the medieval Islamic houses in terms of the functional technique. Yet, the latter had been proven to be more sustainable, energy-saving system, where the wind catchers are factors of Chimney Effect (the same as in Eastgate Centre), while domes are factors of Venturi Effect, which made it possible to naturally draw cool air into the space and dispense with fans, as those in the system of Eastgate Centre, by the more biophilic, energy-saving element of domes. The thermal mass in these houses was an additional aid for temperature regulation. This example shows that, better than starting from zero by studying the biological creatures themselves for biomimetic applications, architects have their own reference book of historical styles, in which they can find ready-for-use biomimetic treatments and bio-inspired functional models.

The discussion in 3.1.a shows also that the design of the Mashrabiya screens is a '**smart**' design that is more sensitive to human comfort than the contemporary system in Qatar Cacti Building. The Latticework in these screens, with smaller opening in the lower part and larger openings in the higher parts, provides a significant amount of air moving in the room without direct uncomfortable draught around the users. Further 'smart' aspect of this design is the curvy surfaces of the latticework that help to overcome the difficulty of adjusting straight blinds, and allow them a selective obstruction for sunrays that does not include the obstruction of air movement. With aid of modern technologies of sensors, like those used in the Arab World Institute in Paris, this system may offer better potentials for human comfort.

Climate-control was found to be a dominant feature in several treatments in the previous chapter, even those that were not meant as climatic treatment. The (mainly) structural model in the Gothic towers, for example, was found to be also offering an integrated self-shading device to deal with excessive heat gain and glare in the summer months, while permitting low winter sun angles to bring daylight and warmth during the cooler months. Novel technologies and materials are able to provide buildings with great structural potentials using the format of these towers for tall buildings.

Cost efficiency is another privilege of historical models over contemporary ones. The spider-web analogy of the *Velarium* was found to be the origin of the system in contemporary stadiums but with more benefits and much lower costs. The lightness and the low cost of such a structure make it also a possible solution to linen other structure for the sake of acoustical enhancement.

Acoustical advantages are also offered by two other treatments: the high angled ceiling in the Gothic arcuated system and the Islamic Stalactites. The main concern in vaulted ceilings is avoiding the focusing that happens directly under the peak. This was unintentionally handled in Gothic vaults, where the peak is continuously interrupted through differences in heights and highly ornamental treatments (as it is also in the case of *Stalactites*) and the ribs work as buffers that decrease echo sound reflection and do not allow such focus to happen.¹

¹ 'Reverberation' sometimes occurs during music performances in these cathedrals due to the great heights and not to the form of the vault. This reverberation is sometimes favorable for musicians because without such 'ring' music becomes 'dry'.

Table 2: Biomimetic application with biophilic quality in historical architecture:

Historical element	Biomimetic application	Function	Biophilic quality	Biophilic characteristic
Mashrabiya Screens (Qatar Cacti Building)**	Behavioral: Cacti Process- Construction	Climatic treatment <i>Economy of materials***</i>	Refuge Fractal Livability & movement Sensory variability Prospect	Enclosure and shelter Self-similarity and hierarchy Water features (jars) Air movement Wide horizons
Gothic Towers (China World Trade Center)**	Behavioral: Bamboo Construction- Material	Structural system <i>Climatic treatment***</i>	Fractal Refuge Biodiversity Enticement	Self-similarity and hierarchy Shading tracery Floral/foilage patterns Complexity/richness of details
Traditional Arab House (Eastgate Centre)**	Ecosystem: Termite Mound Process- Function	Climatic treatment	Refuge Enticement (dome) Livability & movement Prospect Biodiversity Sensory variability	Canopy-like structure Complexity (theory of centers) Water features (fountains) Court Vegetation elements in courts Dynamic light Air movement
Gothic arcuated System (Biotectonic-model)**	Ecosystem: Turtle skeleton Bird's nest Function – Construction	Structural system <i>Economy of materials***</i> <i>Acoustical treatment***</i>	Prospect Refuge Fractal Biodiversity Livability & movement Enticement	High ceiling in the main area Lower aisles an tree-like forms Self-similar patterns Ornamentation Reflecting surfaces Complexity/richness of details
Velarium (Munich Olympic Stadium)**	Organism: Spider web Construction- Function	Roofing system <i>Climatic treatment***</i>	Refuge Sensory variability Sense of playfulness	Shelter Air movement Retractable structure
Stalactite-works (Earthquake-proof buildings)**	Organism: Honeycombs Form – Construction	Structural element <i>Acoustical treatment***</i>	Fractal Enticement	Repetition and self-similarity Richness of details
Eiffel Tower	Organism: thigh bone Form – Construction	Structural element <i>Economy of materials***</i>	Fractal Enticement	Repetition and self-similarity Richness of details

