

TREE METAPHOR IN ARCHITECTURAL DESIGN

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ABSTRACT

Throughout history, trees have been significant for mankind, being the preferred choice in the provision of many needs, from heating to sheltering. Observations of tree-like structures led man to gain knowledge in new constructional methods and structural systems to satisfy their needs. Therefore it is possible to claim that, trees are among the structural elements frequently seen in the history of architecture, receiving particular attention from designers for whom nature is a source of inspiration. Foremost, trees are structural models for designers that are beyond branching patterns/ornamentations used in architectural decorations. Therefore when historical architecture is examined, a very deep and developed intuitive knowledge of construction becomes visible. In the tree, nature has presented the concept of growth and multiplication in which the sequence of trunk, branch, leaflets, and leaves exemplify patterns which are very similar to those governing architectural orders. In this study, trees which are seen as source of inspiration for form finding studies in architecture and learning act within architecture-analogy-metaphor relationship have been investigated. In the conducted literature survey, "historical development and classification of tree-like structures" is conceptualized; and the difference between inspiring by nature and learning from nature is discussed with selected examples.

Keywords: Metaphor, Analogy, Tree-like Structures, Biomimesis in Architecture

1. Architectures Inspired by Nature

1.1. The Term Metaphor

Metaphor, analogy, resemblance, similitude, imitation, inspiration and simile are the terms which are used interchangeably in architecture; and therefore these terms may result in semantic shift in expressions. Moreover, confusion increases when "copy", "replication" and "mimesis" terms are used in this group. As an example, Turkish Language Society defines the term metaphor as the direct synonym of simile. However, "simile" is the art of using words and ideas in different meanings other than their real meaning (Url-1). If different meanings are ascribed to a word in literature, philosophy, education, architecture and art, it is called "metaphor" in European languages which is an analogy used for name changes, meaning transfer, forwarding one meaning to another, resembling one thing to another and comparison.

According to Glucksberg (2001), the definitions of metaphor in different disciplines are fundamentally united in two definitions. The first, metaphor is a type of language. As a figure of speaking, a definite word or a phrase is ascribed on an analogical object or an action other than its actual meaning. This can be described as a metaphoric statement. The second, metaphor is a form of cognitive representation. Metaphor is another representation of a thing (generally intangible); in other words a symbol. These definitions assert two functions of metaphor. 1) Metaphor is rhetorical and poetic figure in language. 2) Metaphor is a cognitive representation. Logical, cognitive, behavioral and affective expressions are all metaphoric. According to Lakoff and Johnson (2003), "The essence of metaphor is understanding and experiencing one kind of thing in terms of another", and "...principally a way of conceiving one thing in terms of another". On the other hand "analogy" means resemblance, similarity and similitude. However, "resemblance" is method for producing information relying on complete similarity on the basis of the principle that presence of complete regularity or same reasons lead to similar results (BSTS/Yöntembilim Terimleri Sözlüğü, 1981). Analogy is "the similitude between the things bearing similar characteristics while their essences are different from each other." In Greek, *analogon* is proportional relationship "according to a ratio". This similarity may be between two different scaled forms (*i.e.* two triangles) while it may be between two different quantities. Another form of analogy is known as "educing by relationship" and it is a way of similarity of functionality. Aristotle gives formulation for these two types of analogies: "C is D with respect to what A is respect to B" and "D contains C if B contains A" (Url-2). Analogy may

be defined as differentiating interrelating similarity which do not resemble one another in two areas of information or exhibiting partial resemblance in some aspects (Kurz *et al.* 1999, 175). Imitation according to Platon and Aristotle is perception of the system within the nature and re-translation of this perception with creativity. Imitation is the definition addressing the individual's instinctual nature which is present as natural in the nature. Thought of naturalness, when integrated with tangible and intangible concepts, gives born to the art addressing pleasure and perceptions. Initiation within the historical processes shows under how cultural environment the art works as conscious and subconscious works, and reflecting values of the society without awareness (Erzen, 2002). Imitation is a creativity apprehending and revealing visible and invisible inner possibilities of the nature.

