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# Biomimetics in Structural Design

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**Abstract:** ***This paper looks into the biomimetic practices that can be applied to architecture such that there is a change in the way structural system is perceived. Age old architects have long ago turned to nature and have drawn inspiration from it in designing structures. The form it conceives, its support systems and other concepts have been a mystery and an area of interest. Nature have worked out a system that is the most efficient and which follows the path of minimum resistance. This is where Biomimicry has a major role. Biomimicry in simple terms is getting inspired by nature to solve human problems. Dendriform structures are those which are inspired by plant and tree forms to create a structural system. There are many ways in analyzing a structure. The success of any structure is when it is structurally efficient and load flows through clear paths with minimum stresses. There is a close relation between course of forces and their shape, which is a functional combination between roof construction and supporting structures .Thus,it becomes a powerful tool that opens the possibility of designing efficient structures and finding its member forces through simple graphical analysis.***

**Keywords:** Biomimicry, Dendriform, Nature-inspired

## 1. Introduction

Throughout history, architects have looked to nature for inspiration for building forms and approaches to decoration[1] . Nature has abundant structural solutions to everyday problems that can even help in evolving a complex form. Nature has already found answers to all problems that we face today. It has developed systems and various modifications in itself to adopt for the different changes that happen all around us. It has been there before us and still continues its life. Whether it is climate change, overpopulation or any other problems, nature holds the key to the chest of answers. Designs in nature ensure the greatest productivity for the least amount of materials and energy. They are environmentally friendly and wholly recyclable. They operate silently, are pleasing in aesthetic appearance, and offer long lives and durability[2].To create an architecture of meaning and beauty we need to return to the source - nature. We should make use of the materials and innovation provided by the natural world and put them to good use according to their true nature, not merely to imitate the appearances of the past.[3] .The concept of biomimicry involves learning from nature in developing new products and methods of construction which do not harm the nature but cooperates with it.

## 2. Biomimmicry

Designs in nature ensure the greatest productivity for the least amount of materials and energy. They are able to repair themselves, are environmentally friendly and wholly recyclable. They operate silently, are pleasing in aesthetic appearance, and offer long lives and durability.[2] Biomimicry, as its name might suggest, involves the study of nature's designs and mimicking them to solve human challenges. The term 'biomimicry' first appeared in scientific literature in 1962, and grew in usage particularly amongst materials scientists in the 1980s. Some scientists preferred the term 'biomimetics' or, less frequently, 'bionics'. [1]. Biomimicry was not a new term although it was coined much later. B I - O - M I M - I C - R Y is derived from the greek word 'bios' meaning 'life' and 'mimesis' meaning 'imitation'.In Biomimicry you look back to the future and into nature's development/evolution and uses something that's right in front of you to improve our life's and create new technology for mankind. This basic idea to combine biology and engineering, is to help humanity treat Nature better and in more harmony, so anyone from a single individual to the largest enterprise, can create better products, become greener and work in harmony with nature.[4]

### 2.1 Ways by which Nature can be inspired

- *Nature as model.* Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g., a solar cell inspired by a leaf.
- *Nature as measure.* Biomimicry uses an ecological standard to judge the "rightness" of our innovations. After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts.
- *Nature as mentor* Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we *extract* from the natural world, but on what we can learn from it. [5]

### 2.2 Levels of Biomimicry

There are three levels of biomimicry:
- Biomimicry at the *organism* level
- Biomimicry at the *behaviour* level and
- Biomimicry at the *ecosystem* level

The organism level refers to a specific organism like a plant or animal and may involve mimicking part of or the whole organism.The second level refers to mimicking behaviour, and may include translating an aspect of how an organism behaves, or relates to a larger context. The third level is the mimicking of whole ecosystems and the common principles that allow them to successfully function.[6]


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### 2.3 The potential for Biomimicry in architectural design

Dissertation by Peter Sproule done in 2010, forms the base giving insight to the origin of civilization, the transformation that evolved through the ages, and delves into the underlying idea of biomimicry to use forms, processes and systems found in nature to create efficient, intelligent, elegant and environmentally sustainable architecture. Man has evolved from making huts to creating cities. The success of man in doing so only based on adaptation to the environment. Turning back to history we see times when exploitation of earth's resources were at its peak due to the industrial revolution. The introductory chapters also looks into the problems that humans face today, mainly due to global warming and climatic change. A summary of what human activities have done to the planet is given. This realizes the importance of Biomimicry in the present times. Nature has been a mentor throughout times inspiring man with its designs. Biomimicry was not a new term although it was coined much later. We see the influence of nature in ancient myths and stories. The Greeks and Romans have tried to understand nature and natural processes. There have been many natural philosophers like Socrates, Aristotle and Plato who tried to find natures underlying laws. Man has turned towards nature in postulating theories and conclusions. The work of Benyus, Darwin, D'Arcy, Thompson, Vitruvius, Fibonacci, etc. have paved way for modern form of biomimicry that can be applied to architecture. Man should turn more to nature for her lessons in feeding, harnessing power, transport and building communities. It is not returning to the way ancestors lived, but creating sustainable solutions for life. Towards the end, we see how biomimicry has been in practice and its use in architectural design. Case studies under natural forms, processes and systems are studied to draw upon a conclusion. The writer concludes that even though biomimicry can increase resource efficiency and renewable energy consumption, it has certain limitations. Limitations start to occur when we do not have the technology to imitate nature's processes. There is also the problem of financing for the projects undertaken.

