BIOMIMETICS

Study of the Blossom of the Hibiscus flower

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SUBMITTED BY:

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APPROVAL SHEET

This is to certify that the special project entitled " BIO-MIMETICS –Study of the blossom of the hibiscus flower", by **Tabitha Purathur,** 05613001, and **Vinatha Babyprakash,** 05613007, is approved for the partial fulfillment of the degree of Master of Design in Industrial Design

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CONTENTS

PART 2 – ANALYSIS

PART 3 – SYNTHESIS

ABSTRACT

Today in contemporary design one can observe non-linearity has taken hold breaking away from Platonic and Euclidean ideals, where objects are not looked at as a whole and absolute but interconnected within a larger system. They derive their formal definitions such as organic, amorphous, folds and blobs through taking analogies from nature by understanding modern sciences such as the theory of relativity, chaos, complexity etc. On the other hand there are contemporary designers whose core concern is to achieve systems which work efficiently and conserve resources and energy. These approaches seeking the higher ethical order and striving to work symbiotically with nature without damaging her tend to lose weight on their aesthetic dimension or artistic foci.

An initial effort was carried out to collect data on the existing areas of bio-mimicry and how they have influenced man's life in innumerable ways through different case-studies.

The five main areas of Simulation, Interpretation, Integration, Replication and Emulation were delved upon with practical applications in the field of design. A brief overlook into some of the research studies carried out at the MIT also shed light on the applications of bionics right from developing intelligent robots to creating artificial limbs for the physically challenged.

The scope of our project revolves around the idea of establishing the key principle behind the blossoming of a hibiscus flower. Owing to the dearth of time, emphasis is given to establishment of mechanisms. The initial study involved the understanding of the physiology and morphology of the flower in general. This was also combined with an in-depth study of the various activities happening at the macro and micro level, right from the development of the bud to the growth of various parts of the flower to its attainment of the full blossom.

The latter part of our work can be broadly looked upon as establishing the principles which makes the blossoming of the hibiscus possible and development of physical interpretations of the hibiscus flower using these principles.

ACKNOWLEDGEMENTS:

We would like to express our deepest gratitude to Prof. V. P. Bapat for his immense knowledge and valuable time spent over series of discussions at every stage of the project.
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To all our classmates and Shaktivel without whose help, this project would never have been a wonderful learning experience.

Aim:

To understand 'Biomimicry' - the act of looking at nature for inspiration, and differentiate it into five design approaches and study the degree of mimicry each has achieved

To study of the physiology of the Hibiscus (*Rosa sinensis*) and understand various mechanisms involved in the opening of the flower

To interpret two mechanisms which aid in flower blossom into a physical model

Methodology:

The study would be in three parts- **comprehension, analysis and synthesis**.

Part one- comprehension would include a detailed description of "Biomimicry", the various approaches to achieve it and the core intention of each approach

Part two- analysis would deal with the study of a Hibiscus flower, its physiology and the detailed analysis of all stages of flower blossoming, highlighting the underlying mechanisms

Part three - synthesis would summarize the inferences drawn through the analysis of the mechanisms involved in the opening of the flower and its interpretation in the form of physical models

Scope and Limitations:

The study would partly rely on published literature and many illustrations are from secondary sources.

Owing to time limit, the study has outlined only 7 major mechanisms of which only two have been interpreted.

Due to the absence of lab infrastructure, the experiments were conducted in a non-controlled environment.

PART ONE
COMPREHENSION

1.0 INTRODUCTION:

1.1 BIO-MIMETICS

Bio-mimetics is the technological outcome of the act of borrowing or stealing ideas from nature. It is also known as biomimesis, biognosis and bionics. It is difficult to trace the origins of this approach, since man has looked to nature for inspiration for more than 3000 years (when the Chinese hankered after an artificial silk). In modern times, the word "bionics" was coined by Jack Steele of the US Air Force in 1960 at a meeting at Wright-Patterson Air Force Base in Dayton, Ohio. He defined it as the science of systems which have some function copied from nature, or which represent characteristics of natural systems or their analogues. In 1966 R-G Busnel, of the animal acoustics laboratory in Jouy-en-Josas in France, organised a meeting on the theme "Biological models of animal sonar systems" in which the Office of Naval Research of the USA was involved. They had already funded other work in the general area of biological engineering, such as TorkelWeis-Fogh's work on resilin (a rubbery type of insect cuticle) and elastin in Cambridge. Busnel's meeting was one of the first at which these problems were discussed by biologists, engineers and mathematicians in order to discover general principles of technology.

The Eiffel Tower and Velcro have their inspirational origins firmly founded in nature. The stable wing plan-form designed by Ignaz and Igo Etrich in 1904, was derived from the large (15 cm span) winged seed of *Alsomitra macrocarpa*, a liana which grows on islands in the Pacific. There is argument as to whether Joseph Paxton really did get his ideas for the Crystal Palace from the leaves of a giant water lily. At least one version of a ribbed low-drag surface was derived from studies on shark skin. But nature can still give us confidence in the correctness of a result since computer techniques allow model structures to be modified in response to changing loads, producing very biological shapes in the process.