Many characteristics of structural occurrences observed in the nature bear metaphoric meanings for man-made structures. Architects and engineers witnessing this horizon have performed many morphological designs and/or structural trials/researches in the last century. In the design-manufacturing process of the architecture, it is stated that one of the methods for inspiration/learning/adaptation and/or application from nature is 'adoption of natural object form with structural apprehension via analogy into a structure'. Antoniades in *Poetics of Architecture* (1990) summarizes that architects' uses of natural forms and encourages designers to draw from nature to enhance creativity. *Cappleman and Jordan's Foundations in Architecture* (1993) describes student designs that use insects and plant patterns.

When architectural literature is studied, definitions of metaphor and analogy are not differentiated with strict borders. Even if opinions that analogy term is restricted to structural apprehensions are dominant, analogy term having various types asserts signs that this approach is not true. Accordingly, there are opinions on the metaphor that it provides designer with a benefits such as starting point by the considerations like reaching to creativity and creating meaning and its use is restricted to this definition.

Cognitive sciences are required to provide reasoning and computation of metaphoric thinking and structuring and representation of metaphor's cognitive process. Therefore, cognitive sciences are oriented to analogical relationships which neglect discussion towards metaphoric meanings and experience in favor of structuring and formalization with a positive attitude. Shortly analogy concept can be regarded as the starting point of the metaphor. When relationships are taken into consideration, system and systematic thinking overlaps with the analogy. Meaning of the analogy is exceeds similarity/similitude/analogy and reaches to metaphor. Furthermore, metaphors are not just a matter of language; they are also a matter of thought and action. They involve all natural dimensions of our sense experience such as color, shape, texture, sound (Lakoff and Johnson, 2005). According to Sayın, architectural design process is transformed into metaphoric interactions and statement not neglecting historical approach at the same time freezing historical aspects within linguistic behavior and articulation during expression in the historicity of the context and spatial presentation in the linguistic environment. As a result, architectural design process is a "discursive organism" (Foucault) and metaphoric (Sayın, 2007).

1.2. Metaphors in Architecture

The role of metaphors in architecture dates back to ancient times. Vitruvius suggests the use of nature as metaphor and observation of things growing like a tree almost two millennia ago. Aristotle was the first philosopher known in the history who pointed out the effective role played by metaphors in creative processes. He briefly defines a metaphor as, "...consists in giving the name that belongs to something else". And he explains the importance of metaphors: "...ordinary words convey only what we know already: it is from metaphor that we best get hold of something fresh... It is a great thing by far to be master of metaphor" (Ayıran, 2012). When history of architecture is considered, it is seen that architects make use of the source of inspiration as they are creating their design in each period. This is realized via tracking a primary architectural figure; sometimes by imitation of living/non living nature; sometimes by art, philosophy or politics. As a result, these designs either resembles a source of inspiration or accords by conceptual means. This case asserts that analogies become "reference" in architecture (Hey, et al. 2008). Gross and Do claims that these analogies are visual references for creative design (Gross and Do, 1995). (Figure1.)