** Similar contemporary projects

*** Additional utility



CONCLUSION

The perceived failure of Modern Architecture is usually attributed to its preoccupation with functional design approach, where ornamentation was done away with and the buildings were cloaked in a stark minimal appearance, which failed to meet the human need for comfort both for body and for eye, as it did not account for humans' desire for beauty and details. The rejection to this style was finally justified through scientific research, which explained why people are so engaged to certain features such as ornaments, colors, and details. Long misinterpreted as a superfluous element in design, these elements were recently found to be a distillation of geometrical connective rules that directly trigger positive neurophysiology (Salingaros and Masden, 2008).

By referring or relating bio-inspired or ecological design theories, only to the functional models in Nature, contemporary architects are making the same mistake of modernist architects by neglecting the core subject in Nature, which is the aesthetics and the visual pleasure in its patterns and arrangements. Looking at the forms and patterns of Nature as if they have no function is the version of 'minimalism' in natural-based or bio-inspired designs and is equally mistaken as looking at ornaments as if they have no function.

Correlating and combining both the functional and the visual/aesthetical aspects in Nature is suggested in this study as a new approach that is firmly rooted within the Nature-paradigm. In this direction, the study addresses a bi-polar, bio-inspired approach to architectural design that combines the functional aspects of Biomimicry with the psychological qualities of Biophilia. With specific models and applications that integrate the modeling of behavior/function together with the reproduction of the spatial experience and the positive psychological effects of Nature, it offers an outline or a framework for this approach. In a sense, only separate applications and models are presented here, and it is up to creative minds to work out a complete structure with these tools.

In quest for simple, cost-effective and hands-on models and applications, with possibilities and potentials in the both directions of Biomimicry and Biophilia, and rather than starting from zero, by studying natural biological creatures themselves, historical and traditional styles were explored, as shown in part 3, for this purpose. The results in part 4 and table 2 show that historical architecture is a valid reference book that is able to provide architects with pioneering models for this approach, which were unintentionally created as an inevitable result of the ancient architects' direct observations from Nature. So, the paper gives some validity to the idea that architects have their own reference book -- the book of historical styles, in which their predecessors had already put their contribution in terms of both Biomimicry and Biophilia in the form of ready-for-use solutions. New technologies of sensors, hoists, software...etc., is all what architects need to 'translate' this reference book into a contemporary modernized language and further investigations in different historical styles should be performed by architecture historian and researchers to come up with other Biomimetic/Biophilic models from this "reference book".

It had been also shown that some of these examples have more sustainable qualities in terms of materials' use and consumption, making use of the smallest piece of local regenerative materials, even those with not very good quality. Acoustical qualities and 'smart' designs for environmental control were also recognized.

One concern, which might be voiced here, is that the approach introduced here relies somehow on specific knowledge and tools that are obsolete and not anymore available. True as this may be, it needs to be seen within the context of the insufficiency of current trends that takes the aesthetic and psychological qualities of Nature and the benefits of this approach for people's psychology and well-being. In this, the paper refers to the ability to develop these historical systems into dynamic responsive systems that may respond to human needs for comfort, energy, and climate responsiveness by use of modern technologies. This, being applied to architecture, it will become possible to develop buildings that are strongly related to and affected by their

surrounding environment, and are much more satisfactory in terms of functional, psychological, environmental and sustainable design.

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