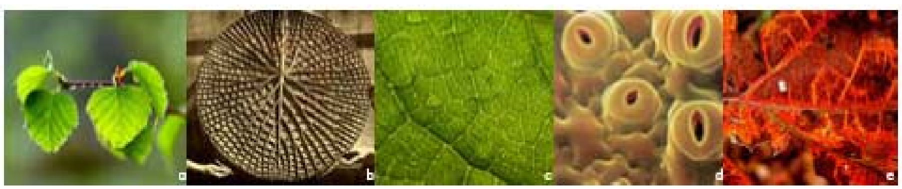
The interest lies not just in the abstraction of useful ideas from the living world but also in the process by which this is done. The underlying rationale is a common approach amongst both biologists and engineers – "expense". How much does it cost to design, make, maintain, and finally recycle, a structure? For engineering structures and materials this is a cash cost and the lowest believable tender wins the contract. For living organisms the cost is energy, and the competition is not that of the commercial market place, but the more severe one of nature, where the fittest survive and where failure equates with death. All organisms, whether of the same or different species, compete with each other for the available energy. Plants grow higher towards the sun and out of the shade of their rivals; animals fight for access to territory, sex and food.

The species which survives best is the one which leaves more viable offspring per unit energy input than its immediate rivals. The other functions of living (growth, repair, locomotion, etc.) all enhance survival. Depending on the lifestyle and habitat of the organism, the energy it has won has to be shared out optimally between these various functions. The design has to be properly stressed with the proper safety factors, materials have to be chosen for their intrinsic properties, appearance and durability, the necessary maintenance and management systems have to be integrated with the structure.

Since organisms have spent millions of years having their structures developed towards the greatest economy it seems rational that designers with their questions about materials, structures, and even mechanisms, should look to nature for an exposition of some energy-efficient answers to similar problems raised by technology.

1.2 DESIGN APPROACH

Many designers have looked at nature for inspiration and have come up with innovative ideas. Even before designers, indigenous cultures have mimicked nature in the process of coexisting with nature. They understood life's processes and lived in harmony with nature. Today in our civilized societies with culture defining our life we are unable to maintain this harmony and balance.



a - Showing form of hibiscus leaves,
b - Structure at the bottom of lily pad,
c - Vein pattern of a leaf,
d – Micro-photo of stomata which aid photosynthesis,
e - Decaying leaf.

In the realm of design nature has always been a source of inspiration. Though designers have looked into various aspects of nature, the aspect of integrated functionality has not been understood and employed in the design of our life systems.

For example one can look at a leaf and simulate its appearance, observe its geometry by which it achieves its form, gaze at it stability when it sways with the passing breeze, understand its structure and also learn its genius of harnessing energy from sunlight. But as we observe, the veins in a leaf contribute to the appearance, form geometry, structure and also photosynthesis and thereby the nourishment of the plant. Here the veins not only contribute to one defined function but form an integrated system achieving great efficiency. When one places this part in the whole, one can observe its efficiency in coexisting with other species within the complex interconnected ecological system. Even the way it decays, decomposes and becomes manure demonstrates its efficient system through which it becomes the part of the larger ecological system, forming closed loop systems.

The various ways to transfer technology from nature to everyday life is of much importance. Initially the nature of questions from engineering has to be identified and they have to be linked correctly to the answers from nature. There are so many mechanisms waiting to be discovered in biology that perhaps the study of living organisms is the basic science, and physics is just a special case. This type of technology transfer, where the origin of an idea may lie far outside the accepted limits of a subject area, comes into the general area of "creativity". This does not necessarily aid the generation of creative ideas, so in parallel the ideal is to generate a methodology which will achieve the same ends. At first sight this may seem counter intuitive.

If creativity is the means by which ideas can be generated, how can one generate them with a method which needs to have the ideas incorporated into it at the beginning? However, even the most creative person relies on the existing image bank from memory as the "database" for ideas. The ideal approach would be to identify the need at the functional level and develop solutions from analogies from nature.

1.3 BIOMIMETIC APPROACHES

"Simulation" involves feigning or copying the appearance of forms in nature. Buildings at this level do not aspire to any greater environmental responsibility.

"Interpretation" involves an understanding of the principles and working of nature and employing this interpretation in buildings. This approach can be further classified into Tectonic interpretation- which looks at geometry and structure and System interpretation- which looks at natural systems as a means to achieve high-energy and resource efficiency, thereby reducing their ecological footprint.

"Integration" as an approach tries to integrate the tectonics derived from forms in nature along with the efficient systems which can be derived from natural systems to make the building work more in harmony with the ecological system.

"Replication" approach can also be termed "elementary biomimicry". In this one tries to model natural processes, not by copying or interpreting specific solutions such as form, geometry, structure, function etc. but by approaching it as a cohesive whole. In short, it tries to attain the integrated functionality which is observed in nature like plants and other organisms which have the ability of self- cleaning, self-regulation, self-organization, even self-assembly and self- repair. This approach replicates such processes of self-cleaning, self- regulation and self- organization.

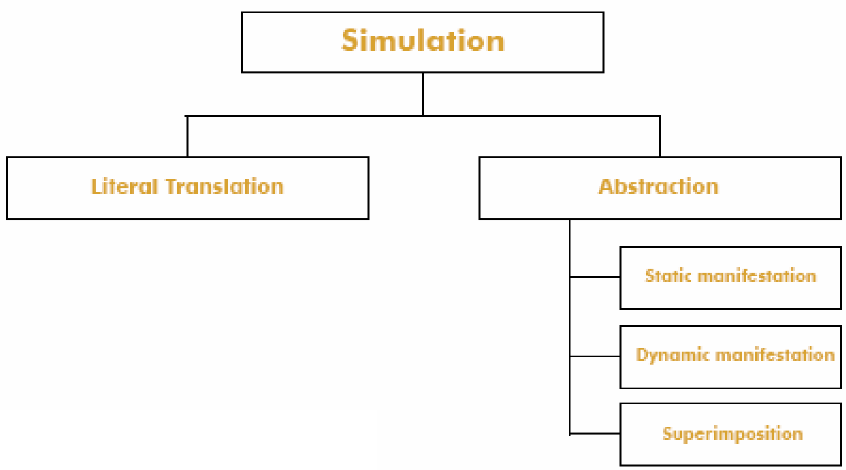
"Emulation" can be termed as "advanced biomimicry," which is based on modeling natural processes to the degree of self-assembly and self-repair. Before analyzing these approaches one needs to get an understanding of the relation between man and nature. A brief historical overview can help understanding this relation and later, to critically look at these approaches and analyze them.