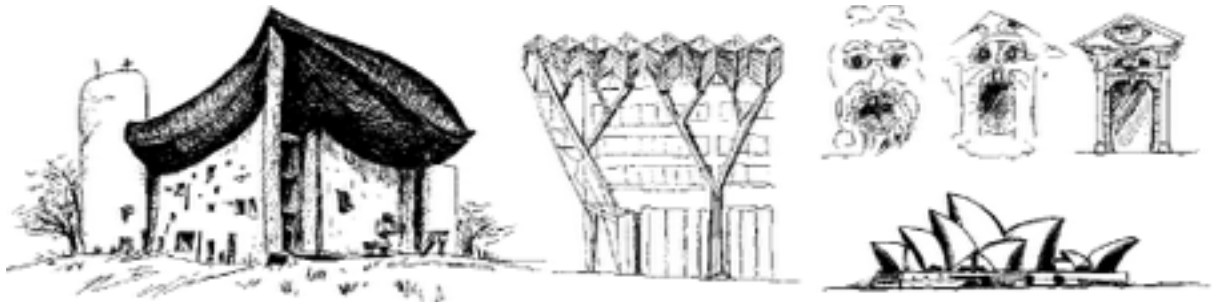


Figure 1. Examples of shape reminding: [a] Le Corbusier claimed the roof for the chapel at Ronchamp was inspired by a horseshoe crab shell; [b] Columns at Calatrava's BCE Place Gallery recall palm trees; [c] Michelangelo's Porta Pia may have derived from a drawing of a head in agony; [d] Ove Arup, Utzon's construction partner, claimed the Sydney Opera House's shell forms reflected the image of yachts in Sydney Harbor. (Gross and Do, 1995)

When historical process is investigated especially in the middle of 20th century, it is seen that examples in the nature were imitated by only form, pattern or color used in the façade design. Likewise, many architects design inspired by some objects from nature or predecessor movements, architectural approaches. It is known that metaphors and analogies provide a starting point in the architecture for concerns such as reaching creativity, making a meaning and delivering a message. Collins (1965) divided analogies adopted in the architecture into 5 classes; Biological, Mechanical, Gastronomic and Linguistic Analogies. Various structures which Abel (1988) identifies by resemblance models become a visual model and a strong source of inspiration used in creating different structures within sense of pluralism. These models can be listed as Spiritual Models, Classical Models, Military Models, Utopic Models, Organic Models, Mechanical Models, Artistic Models, Semantic Models, Commercial Models, Identifying Models, Architecture without architectures Models and so on (Url-2). It is inevitable that these classification requires update upon changing design needs and comprehension and this is a topic of another study.



Figure 2. A few examples on natural analogies in architecture (Portoghesi, 2000)

It is possible to assert that most common analogies adopted in the architecture are "biological analogies". All living creatures harmony living and non-living characteristics of the environment. Therefore, it is inevitable that structure and environment are in a harmony. However, this harmony is to be maintained as functionality not should be restricted only to its form. Since 19th century, by development of scientific explanations regarding nature and emerging biology as a scientific field, the previous architectural interest in imitating the nature have been changed by the laws and scientific explanations explaining the nature. By the advancement in the technology in our time, it is evident that the things that can be learned from the nature is not restricted to the concept of metaphor. Development of new technologies and structures learned through useful information obtained from the nature, forms the content of "biomimesis".

1.3. Biomimesis in Architecture

In literature, it is seen that biomimesis concept has been used with terms such as biomimetics, biomimicry bionics (Vincent, 1995), however, there are differences in meaning. Despite the terms used, materials, conservation of energy, lightness, "strength despite the lightness" inspire many architects and engineers (Arslan Selçuk and Gönenç, 2007). The science offering solutions in today's design in harmony with the nature and by learning from the nature leads designers to this field by highlighting that the nature includes systems beyond being an only visual/structural source of inspiration.



Figure 3. Biomimetic approaches in architecture; MMA Office Building inspired from desert cactus (Url-3), Wuhan Energy Flower Building inspired from Calla Lily (Url-4)

As can be seen in Figure 3 the Minister of Municipal Affairs & Agriculture's (MMAA) new office in Qatar, inspired by a cactus successfully surviving in hot, dry environments. Taking inspiration from the way these plants deal with the scorching desert climate. Considered as a successful example of desert architecture, this building is designed to be the energy-efficient structure features sunshade panels that open and close according to the intensity of the sun at a particular moment. Depending on the intensity of the sun during the day, the sun shades can open or close to keep out the heat when it is too much. This is similar to how a cactus performs transpiration at night rather during the day in order to retain water (Url-3). Similarly, Netherlands-based firm Grontmij, in collaboration with Soeters Van Eldonk architects, recently won the award to design and construct the new research center which will be both zero carbon and zero energy and include a slew of other green building strategies claims that a flower, Calla Lily inspired research center for Wuhan University in China is a candidate for being one of the most sustainable buildings the world (Url-4). These examples/trials encourage designers and researchers to further study nature. In this context, biomimesis is a prominent approach to develop new and innovative solutions for forms, structural, mechanical systems, energy efficiency and more. It can also serve to develop processes and related systematics and methodologies for environmentally friendly structures/artifacts, as can be observed in structures/forms in nature.