### 2.4 Biomimcry: Innovations inspired by nature

In this book, Janine Benyus explains biomimicry and why it is important. The author explains through experiences in her life and stories she came about to know. The introduction in the book talks about why biomimicry becomes important in this evolving world.in her book, she explains that nature has already invented many things prior to humans and that too in the most efficient way. All around there are miracles happening which we seldom notice. Animals and plants have evolved mechanisms that we humans are struggling to create for generations. Within each part of the book, Benyus have researched upon different areas where we could improve like making food, harnessing energy, material study etc. Chemists, biologists, scientists from different areas have invented inspiring technologies that show what a common man thinks as a nuisance for example' like weeds' are nature's secret lessons to be learnt. Principles found in nature is stated under most areas of study. The experiments on farming from the analysis of a Prairie, techniques from all around the word, harnessing of energy to avoid unnatural sources which deplete the earth's resources, are looked upon. The author talks about storing what we learnt, healing ourselves, and to live sustainably using needed resources sparingly. Animals, plants, insects, and all systems in life are cited as examples to make the readers understand that everything is possible if we mimic nature. The author worries about the future of biomimicry. She wonders how the new designs and processes will be used by the humans. Will it be used for the greater good or for destruction? The book provides a useful insight about what is taking place around us, new technologies, the interaction of humans with nature, and what nature can teach us.

### 2.5 Tree inspired dendriforms and fractal-like branching structures in structural design

The paper discusses the biological functions and mechanical properties with regard to their shape. The evolution of dendriform structures throughout history is seen. Architects have kept in mind the relation between shape and structural strength to design many dendriform structures. The evolution of such structures has varied in time because of the technology and materials available then. The paper also discusses the underlying geometric characteristics and fundamentals of fractal forms and configurations. For many centuries , the variety of nature's forms which present itself in fractals for structural appearance like cells, trees, have been studied by architects and engineers to produce bridges, tents, shells and light weight structures. Fractal like branching seen in trees has been given different explanations according to various angles of discipline. The basic explanation being its functional needs. Branching is the result of an optimized network of transporting fluids to leaves, fruits and buds. The scientific explanation being to minimize energy expenditure and optimum energy utilization.Trees are exposed to different types of external and internal loads. Trees configure its shape so that it can withstand strong gusts of wind forces and tackle bending moments. During the action of winds, stresses change from tensile on the concave side to compressive on the convex side. Axial compression is another load that is carried by tree trunks and stems. Internal stresses prevent the component parts from slipping on shear-loaded interfaces. Internal stresses are distributed evenly and homogeneity is maintained. This is done by the optimization in shape to follow the structural demand.

## 3. Biomimetics and architecture

### 3.1 Biomimicry and built form

Forms in nature, like those of the built environment, are subjected both to the limitations of the materials strength and external forces such as gravity. Lessons from nature are often applicable to the built environment, providing useful insights into new techniques for advancements in structural efficiency. The philosophy of Biomimicry has significant potential in the structural realm, whereby rather than simply copying the forms of nature which can be problematic due scales of magnitude, the true profundities are believed to come from an improved understanding of how nature and its forms work.[7].Imitating nature has become a meaningful


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approach for contemporary architects and design futurists to the built environment, especially for those who foster a future that doesn't compete with nature but coexist with it. [8].

### 3.2 Imitating shape, process and material

Biomimicry could offer sustainable alternative solutions to conventional design practice, as its basis is to reduce the energy consumed by the system by combining functions and reducing wastage. It can be applied not only to design the shape of the development but also to provide solutions in construction and operation processes, as well as in selection of the materials used.