Each of these approaches are discussed in detail in the following pages.

1.4 SIMULATION

Simulation involves feigning or copying the appearance of forms from nature. Buildings at this level do not aspire to any greater environmental responsibility. The intention of this approach is to achieve tectonics which are mimicked from nature and technology becomes the tool in realizing such forms.

Simulation as an approach is not new. Age old civilizations such as the Egyptian and Greek civilizations constructed buildings with elements copied from natural forms like the bud capital in the temple of *Amun* in Karnak and the *Erecthion* in Athens. The architecture of Renaissance and Baroque has also copied natural forms in their ornamentations. Even the *gopurams* in Indian temple architecture imitate the mythical *meru.*



The Art Nouveau was the first full-fledged architectural movement to take on the natural world with an impulse to celebrate nature. However the lack of wherewithal to follow it through resulted in very few buildings which were built following this style. For most, it proved too expensive to cut each piece of glass or bend each piece of wrought iron by hand to create the desired effect.

1.4.1 LITERAL TRANSLATION

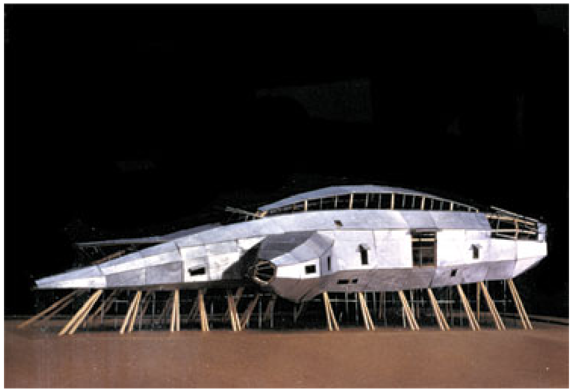
As the name suggests, this approach involves copying nature's form and appearance literally. The scale of the mimicked natural form might greatly vary from the original inspiration. The competition scheme for seafront development in Morcambe by Birds Portchmouth Russum is a good example where the architects have literally copied the form of shrimps which happens to be a local delicacy. In these shrimp like massive steel structures are accommodated various functions such as a marina, an amusement arcade, a theatre and a concert hall becoming a monumental feature on the coastline.

"Imitation is our primary source for form, and at root we can only imitate nature" –
Michael Sorkin
Williams, Hugh Aldersey-*Zoomorphic*- New Animal Architecture, Laurence King, U.K,2003, p.65.

Simulation approach encompasses built forms which are literally translated or abstracted from nature. Most buildings out of this approach are given a biomorphic character by enlarging the scale of the inspired natural form. Depending upon the degree of detail preserved in the designed artifact, simulation approach can happen at two levels- One is through literally translating the form and the other by abstracting it. The degree of abstraction depends upon the strength of the metaphor the designer wants to convey through such symbolic biomorphic form in a particular context.

1.4.2 THE CARP

A series of so-called Beached Houses by **Michael Sorkin Studio** are individually named Carp, Ray and Slug. Each is a straightforward two-storey house, but the animal resemblance remains strong in the overall form, and in the cladding which resembles scales. The asymmetric kick in the tail increases the aura of life.
(http://www.vam.ac.uk/vastatic/microsites/1269_zoomorphic/homepage.htm)



"Fish are symmetrical but only until they wiggle. Our effort is to measure the space between the fish and the wiggle. This is the study of a life time."
– *Michael Sorkin*

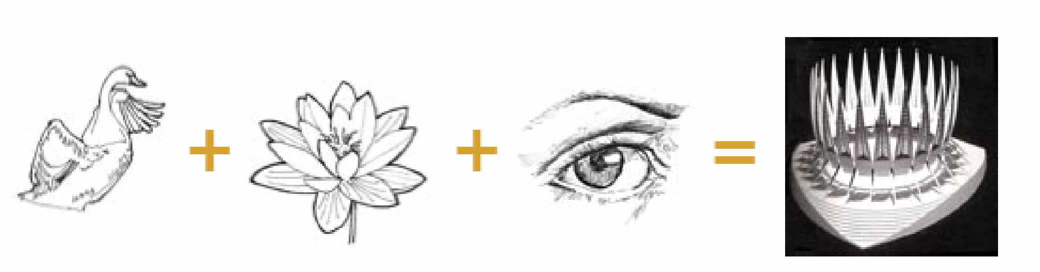
1.4.3 ABSTRACTION

Abstraction is the process of reducing the information content of a concept, typically in order to retain only information which is relevant for a particular purpose.*
*See http://en.wikipedia.org/wiki/Abstraction

Going further from just copying the exact forms in nature, in this approach one goes on to abstracting forms which in their essence could be associated to natural forms. While abstracting such forms, some designers look at the static attributes and others the dynamic attributes. Designers manifest their buildings in static equilibrium and demonstrate the dynamic character in the static state or might go one step further to result in dynamic equilibrium, where parts of the building start moving.