2. Tree-like Architectures

Design is a process that man has experienced and accumulated for centuries and transferred it to the future. There are many different understandings, approaches and applications have been used and experienced from the day the design is called "as a process". Similarly, different approaches have been used in the form finding process which can be called as one of the most prominent processes of the design. The most common approaches are typological, pragmatic and canonic approaches (Broadbent, 1978). It is possible to argue that systems, principles, forms and structures found in nature are among the most prominent inputs accelerating the design process.

In this content, many examples from the living/non-living organisms in nature; shells, crystals, spider webs, soap bubbles inspired mankind in their design process. Likewise, there are on-going relationships between "trees and architecture". From the prehistoric ages till today, trees are source of inspiration for the people in both art and architecture. In this regard, it is not surprising that photographer Beth Moon chased the oldest trees as an artistic object through the world for 14 years (Figure 4).



Figure 4. Images from Beth Moon's gallery called "Portraits of Time" (Url-5)

2.1.A Brief History on Tree-like Structures in the History of Architecture

The emergence of trees and plantlike shapes in architecture are unknown; however, there are plenty numbers of old cave art and paintings showing tree and plant figures. Therefore, in prehistoric ages, it can be said that people admired trees and plant forms. Especially, Egypt architecture is full of figures and metaphors having tree and plant shapes. Plantlike patterns are important decoration elements in Egypt palaces and pyramids and even in ancient Egypt hieroglyphs (BC3000 – BC600) and also in first architectural examples. The columns of Luxor Temple (BC1400) made of sandstones in shape of papyrus stack, tree-shaped column imitating the umbrella shape of the papyrus plant constitute the oldest examples. Moreover, there are Egypt stone column bodies resembling tree trunk and reeds like bunches and column heads decorated by resembling lily, lotus, palm tree or papyrus plant and also having different characteristics (Rian and Sassone, 2014) (Figure 5).

Once historical process is considered, another oldest example in which natural forms and structures have been used in architecture can be found in Ancient Greek civilizations. In Greek and Roman architecture, there are similar patterns and examples resembling tree and plants. However, metaphor term is not readily evident since there is a one to one resemblance and it is more like an approach. In the ancient times, tree and plant patterns received attention of the people and those natural objects are frequently used as part of their daily life. Prominent decorative characteristics of trees and plants are known to be used in Classical and Roman periods (BC500 and BC400). There are cardoon leaves on the head of Classical Corinth column. In the heads of serial columns and wall decorations of old Greek and Roman architecture and other decorative fields, acanthus plants are frequently observed (Rian and Sassone, 2014).



Figure 5. Acanthus plant and Column Head in Pantheon Roma Corinth (Portoghesi, 2000)

Tree like structures in Medieval Age, were constructed in buildings with the annular vaults which were the basic and most advanced tectonic of this period. Water cistern built in 6th century in Byzantines period, tree like patterns are observed. This large underground water depot was built as imitating a forest with 300 marble pillars higher than 9 meters (Figure 6). This pillar forest was designed to support large vault structures comprising of semi-circled arches (Rian and Sassone, 2014).

Gothic architecture had been prevalent from 12th century to 15th century. In this period, similar metaphoric approaches are adopted. In the beginning of 12th century, fan vaulting became common which may be

considered as intangible form of tree like forms by the advancement of cathedral architecture (Figure 6). One of the first examples of these vaults is Saint Chapelle in Paris built in 1242-1248. (Rian and Sassone, 2014). These vaults, examples of classic Gothic movement regarding characteristics, are supported by columns which are formed as rib nets to bear those vaults, they comprise of thin column bunches covered by painted glass.