### 3.3 Imitating shape

Imitating shape and geometry from nature is probably the most well-known type of biomimicry in engineering. A number of structural systems that are considered great manmade achievements are in fact inspired by the natural environment. Suspension structures, such as long-span suspension bridges, share the same structural principles with spiders' webs. Membrane structures, such as modern stadia roofs and canopies behave very similarly to cell walls, gaining strength by being constantly in tension. The Pantheon in Rome is a biomimetic example, not in terms of its material but because of its structural behaviour, which is similar to that of a sea shell. Like seashells, the roof of the Pantheon gains its strength from its multi-dimensional curvature, which results in a structure not requiring extra reinforcing and hence being much lighter than conventional reinforced concrete spanning structures.

### 3.4 Imitating the process

Imitation of natural processes is also a key factor in biomimicry. Most of the environmental hazards the world is facing today are as a direct or indirect result of power generation and use. Natural ecosystems have existed as minimum energy systems for millions of years, being driven primarily by solar energy. It is timely to determine whether the same principle could be applied to building structures, which themselves are artificial ecosystems where people live and work. Renewable sources could be incorporated into the method of construction, used for power supply, ventilation climate control and lighting.

## 4. Examples

### 4.1 East Gate Building

The East gate Building, an office complex in Harare Zimbabwe, has an air conditioning system modeled on the self-cooling mounds of termites that maintain the temperature inside their within one degree, day and night while the temperatures outside swing between 3 °C and 42 °C. Eastgate uses 90% less energy for ventilation than conventional buildings its size and has already saved the building owners over $3.5 million dollars in air conditioning. The main focus of Mark Pearce's termite mound was to use convection currents to keep the internal atrium and offices at a constant temperature throughout the year using the sun and wind energy, not conventional air conditioning units. Termite must maintain this homeostasis to survive, if fact if the temperature varies by more than 2 degrees the entire colony is in serious danger of being eliminated. The termites farm a specific fungus to live off of that can only grow at a constant temperature of $87^0$ F. The termites maintain this temperature by continually opening and closing self made vents, allowing cooler air to get sucked in towards the bottom, and then circulating throughout and up a central shaft because the air eventually warms from the termites and their fungus garden. The flow rate of the air current is about 5 inches per minute.

**Figure 1:** Eastgate Building

The East Gate Center was built in a similar process. Pearce "took advantage of night cooling, thermal storage and convective air currents to moderate temperatures." The large complex has two buildings side by side with an open space, covered in glass, in the center. The building is made of concrete which has the capacity to store the heat from the day for later use. The cool air during the night is channeled to the bottom of the building, using large fans, taking the place of the rising, warmer, daytime air. This air is channeled out of the chimneys' at the top of the building. The offices work in a similar way, adding colder air to the bottom of the rooms, which takes the place of the rising warmer air, as it is vented out of the ceiling.

### 4.2 The Crystal Palace

The Crystal Palace was designed by landscape designer Joseph Paxton, who drew inspiration from Victoria Amazonica, a species of water lily. Despite its very fragile appearance, these lilies possess huge leaves that are strong enough for people to stand on. In January 1850 a committee was formed to choose the design for a temporary exhibition building that would showcase the latest technologies and innovations from around the world: The "Great Exhibition of the Works of Industry of all Nations." The structure had to be as economical as possible, and be built before the exhibition was scheduled to open on May 1st, 1851. Within 3 weeks the committee received 245 entires, all of which were rejected. It was only after this that Paxton showed his first interest in the project.


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**Figure 2:** Crystal Palace

Paxton' design was based on a 10in x 49in module, the size of the largest glass sheet available at the time. The modular system consisted of right-angled triangles, mirrored and multiplied, supported by a grid of cast iron beams and pillars. These basic units were extremely light and strong and were extended to an incredible length of 564 meters. The design was also influenced by Paxton's passion for biomimicry; he drew inspiration from the giant leaves of the Victoria Amazonica waterlily. [9]

### 4.4 The China World trade Tower competition

The geometric characteristics of bamboo are applied to the structural systems of the China World Trade Center Tower Competition submission. The tower is divided into eight segments along its height. The structural demand from lateral load is highest at the base of the Culm (or tower), therefore internodal heights are smaller compared to the mid-height. Smaller spacing increases moment capacity and buckling resistance. Beyond the mid-height of the culm (or tower), the heights of the internodes decrease proportionally with the diaphragm diameter. Thus, the form of the tower responds to structural demands due to lateral loads.

## 5. Structural Artists

Forms in nature are derived from the forces by which they are or have been subjected. In contrast, the built environment tends towards pre-determined forms such as flat planes, which due to their inefficiencies are compensated through mass or the addition of supporting members. In this regard, architect Antoni Gaudi was well before his time. Structural efficiency is important not only economically, but is also critical in creating more sustainable designs. As evident in the work of Gaudi as well as other structural artists such as Torroja, Dieste and Candella, structurally efficient forms, in following the laws of nature tend to result in elegant and beautiful forms.