In the contemporary scenario, architect and engineer **Santiago Calatrava** abstracts the attribute of movement in natural forms and manifests it dynamically in several of his sculptures and buildings. His building complexes fit and enhance the landscape like enormous living organisms growing out of it or living within it. However, his forms do not merely copy the formal aspects but also takes cues from the skeletal, circulatory system and the skin of the organisms, many forms focusing on how the human body functions and flourishes. He symbiotically unifies these attributes such as structure and movement which he gets inspired from natural forms.**

**Extract from Tzonis, Alexander, Santiago Calatrava- *The Poetics of Movement*, Thames and Hudson London, 2002, p.12.



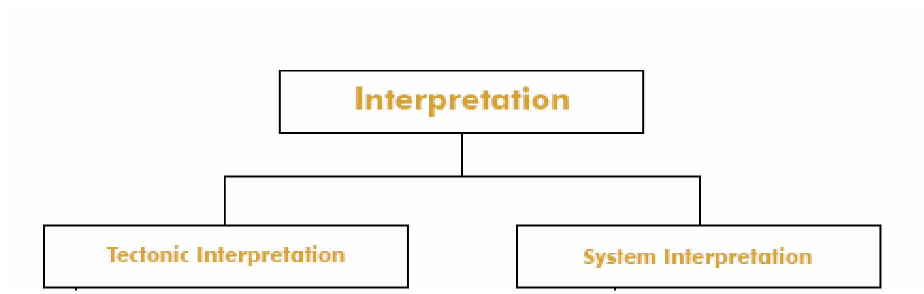
Swiss Confederation Pavilion is a composite structure where superimposed the image of a gliding swan has been superimposed with an image of a slowly dilating water lily. A third image of an opening and closing eye is in turn super imposed on this water lily and all have been integrated into a new cognitive composite.

In the Kuwaiti Pavilion, there is similar agreement in superimposition of meanings on the moving elements of the structure. When the roof opens it resembles a spreading falcon's wings, an image of waving palms are superimposed while the roof moves and the image of interlocking fingers is assumed when the roof elements come together.

1.5 INTERPRETATION:

Interpretation as an approach involves the understanding of the principles of nature (geometry and structure) and the interactions between the built and natural environments and employing this understanding in design. The intention of this approach is to achieve systems which are derived from nature by understanding the principles and functioning of natural systems.

"We do not seek to imitate nature, but rather to find the principles she uses"[1] – Buckminster Fuller

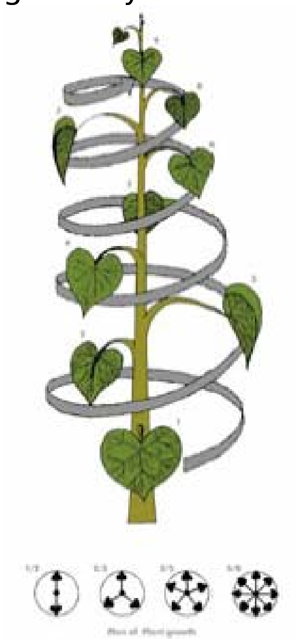


1.5.1 TECTONIC INTERPRETATION:

Geometry and structure have an integral relationship. Geometry is the spatial arrangement of objects or constituent parts. Structure inherently has a geometric definition even though it might be irregular at times.
While the fundamentals such as symmetry, proportions and fractals have been interpreted and employed as geometrical systems in buildings and design, forces in nature have been interpreted and employed to achieve structural systems. Such structural systems too inherently possess a geometrical system.

The principles of nature such as geometry and structure is based on human perception. Perception is the result of experiential stimuli, images stored in the mind, and basic human motivation to understand.

Geometry is a human construct which is derived from observing nature's generative process and evolution. Therefore geometry in itself is a concept which interprets nature (rational geometry).



The above figure shows the growth of new leaves from the stem of a plant which occurs in sequences that describe a spiral. The amount of turning from one leaf to the next is a fraction of a complete rotation around the stem. The fraction is always one of the Fibonacci fractions. Nature spaces leaves in this manner to avoid higher level leaves shading the lower ones from the nourishing rays of the sun. In the figure shown there are five complete turns, with eight spaces between the leaves 1 to 9, so that the ratio of the spiral is 5:8.

Nature is characterized not by fixed geometries (Euclidean geometry), but by evolving ones: geometries that are mathematically accelerating or decelerating.

- Symmetry
- Proportions
- Fractals

are 3 important geometrical characteristics of nature which accelerate or decelerate as nature grows and evolves.

1.5.1.1 SYMMETRY

Symmetry - an exact correspondence, in relative position, size, and shape of the parts of something with respect to a central point or one or more dividing lines or planes in an object or structure.10Symmetry in nature occurs due to growth and movement. Symmetry can be classified as bilateral symmetry, cylindrical symmetry and spherical symmetry depending on the number of dividing lines or planes

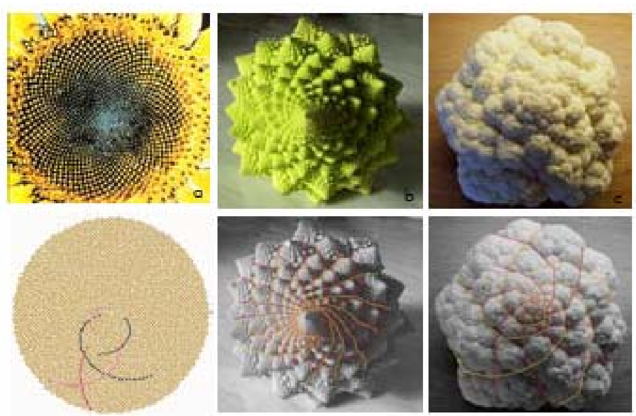
Air breathing animals must fight against the force of gravity; in the struggle, any up – down symmetry, that is symmetry about an imaginary horizontal plane perpendicular to the line of action of the gravitational force, is lost. Many water creatures effectively exist in zero gravity environments, and retain this symmetry in large measure. The requirement to find food and escape predators demands a means of independent locomotion, which then destroys symmetry along the front-back axis.