Figure 6. Column forest in the Basilica Cistern built in İstanbul in Byzantine period (Url-6); Westminster Abbey Chapter House built in England in 13th century (Url-6), early Gothic period fan vault in Sainte-Chapelle in Paris.

The most common tree and plant motives are seen in buildings which are designed under Art Nouveau movement as color, form and texture. Art Nouveau movement turning its back to Classicism with a Romantic approach sought the inspiration in the nature and adopted organic forms of the plants representing getting closer to the nature (Escritt, 2000). In this period, “cast iron skills” enabled designers to experience structural characteristics of tree and plant forms as well (Figure 7).

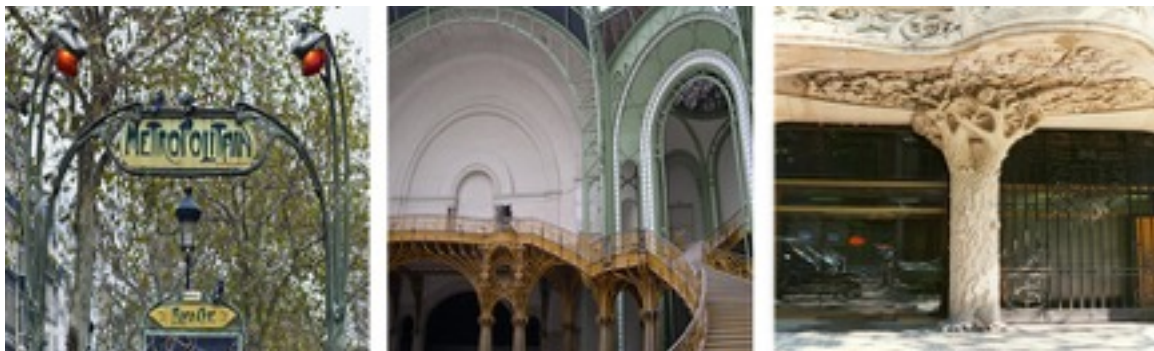


Figure 7. Paris Metro entrance designed by Hector Guimard in 1900 (Rian and Sassone, 2014), Grand Palais built in Paris in 1900 (Url-7); Tree, Barcelona (Escritt, 2000)

Similarly, Antonio Gaudi, who practically never journeyed anywhere, drew his inspiration from his ability to observe and reuse the countless details offered by nature. When one enters the crypt of Sagra da Familia in Barcelona, the four inclined basalt columns standing out give the sensation of an organic and natural structure, like trees in a forest (Figure 8).

In the first half of the 20th century, many architects and structural engineers have applied structural characteristics of trees with “structural simplicity” tendency with the advancing technique and accumulated knowledge. In the beginning of the 20th century, reinforced concrete emerged new advancement in structures. Architects have investigated conditions for structuring and arrangement of this new material and sought for new way of expression while engineers were developing building methods suitable for the material. Accumulated knowledge in reinforced concrete, widespread reinforced concrete structures have provided easy and numerous structural solutions for architects and engineers to create free shaped, shaped and intangible structures.



Figure 8. Sagrada Família Church designed by Gaudi in Barcelona (Url-8)

Frank Lloyd Wright (1867-1959) was accepted as one of the most innovative and influential figures in Modern Architecture. In his radically original designs, as well as in his writings, he championed the virtues of what he called organic architecture, a building style focused on harmony with nature. For Wright, the word “organic” was tied to the use of the concrete cantilever as though it were natural “tree-like” form. In the Johnson Wax Administration Building this organic metaphor revealed itself in tall slender mushroom columns becoming thinner towards their bases (Heinz, 2000).



Figure 9. A long mushroom (Url-9) and Johnson Wax Administrative Building interior photograph from the main saloon 1939 and 1944.