### 5.1 Antonio Gaudi

Gaudi looked to nature as his mentor, and his building forms, like nature were derived from the forces acting upon them. Through the intelligent use of form, Gaudi provided resistance to the acting forces, subjecting his materials to high levels of force within their capabilities achieving great structural efficiency.Gaudi was a man of simple ideas and common sense. In his architecture it fuses structure and decoration. He clearly accepted nature as his guide. All aspects of his work evince this. It does not copy the nature but that includes/understands its geometry and its principles: it has infinity of forms that can be studied by means of regulated geometry; he studies the laws of statics and dynamics like for example; the natural structures of fibrous composition, such as rushes, canes and bones. Gaudi viewed the natural world as perfect, a creation from which he drew inspiration.

The nature always works looking for functional solutions, since it is put under the inexorable law of the gravity, Gaudi was very wise to study the natural structures that during million years have gained a perfect operation. Knowing the essence of these structures, it was his intention to take them to the land of the construction. In the course of time, as Gaudi's work developed, the influence of natural forms became more noticeable in his larger shapes. He no longer applied them decoratively as he did in his early buildings. Natural shapes created to resist wind and weather requires sound structures. Shell shapes that have these qualities may have inspired the towers of the Sagrada Familia.

### 5.2 Felix Candela

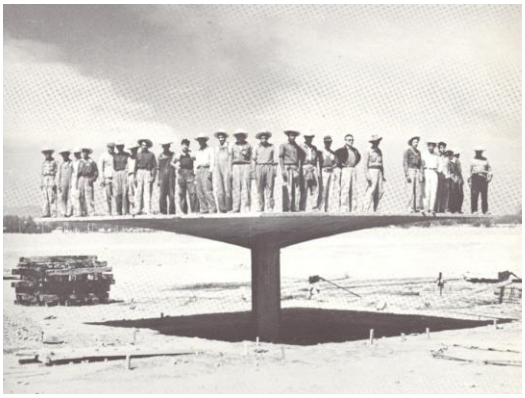

**Figure 3:** candela's experiment with mushroom column

In the period of 1950-1960, one of the most pioneer designers of thin shell structures was a Spanish structural engineer and architect named Felix Candela. Candela was born in Spain, and was exiled in 1939 to Mexico where he created all of his major thin shell concrete constructions thus creating structural art by playing with the material.Candelas tree inspired structures not only act as structural supports but covers large span. The architect was the one to make first umbrella structures, entirely of reinforced concrete in the shape of mushroom columns. After successful experimentation, he constructed series of structures for markets and warehouses.[10]

### 5.3 Pier Luigi Nervi

Pier Luigi Nervi (June 21, 1891 – January 9, 1979) was an Italian engineer. He studied at the University of Bologna and qualified in 1913. Dr Nervi taught as a professor of engineering at Rome University from 1946-61. He is widely known as a structural engineer and an architect, and for his innovative use of reinforced concrete.[11]


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## 6. Dendriform Structures

### 6.1 Inspiration from tree

Trees are an intriguing paradigm of growth and development. They represent much more than an aggregate of twigs and branches attached to a common axis. Trees growth does not evolve equally in all directions. One of the main effects on the trees' form is gravity, because it is a continuous, uniform applied force. The branches do not grow randomly in all directions but are regulated by the effects of gravity and light. The shape of the tree crown is then dependent on the internal branching patterns that permit optimal use of space and light. Light, gravity, and the struggle for growing space interact to determine the overall size and shape of trees. In architecture, light and space are pre-determined; the shape and dimension of the treelike support is only defined according to the load it is expected to bear. Once defined during the planning stage, unlike trees in nature, the tree-like structure cannot grow any further. Tree models are based on branching structures of internodes (branches) and nodes (bifurcations). The branch is defined physically by its length, diameter, start point and direction.[12].The dendriform is defined as having a branching or tree like appearance. Dendriform structures do not form closed loop but they branch outwards like trees. These are mainly used as compression systems to carry gravity loads to the ground.

### 6.2 History of dendriform structures

Looking back to the history, man has always been fascinated by the natural world around. The scripture, during the time of Solomon depicts the usage of elements inspired by palm trees that are found in the holy land embedded into parts of building. John Sidney Hawkins says that one possible reason is that the architecture for every country must bear some relation to the materials and forms that the country has to offer. No trees of greater diameter was found in Israel. Palm trees that were very slender throughout its great height began to be obviously inspire the builders of that time for the columns of the buildings.In the Classical and Roman periods (500 BC to 400 AD), vegetal and floral shapes were designed in accurate proportions for decorating purposes which was main feature of the architecture at that time. The ancient edifices were made of wood with trees forming columns and even when stone was used for construction, the columns were made to taper from the base to imitate trees. Being originally of wood, the bound them with rings at top and bottom, to prevent them from splitting. Thus the bases and capitals in different orders seem originally derived from these bandages, though they now became essential ornaments.[13]