1.5.1.2 PROPORTION

Proportion is an ordered relationship between two comparable entities. It is the relationship of one part to another or to the whole, or between one object and another. The apparent size of the object is influenced by the relative sizes of other objects in its environment. Proportion is an inherent phenomenon in nature which is a resultant of generative processes and growth which are universal to all forms of nature. It is through this that forms in nature achieve unity and harmony though they have diverse generative processes. Many natural forms show proportions through rhythmic progressions like in shells, horns, flowers, tree branches etc.*

*Berry, Shagun- *Harmony*- An Exploration into the Process of Creation in Nature and Architecture, Unpublished thesis, School of Architecture, Ahmedabad,1997, p.1.

Most of such spirals that occur in nature and other natural forms which grow follow a progression known as Fibonacci sequence. The Fibonacci sequence (1,1,2,3,5,8,13,21,34,55…) has a unique character wherein each number in the series is the sum of the two preceding numbers. The ratio between two successive numbers remains almost a constant, (1/1=1, 2/1=2, 3/2=1.5, 5/3=1.666, 8/5= 1.6, 13/8= 1.625, 21/13 =1.61538… and so on) settles down to a settling value approximately 1.618034 which is known as the Golden ratio or “Phi”.



The illustrations above show spirals observed in natural forms such as sunflower (*Phyllotaxis*), Romanesque broccoli and the cauliflower. The same happens in many seeds and flower heads in nature. The reason seems to be that this arrangement forms an optimal packing of the seeds so that, no matter how large the seed head, they are uniformly packed at any stage. All the seeds being the same size, there is no crowding in the centre and are not too sparse at the edges.*

*see http://www.mcs.surrey.ac.uk/Personal/R.Knott/Fibonacci/fibnat.html

1.5.1.3 FRACTAL GEOMETRY:

Fractal geometry is the study of mathematical shapes that display a cascade of never-ending, self similar, meandering detail as one observes them closely. Leaves, branching in trees, mountain edges, flood levels of a river, wave patterns, nerve impulses and other such natural forms and formations display this progression of self-similar form. Apart from nature's physical form, the way nature changes through time is also fractal. Richard Voss in 'The Science of Fractal Images' points out that ocean flows, changes in the yearly flood levels of the Nile river, and voltages across nerve membranes display fractal characteristic*

* See Bovill, Carl- *Fractal Geometry in Architecture and Design*, Birkhauser ,Boston 1996, p.3

In contemporary design, the idea of order is understood differently. Modern sciences and theories such as the theory of relativity and chaos - which explain the non-linear phenomenon and complex behaviour of natural systems - views order as a uniformity that arises out of chaos or extreme disorder. Many contemporary designers use fractal analogies to represent this idea of order created by disorder in nature. Therefore, in the contemporary approaches the intent is to achieve not an aesthetic order, but rather a representation of the complex order that exists in nature.

1.5.2 STRUCTURAL INTERPRETATION:

Nature proves to be in a state of constant motion. Animals, birds, trees and even mountains - all are constantly moving, flying, swaying and morphing. Such movement is momentary and leaves the overall stability and permanence of the body and structure undisturbed. All anatomical structures of natural forms are a resultant of the action of gravity, growth and movement. It is within these laws of nature that such diverse forms have evolved.*

"The form of an object is a diagram of forces" - D'Arcy Wentworth Thompson

D'Arcy Thompson says, "morphology is not only a study of material things and the forms of material things, but its dynamic aspect, the interpretation in terms of force and the operations of energy.