Figure 10. Examples according to the branching theory of Frei Otto (Otto,1995)

In the 1970s, great interest was given to architectural structures derived from the ramification concept in nature. Frei Otto studied the “minimum path system” to investigate a form for compression-loaded ceiling and roofing (Roland, 1970) in Institute of Lightweight Structures, Stuttgart. Otto claims that the fan structure as used in timber and steel building can be addressed as a materialized direct path network. The branched fan construction is more effective in many cases as the buckling lengths of the compression members are reduced; while the tree branched structure is a materialized path network with minimum detours, needing a relatively

small amount of material and with a load bearing capacity that can be increased by thin branches (Figure10) (Otto, 1995). Several structures were constructed by Otto following this concept, and later many architects have been following his design principles. Following the Otto's work of art, there are many buildings which are expression of tree columnar architecture and light structures.

Calatrava, who has inspired by nature in search of his building from, has characteristic style to be a bridge between civil engineering and architecture in the 30 years. His designs are based on the models found in nature especially inspired by skeletal systems of mammals. However, some authorities assert that buildings by Calatrava are not the results of "cognitive learning from nature" and the forms and structures in his designs can be described as "overdesign" (Zardini, 1996). Interaction with the nature in Calatrava's designs were just in the level of "seek of form" and it is criticized that sustainable architectural characteristics such as lightness, structural strength and standing static and dynamic loads, energy efficiency and materials observed in the designs could not be satisfied in his designs (Arslan Selçuk and Sorguç, 2007) (Figure 11).



Figure 11. Samples from tree shaped structures of Calatrava; Oriente Station (Url-10), BCE Place (Url-11), Cathedral of Saint John the Divine (Url-12).

The roof of the Stuttgart Airport Passenger Terminal, Germany (1996), designed by Meinhard von Gerkan, is also among the contemporary examples of tree-like structures. The huge sloping roof is supported by 12 very tree-like steel structures, in which the loads can be seen to be descending through an elaborate hierarchy, from twigs to branches to trunks, all fundamentally in compression. More directly, the construction of the terminal roof is based on the structure of a tree, thus providing an unmistakable and individual feature for Stuttgart Airport (Arslan Selçuk, 2009) (Figure 12).



Figure 12. Stuttgart Airport Passenger Terminal by Von Gerkan and Partners (Von Gerkan, 2007). This roof was designed by directly adopting the branching theory of Frei Otto.

2.2. Tree metaphor in 21st Century Architecture

Tree and plant like forms have been considered as complex and complicated to define for centuries and therefore used in architecture by "abstracting" the related forms. Today, inspiring and learning from tree-like structures are increasing since these structures can be explained by fractal theories. Advanced calculation

methods and algorithms let architects experience these forms in a short time with many alternatives. Furthermore, rapid prototyping technologies and other computational manufacturing techniques allow designers transform designs with complex form to tangible structures fast and easily.

The number of samples exploiting all good ideas from trees are increasing by the advancing design tools and materials technology. Wood and steel let architects create lighter and more sustainable structural solutions. In this regard, Tote Restaurant by Chris Lee and Kapil Gupta of Serie Architects built in Mumbai in 2009 receives particular attention with its forest like interior atmosphere (Figure 13). Architects, reprogramming/reusing an abandoned colonial building, have offered load bearing structures in tree branching forms to maintain presence of green nature surrounding the building within the interior. Structural system inspired by the trees in the rain forests created a distinctive aesthetics. Tree like and asymmetrical structures support this roof and promotes the sense of forest by intercepting at the same time (Gawell, 2013). The design incorporates branching steel columns with an I-shaped section.



Figure 13. Mumbai Tote Restaurant, India (Url-13)

Centre Pompidou-Metz (an original attachment built for Centre Pompidou Modern Art Museum in Paris), one of the designs made with natural materials by Shigeru Ban, was completed in 2010 (Figure 14). By its structural form, Ban who is inspired by tree like structures, sets an example for how wooden materials can be effectively employed by sustainable approaches and use of technology.