**Figure 4:** Decorative elements in orders inspired by acanthus

Dendriforms were included in the arches and vaults of masonry construction during the medieval period. In the 19th century, during the time of Art Nouveau, the fascination towards vegetal and floral forms reached its apex, especially when architects and sculptures learned to work with cast iron. In the same century, 'graphic statics' developed as a theoretical approach helping architects to understand the association of structural form and the equilibrium of forces allowing to build several unique dendriform structure.[10]. Sagrada Familia which was designed by Antonio Gaudi as his masterpiece is one such structure which has derived its form from graphical analysis and models.

### 6.3 The Dendritic columns of Sagrada Familia

Sagrada Familia is located in Barcelona, Spain. Its construction began in 1882 when Josep Maria Bocabella visited Italy and felt that Barcelona needed a cathedral that is dedicated to the holy family. It is a design unique to itself reflecting Gaudi's vision and mysticism along with his gifts of design and use of materials. Gaudi spent ten years working on studies for La Sagrada Familia. He developed a creative new method for calculating structural stress.[14] The weights and centers of gravity of the main parts are fixed. By incorporating the graphical method, Gaudi was able to design the tree that is going to collect the weights and take them to the bases of the columns. The architect came to this solution after a long and careful empirical study of invested load by means of ropes or cables and graphic calculations. [15]

**Figure 5:** Columns of Sagrada

The main idea is to attain equilibrium between the various blocks that compose the structure, as it would be done in a set of scales. The structure is analyzed in three main sections (central aisle, wall and side aisle). Their total weight and centre of gravity position are calculated. Each section is composed of a range of elements. The process is as follows: firstly, the weight and centre of gravity of each element is calculated using the standard graphic statics methods, and, once these values are known, the weight and centre of gravity of each section is calculated.

The main problem is how to take these loads to the bases of the columns, which are already fixed in position (the crypt of the old neo-gothic design was already built); i.e. a skeleton of columns, a "tree" of columns, must be designed to be capable of collecting the loads from the centre of gravity of each section and transferring them to some fixed points on the


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ground. It is assumed in this equilibrium calculation that each section transmits its load vertically to the corresponding branch of the tree. This concept of equilibrium is what we could call global or for a "block system structure, where each part, made up in turn of a series of elements, forms a block. These blocks don't interact with each other, but the branches of the skeleton seek to collect their concentrated weights at their centre of gravity. There is no arching action, no lateral thrust, and this is because they would be made of a "concrete-like" material through the use of metal reinforcement. The weights and centres of gravity of the main parts are fixed. The base of the column was also fixed. Gaudi used graphical method to design the tree that is going to collect the weights and take them to the bases of the columns .The weights and centres of gravity of the main parts are fixed. Gaudi used a graphical method to design the tree that is going to collect the weights and take them to the bases of the columns.

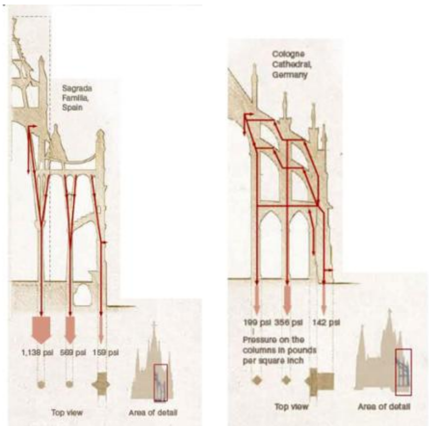


**Figure 6:** Comparison of flying buttress of Sagrada with gothic churches

The architect came to this solution after a long and careful empirical study of invested load by means of ropes or cables and graphic calculations. With these models he determined the inclination of the supporting tree-columns and optimized structural behavior to transmit loads to its core. In this way elements work in compression and bent elements are minimized. This also brings down loads to major interior pillars and not to perimeter buttresses. [16]

The most polemical aspect of this process could perhaps be the assumption that vaults and roofs don't generate any thrust. Given the extensive experience Gaudi had designing and building thin vaults, it is very likely that Gaudi knew about the existence of the thrust but ignored it in the design of the main skeleton because it is secondary in the full scheme of equilibrium. In the Sagrada Familia, the enormous weight of the pediments and the tracery of the windows is what equilibrates the main part of the thrust. But, Gaudi, even though he criticizes the Gothic style ,incorporated eventually "hidden" flying buttresses which may be seen in the cross sections and, also, in the roof model. Their function would be to transfer the remnant thrust from the vaults and roof to the columns of the lateral aisle. [16].