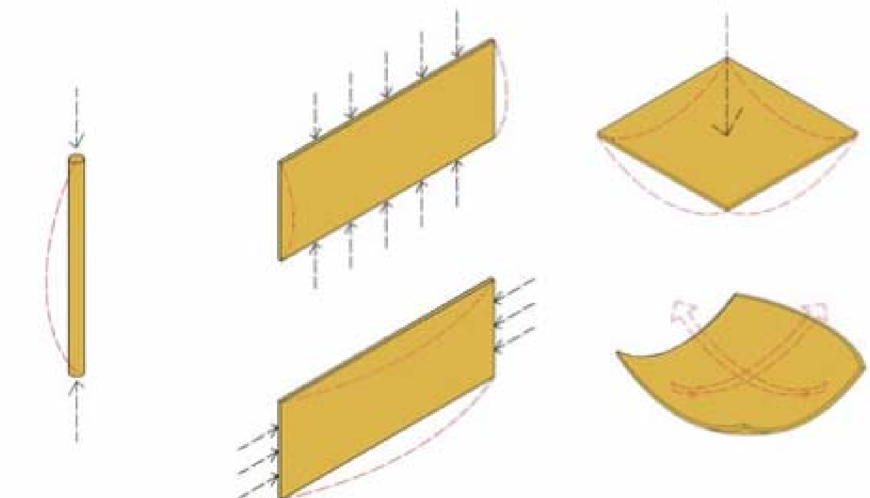
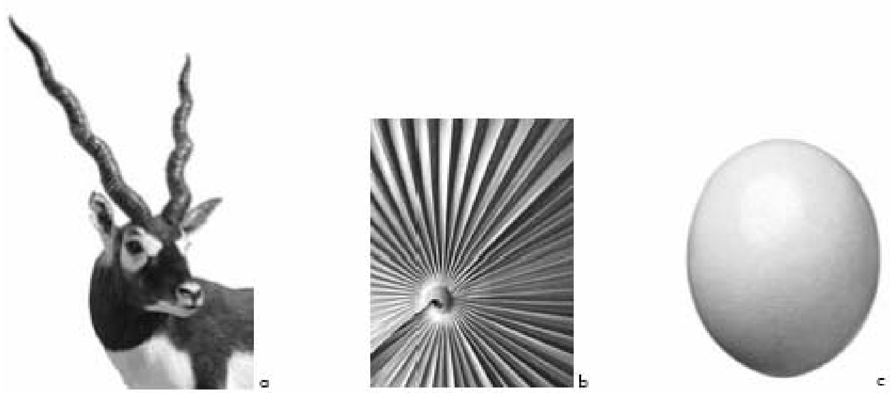
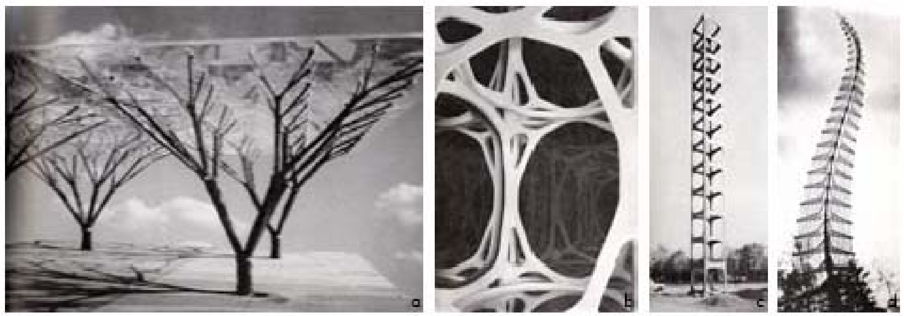


Figure 4.31
Linear (one dimensional) Planar (two dimensional) Space (three dimensional)



Natural forms have evolved to be structurally stable configurations by reducing the bending moments efficiently with optimum usage of material. Black Buck's horns, avoids linear bending by twisting into a helix, a palm leaf gets its structural stability through laminar folding (corrugation) and an ostrich egg shell forms a three dimensional hard surface relatively to the amount of material used.

The idea of material optimization through an efficient structural configuration has been interpreted from nature. An optimized structural system allows minimum bending to occur by using pure stresses. Based of the attribute of pure stresses the elements making the structural configuration can be classified as linear - (straight prestressed, inclined tensioned, catenary shapes) and Surface- (planar prestressed, surfaces curved in one direction and Surfaces curved in two directions). Conoids and vaults are types of surfaces curved in one direction, while surfaces curved in two directions can be further classified as synclastic and anticlastic.



Frei Otto's experimental structures:

a- **Tree structure** (1960), derived by hanging a plane surface from 4 high points and 256 low points by a symmetrical system of turcated strands. The compression members are obtained by stiffening and then inverting the suspension model.

b- **Space frame** (1962), a minimal lattice structure which avoids bending by short compression members and rigid joints which resemble the internal structure of bones.

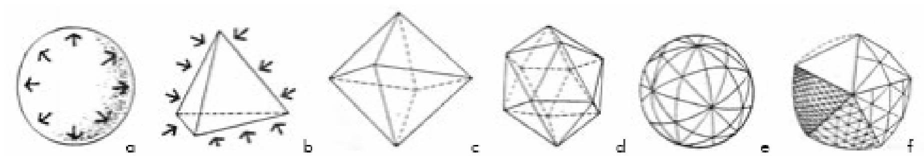
c- The **Bell tower** of the Protestant Church in Berlin (1963), 24 meter high supporting heavy bells was evolved from the study of lattice frame-work and rigid joints in Radilarian forms and Diatoms.

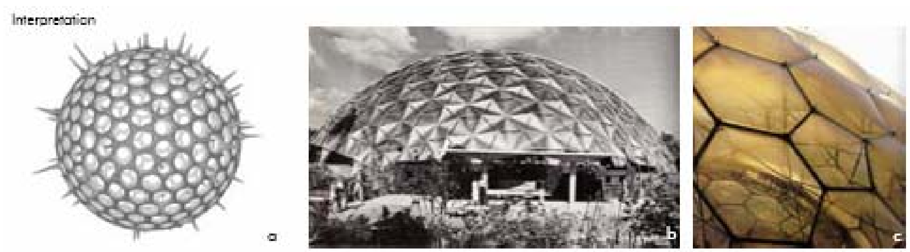
d- **Flexible column** (1963) with a central compression member and cables in tension resembling a vertebral column of a giant dinosaur.

Buckminster Fuller's study of the three dimensional arrangement of polyhedral cells in chemical structures led to his invention of the resource-efficient geodesic dome, an application of natural structure.
Triangle is an inherently stable and structurally efficient shape. The "network of triangles" is an organizational pattern that recurs throughout nature. Triangular networks facilitate the closest packing of the parts which is necessary for efficiency. Like the packing of hexagonal cells in honeycombs, soap bubbles forming an irregular triangular network. Seen three-dimensionally, soap bubbles always meet in three around the vertex. Arrays of soap bubbles form an irregular triangular network consisting of tetrahedral. Triangular shapes and tetrahedral networks

are also used for their high strength to weight ratios in architectural engineering. For example, the archetypes of truss, folded plate, space frame, and geodesic dome.