Figure 14. Sample wooden structures inspired by trees designed by Shigeru Ban; Centre Pompidou-Metz, Nine Bridges Country Club Building, A proposed design in Paris' 4th arrondissement (Url-14)(Url-15)

The column located at the entry of Qatar National Congress Center in Doha designed by Isozaki has been inspired by "*sidra*" tree which is grown in dessert climate and a symbolic plant (Url-16). This structural column bearing the load of open entry valance, have been designed as a statue by using evolutionary algorithms. (Figure 15). National Gallery in Singapore (Figure 16) is a prestigious building known by its tree columns located within the building. It was opened in November 2015 by the restoration realized by Studio Milou and CPG. The building completed in recent history, can be shown as an example for the tree like structures powered by technologies of the 21st century.



Figure 15. Qatar National Congress Center-2011 (Url-17)



Figure 16. Singapore National Gallery-2015 (Url-18)

35 meters high, diameter of 2 meters and a half with a wooden canopy 42 meters wide, the "Tree of Life" is a sculpture and interactive installation. The symbol of Expo Milano 2015 was built as a metaphor of Italy growing from its roots, feeding off them but growing upwards (Figure 17), (Url-21).



FIGURE 17. TREE OF LIFE AT MILAN WORLD EXPO 2015 (URL-19), "GARDENS BY THE BAY" IN SEOUL (URL-20)

"Gardens by The Bay" located in the center of Singapore have been designed in a way that parks having "huge" tree-like structures can imitate ecological functions of the trees (Figure 17). By use of photovoltaic cells located on, they absorb sun power and use this energy for meeting illumination needs. Meanwhile, as the natural trees use rain water, they accumulate rain water in glass cages and designed to use this water for irrigating tropical plants. (Url-22)

To sum up, in the conducted literature research; it is seen that tree like structures and tree metaphor in architecture -together with computational design and manufacturing tools and Biomimetic studies- constitutes the language of 21st century architectural designs and continue to be source of inspiration for the designers.

Results and Future Remarks

When history of architecture is investigated, metaphors, imitation of nature and learning from nature are widely adopted in design. It is seen that fractal construction of the branched structures like trees and leaves, spider web structures, shells, crystals and soap bubbles are used in a wide spectrum in architecture. As seen from the examples discussed in the paper, man has learnt the concept of growth and multiplication via "tree" since ramification lies at the very heart of its nature. The branched support tree-like structure can be first observed in the ribs of the Gothic style, while today tree-like structures in architecture are mostly three-dimensional support systems, which have been used increasingly in steel, wood, and concrete buildings.

From the analysis of a number of tree-like structures from the history of architecture to contemporary times, it is seen that tree like structures have been widely used in architecture and have always been a subject of interest due to their high structural performance and their potential to provide clear/wide span spaces. Furthermore, trees in nature, which has always been a subject of interest for architects due to its forms, functions and structural behavior is very convenient to inquire into the efficiency in form- structure and material usage relationship that architects looking for in their design.

In the tree, nature has presented the concept of growth and multiplication in which the sequence of trunk, branch, leaflets, and leaves exemplify patterns which are very similar to those governing architectural orders. Even though the scale, function, and process may be different in nature, design constraints and objectives are very similar: functionality, optimization, and cost effectiveness are targeted to co-exist in man-made products. Therefore, it is no surprise that mankind has always admired tree like structures and has often been inspired, not only by their aesthetic attributes, but also by their design and structural properties.

During the history, terms such as 'tree shape' or 'branched structure' are basically used to state formal resemblance between architectural structures and natural structures in architects and engineers. The most inspiring characteristic of a natural tree is definitely the capacity to carry a wide surface supported by a narrow element via fractal like branching structure. Such sort of thinking has inspired and taught architects on comprehending complex structures of the nature and increasing efficiency of application of their own design throughout the history.

Many features regarding tree shapes and functions are seen in today's designs. Therefore, designers adopting cutting edge technologies; offer tree like structures which does not only provide solutions for structural, spatial and one of the most important design criteria of today's world, to provide solutions for ecological problems but also these are more innovative and more suitable regarding architectural and structural meaning in aesthetical aspects.

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