### 6.4 Frei Otto and branching structures

Trees and forests have inspired structural forms in architecture. The German Architect, Frei Otto, carried out systematic research on lightweight and adaptable construction and described buildings as “Natural Construction”. He published papers on fundamental aspects of the relationship between architecture and nature. His remarkable works include: suspended construction, dome shells, grid shells, inverting the suspended shades etc. Frei Otto worked on tree-like columns and on the model of branching structures.

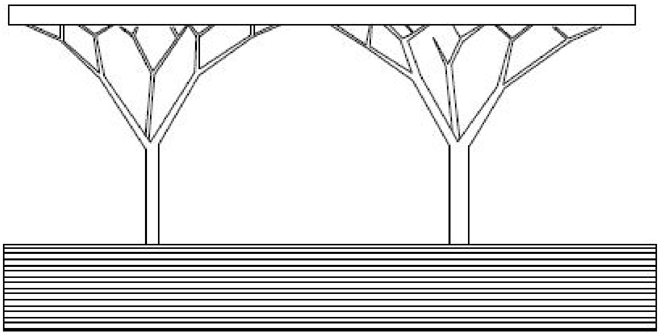

**Figure 7:** Design sketches by Nervi

Frei Otto developed many different branching structures. He used hanging models to mould designs for structural support of footbridges, for conference halls and for large hexagonal grid domes. Eventually, Frei Otto developed systems of branched columns which he managed to convert into a harmonious structure of the dome that became melded into a single structure.

**Figure 8:** Ottos hanging structure model

### 6.5 Santiago callatrava : oriente station , lisbon

Orient station in Lisbon designed by Santiago Callatrava have platforms that are roofed by a metal structure 25 meters high. This elegant solution consists of a series of slender pillars that split on the top and connect with each other to create a continuous folding structure. The group of pillars resemble palm trees or lilies, and in a geometric sense it is not far from the also floral fan vaults of the British perpendicular gothic. The structural elements are painted white and the nerves of these so-called palms spread out to hold a folding glass roof where geometry and organic shapes find a synthesis in abstraction.[17]


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**Figure 8:** Lisbon Station

## 7. Analysing structures with hanging model

The hanging model functions like a "designing machine". Gaudi attempted to represent space using one of the methods described in the previous paragraph. Lastly, he measured over the model to prepare the drawings. It is easily imagined how laborious the whole process is.

Gaudi achieved the desired forms through the control of three variables - anchor points of the strings, the length of the strings, and the weights attached to them. Strings responding to gravity and can be arranged to form structures that are far more organic and beautiful. By designing forms this way, Gaudi knew that the resulting geometry would act purely in compression when inverted. He also had a fairly precise estimate of the loads necessary on the different members of his construction. Therefore, Gaudi could construct buildings that would not collapse or require extra support structures. He imagined interiors by painting and tracing over the “wire frame “models of lines, which were simply photos of his string forms. [15]

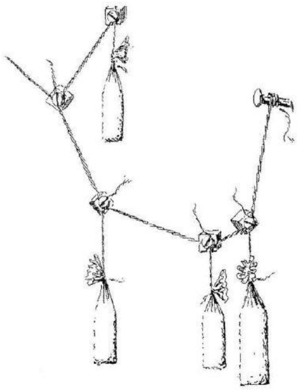

**Figure 9:** Using sachets to apply loads to hanging model

### 7.1 Hanging structures in compression

In a paper done by Peter Von Buelow which looks into branching structures and models for its generation, we see that branching structures are based on geometric systems that expand through bifurcation without returning to form closed cells. In this sense, branching structures resemble the structure of trees that branch continually outward. In architectural engineering, these forms can be used either as tension or compression systems. Numerous built examples have been produced since the initial inspiring studies made by Frei Otto in the early 1960's. Form finding techniques based on models have been used in the past to study these forms. Although thread models can be effective in the study of force paths, they cannot distinguish between tension and compression and have no way to take member buckling into account. But buckling does have an influence on appropriate geometry of a compression system. Also, minimal paths (or pseudo minimal paths based on surface tension thread models) have been used to explore possible geometries for branching structures. In this paper, both surface tension thread models dipped in water, and weighted string models are shown. Models have been used to explore structural form. [18].