Fuller assumed that the most economical structural energy web might be derived through the fusion of tetrahedron and sphere. The sphere encloses most space with the least surface and is strong against internal pressure (the case of a complete soap bubble); the tetrahedron encloses least space with maximum surface and is the strongest against external pressure. This may be accomplished via icosahedrons, a multiphase tetrahedral, all of whose vertices lie on the surface of a sphere. By exploding this form onto the sphere and symmetrically subdividing its faces, we arrive at a three way circular grid of the geodesic structure.





Following geodesics, Fuller developed "Tensegrity", through the phenomenon of energetic and synergetic geometry. Tensegrity (Tension and integrity) is a structural system wherein the parts are polarized into compression and tension members.

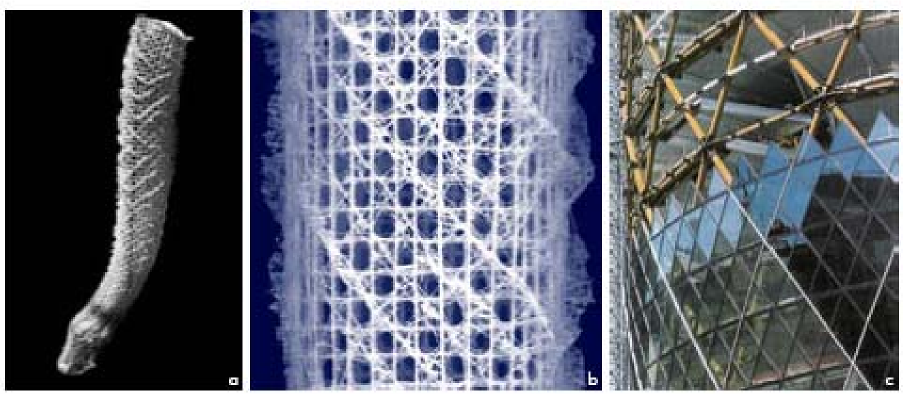
The structural interpretation approach largely concerns the usage of minimum material and achieving high structural strength like in natural systems.

1.6 INTEGRATION:

"Integration" as an approach deals with integrating the tectonics interpreted from nature as well as the efficient systems derived from nature to make the building work efficiently, in harmony with the ecological system. This approach can be viewed as an integration of the tectonic and the system interpretation approaches discussed in the earlier section.

Biomimetic approaches envisage achieving the integrated functionality of nature and fitting form to function. They assume nature as a model, mentor and measure and also try to employ bottom up emergence rather than top down imposition.

In the integration approach one can integrate formal expression or tectonics interpreted from biological forms sequentially adapting efficient system to arrive at a low-energy building that would work efficiently with nature's dynamic systems, where one complements the other. The 30-St. Mark Axe designed by Norman Foster (1997-2004) is a 40-storey high rise building housing the Swiss re-headquarters. The building is generally called as 'The Gherkin' - a young cucumber used for pickling as it resembles one, in its form. It is claimed to be the first environmentally progressive high-rise building using passive energy saving systems.



a - Exoskeleton of '*Euplectella*' sea sponge with the opening at the top (*osculum*).
b - Detail of the helically wound lattice structure in *Euplectella.*
c - Structural configuation showing tubular helical struts with triangular faceted glass cladding.

1.6.1 FORM:

The building's form resembles various sea sponges. Among many small marine creatures that affix themselves to the seabed, among them glass sponges (*Porifera*), anemones and Foraminifera (the word means hole bearing or perforated) have calcareous or siliceous elongated exoskeletons. As the animal grows, it builds up a tracery of geometric regularity. These delicate frames are sufficient to support and protect the enclosed soft body of the organism in the gravity-neutral deep-sea environment.

1.6.2 STRUCTURE:

The structure of this gherkin-shaped building is made up of an external diagonal grid of steel beams stiffened by horizontal hoops. The curved, tapering structure is realized through the use of a diagonal steel structure called a diagrid, made from intersecting tubular steel sections which give vertical support to the floors, rendering them column-free. The diagonal matrix has light wells/ventilation shafts that spiral up the building and break up each floor's circular plan into smaller areas.

When the diameter of the sponge's skeleton increases beyond a certain point the outer structure is reinforced by ridges in a spiral pattern which counteract an effect known as "ovalization", Stabilizing its skeleton with external ridges, the sponge makes itself difficult to crush as against regular cylindrical structures. These sponges are formed perfectly with exactly the right amount of material needed to optimize the design.

1.6.3 COEXISTENCE WITH NATURAL FORCES:

The tower is aerodynamically designed to reduce wind load on the structure, whilst the lower part tapers so that wind wraps around the tower and reduces the incidence of downdraught on the surrounding plaza. The grid is highly resistant to wind loading and weighs 2,500 tonnes.

The integration approach is an aggregation of concepts put together to form a cohesive whole as a building system which functions efficiently reducing energy consumption and with it also symbiotically unifying the tectonics derived from natural forms. The dynamics of nature is being reflexive and transformational due to generative processes; it follows a higher order of integration forming a complex whole.

1.7 REPLICATION:

"Replication" approach might also be termed "elementary biomimicry". In this, one understands and models natural processes not by copying or interpreting specific solutions such as form, geometry, structure, function etc. but by approaching it as a cohesive whole. In short, one tries to replicate the integrated functionality which is observed in nature.

Plants and organisms have the ability of self-cleaning, self-regulation, self- organization and even self- assembly and self-repair as they grow, evolve and adapt to their immediate, changing and dynamic environment. Self-organization is a process in which the internal organization of the system adapts to the environment to promote a specific function without being controlled from outside. In biology, this includes the processes that concern developmental biology, which is the study of growth and development of organisms and comprises the genetic control of the cell growth, differentiation and morphogenesis.*

**Techniques and Technologies in Morphogenetic Design*, Architectural Design Journal edited by Helen Castle, Academy Editions, London, Vol. 76 No 2, Issue March/April 2006, p.13

The replication approach mimics the processes of self-cleaning, self-regulation and self-organizing from natural systems.