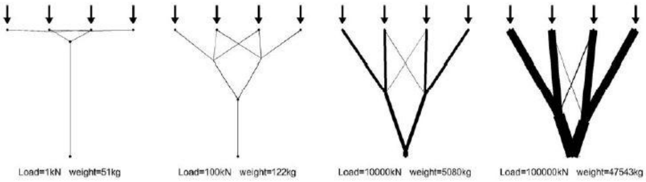


**Figure 10:** Branching columns loaded from above in compression using four levels of loading

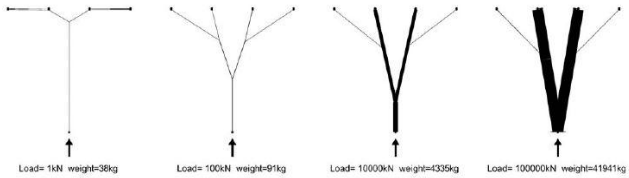


**Figure 11:** Branching columns loaded from below in compression using four levels of loading

The above 2 figures shows branching columns in compression under different levels of loading. In figure 10, load is applied on the top nodes with reaction on the bottom node. In figure 11, load is applied on the bottom node with top nodes held as reactions. The range of loading is deliberately taken from low to high to get the geometric pattern. Under loading, different analysis are made:

- Level of loads plays an optimum role in determining ideal shapes of systems.
- With higher load levels, the efficient members are longer. With lower loads, smaller sections are required and lengths are shorter to maintain the slenderness ratio. Therefore length is proportional to the loading. There is progressive length of upper branches as loading increases. The nodes shift accordingly.
- Member weight also increases as load increases
- Figure 10 has two members added for stability which is not required in figure 11 when loading is from below and fixed above.
- Load path follows the geometry of minimum path between points

## 8. Literature Case Study

### 8.1 Stuttgart terminal 3

Designed in 1991 by Von Gerkhan, Marg and Partner, The Stuttgart Airport is one of the six busiest airports in Germany. The most attractive feature here are the tree-like columns which gives vast amount of uninterrupted space which aids in occupying volumes of people. Structural branches penetrate the wall glazing at first floor level to support the entrance canopy.The actual roof surface is divided into sections; each supported by a “steel tree” with passes the loads down through the branches to be collected in the tree trunk.


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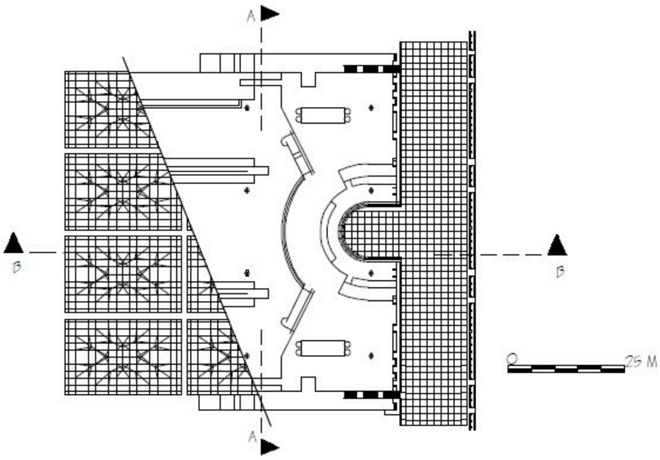


**Figure 12:** Plan of Stuttgart terminal 3

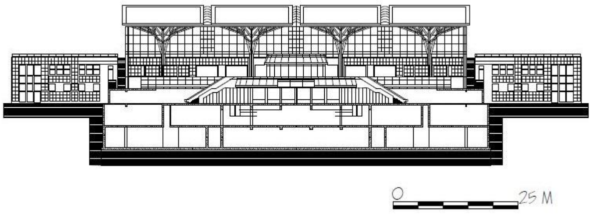


**Figure 13:** Section AA of Stuttgart terminal 3

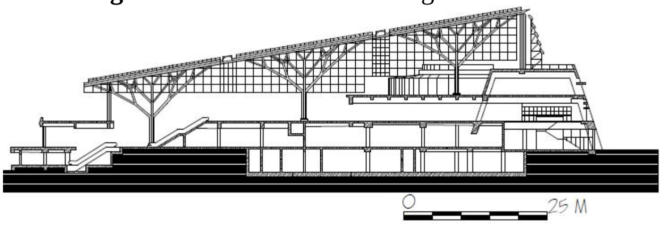


**Figure 14:** Section BB of Stuttgart terminal 3

The functional demand is outstandingly met for airport requirements. It offers an ease of orientation and smooth flow of passengers, staff and baggage. The appearance of this airport is characterized by the remarkable roof of the hall. The space serves for baggage pick up and is easy to access, having a great view due to its open space concept. Passengers can easily walk through and find their way.The most important element is the tree-like structural system that supports the roof. The actual roof surface is divided into twelve equal rectangular sections measuring 26.6 x 43.4 m, erected as a two-way steel section system. Each area is supported by a “steel tree,” outlined by strips of glass, with the loads passing down through the branches to be collected in the tree trunk. The architect mentioned that his inspiration came from the neighboring Black Forest.

The building is of rectangular shape and the roof is mono-pitched. There are three different levels, whereby tubular tree-like columns are placed on each level forming a cascade and the drop of the roof. A single support is composed of four tubular poles that are attached to each other and spread to form the tree branching in three different levels (each column forms three branches, with four sub-branches each, to finally support the roof). There are four sets of similar branching systems that repeat themselves up to the roof. Even though these columns have organic appearance, they are distributed to carry the roof loads in compression with minimal bending moments. The multiple branching systems direct the forces into smaller resultant points until they cluster the resultant on four tubular steel trunks that work as one[12].

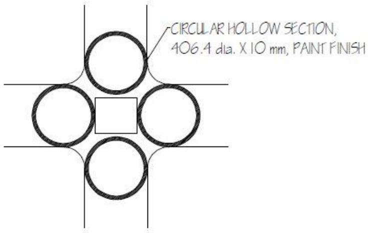


**Figure 15:** Diameter of main trunk

### 8.2 The Tote by Serie Architect

This structure was designed at Mumbai comprises of restaurant, Banquet hall, bar, and reception room with an area about 2500 sq m. It was designed as a part as extension of colonial buildings. The conservation guidelines call for the preservation of the roof profile for three-quarters of the buildings and full conservation for the remaining one-quarter. The interesting aspect of the site, however, lies not in the colonial buildings but in the open spaces covered by mature Rain Trees. These spaces are shaded throughout the year by the thinly wide spread leaves of the Rain Trees, allowing almost the entire proposed program to occur outdoors.

**Figure 16:** Entrance Tote Mumbai

The design was inspired by trees on the site and incorporates branching steel columns with an I-shaped section. Lighting is installed at the points where these branches meet the ceiling. The walls of the bar upstairs are clad in faceted wooden panels, arranged according to a pattern of crossing tree branches that is picked out in bronze. The structural system adopted here is that of a tree-branch. The propagation of the branching system along the longitudinal section of the conserved building is differentiated in its growth along the transverse section. This differentiation reorganizes the old buildings with new dining programs. Therefore each dining program (wine bar, restaurant, pre-function and banquet facilities) is captured within a different spatial volume, defined by the variable degree of the branching structure. As the structure branches into finer structural members as it approaches the ceiling. When the branches touch the ceiling, the ceiling plane is punctured with a series of openings corresponding to the intersection of the branches with the purlins and rafters. These openings become light coves and slits.


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**Figure 17:** Dendriform Column of Tote Mumbai

The tree structure was designed to be a steel truss and the challenge lay in working through the construction system compatible with local skills. Rather than looking at steel fabricators within the building construction sector, boiler fabricators for high precision work were sourced. Two sectional profiles for the truss, a box section and an I-section were used.The choice of the I-section was based on the fact that the web could be laser cut to ensure dimensional precision, while relying on the skilled fabricators to weld the flanges on and assemble the truss accurately. The truss geometry was altered for smooth branching as opposed to an angular one to reduce the number of weld joints. The success of the installation is that the final product conceals the fabrication method and appears to be a system of curved sections. The interior of the Lounge Bar on the upper level is an intricate arrangement of 3-dimensional, faceted wooden panelling, acoustically treated with sound proofing material. The pattern of the panelling is a series of trees with intersecting branches.

## 9. Inference

- Comparing with the regular geometrical structures, dendriform structures have high efficiency of force transfer since branches are designed along the load path. There is a close relation between course of forces and their shape, which is a functional combination between roof construction and supporting structures.
- One of the main advantages of tree like branching system is having short distances from loading points to the supports. Thus we see that geometry is used to create best possible routes for loads to travel along. There is limitation of building these structures using conventional tools and methods of construction.
- Branching structures exhibit a particularly close relationship between the course of the forces and their shape, both in their overall appearance and in the nature of the structure itself. It is a functional combination between the roof construction and supporting structures. The advantage of the tree-like branching system is to have short distances from the loading points to the supports (Ahmeti, 2007) .The angle of tapering of the branches also affects the load flow.

## 10. Conclusion

Imitating nature has become a meaningful approach for contemporary architects and design futurists to the built environment, especially for those who foster a future that doesn't compete with nature but coexist with it. [8].Biomimicry appears as a highly plausible guideline whereby inspiration from nature could provide humanity with the framework for more intelligent design. The built environment play a critical role and developments in structural efficiency provide enormous scope for significant improvements. [7].Therefore to get inspired by nature which have taken millions of years to perfect is a good solution. However, since Biomimicry is still in its early stages, ways of applying these solutions are difficult. We must not go beyond other factors like material availability or cost to achieve this aim. It is important to keep in mind all factors while designing.

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