1.7.1 SELF- CLEANING:

In nature, plants are exposed to different kinds of contamination. Leaves which have rough surfaces display a self-cleaning phenomenon wherein the adhesion between the contaminant and the leaf is reduced by virtue of its rough surface. Also the water which comes in contact with the surface does not really stick to the surface. When a water droplet rolls over the dirt particle, the particle is wetted and adheres to the surface of the droplet and is thus taken away and removed from leaf's surface. This can be clearly observed in a lotus leaf.

a - Lotus leaf (*nelumbo nucifera*).The water droplets touch the leaf's surface only at few points forming balls as it completely rolls off at the slightest declination.

b - Magnified picture of the water droplet absorbing particles of dirt as it rolls.

c - Microscopic picture of the lotus leaf's surface. A double structured surface optimized through the combination of micro- (cells) and nanostructure (wax crystals) contact areas are minimized.

The process of self-cleaning by replicating the nano surface structure of lotus leaf is used in surface finishes of buildings such as exterior paints, wood surfaces, masonry etc. There are also sprays of aerosols which are developed which could be sprayed onto various surfaces to achieve this nano-surface texture.

a - 'Lotus effect' aerosol sprayed on a wooden surface making it water repellant.

b - Exterior paint, self-cleaning with rainfall

1.7.2 SELF- REGULATION

Natural systems are quite different wherein most of the sensing, decision making and reactions are entirely local and the global behavior is the product of these local actions. This is true across all scales, from small plants to large mammals.

Plants, lacking a central nervous system like mammalian brains, make growth movements to orient themselves to the sun or to correct their inclination.*

*Jeronimidis,George-*Biodynamics*-Emergence: Morphogenetic Design Strategies-Architectural Design Journal edited by Michael Hensel, Achim Menges and Michael Weinstock, Academy Editions, London, Vol. 74 No 3, Issue May/June 2004, p.92

1.7.3 SELF – ORGANISATION

Nature's complex forms and systems arise from evolutionary processes of self-organization. Living forms grow, and growth is a complex process, intertwining contributions of the genotype with the phenotype. In nature the genotype comprises of a genetic constitution of an individual organism, while phenotype is the characteristics of that individual organism resulting from the interactions between the genotype and the environment. The properties of natural forms stem from the generative processes that work upon successive versions (generations) of the genome. This genome is the compact data that is transformed into the biomass of increasing complexity through generations.**

**Weinstock, Michael- *Morphogenesis and the Mathematics Of Emergence*,Emergence: Morphogenetic Design Strategies, Architectural Design Journal edited by Michael Hensel, Achim Menges and Michael Weinstock , Academy Editions, London,Vol. 74 No 3, Issue- May/June 2004 p.-10-17

Flocks of birds and schools of fish produce what appears to be an overall coherent form or array, without any leader or central directing intelligence. Insects such as bees and termites produce complex built habitats and highly organized functional specializations without central planning or instructions. Structured behavior emerges from the repetition and interaction of simple rules. Complex patterns emerge from these distributed dynamic models.

Form and behavior emerge from the processes of complex systems. Processes produce, elaborate and maintain the form of natural systems and these processes include dynamic exchanges with the environment. There are generic patterns in the process of self-generation of forms, and in forms themselves. Geometry has both local and global role in the dynamics of form in self-organized morphogenesis.

Living organisms are made of materials wherein the structural logics, feedback, growth adaptation and evolutionary characteristics are embedded within the material itself (like the DNA). The next degree of biomimicry, where buildings have the ability to self-assemble and self- repair awaits the emergence of intelligent materials which have embedded logics of growth, adaptation and evolution.

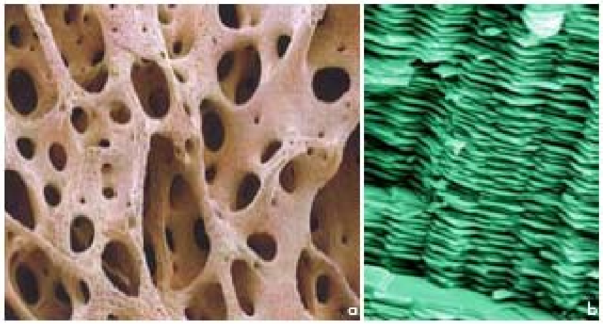
1.8 EMULATION

Emulation can be termed as "advanced biomimicry," it is based on modeling natural processes to the degree of self-assembly and self-repair leading to a holistic, integrated functionality like natural systems.

Natural materials develop under load, and the intricate interior structure of biological materials is an evolutionary response. At the level of the individual, there is also an adaptive response as, for example, bone tissue gets denser in response to repeated loads, in athletic activities such as weightlifting. Bone is a cellular solid, a porous material that has an appearance of mineralized foam, and its interior is a network of very small and intricately connected structures. When a bone becomes less dense, due to age or prolonged inactivity, it is the very small connective material that vanishes, so that the spaces or cells within the bone become larger making it weaker. Such evolutionary processes, responsive to the external conditions occur in natural materials due to self-organization at the molecular level. This can also be observed in the 'mother of pearl' shells which self-assemble layer by layer, to respond to the external forces.*

*Weinstock, Micheal – *Self- Organisation and Material Constructions*- Techniques and Technologies in Morphogenetic Design, Architectural Design Journal edited by Helen Castle, Academy Editions, London, Vol. 76 No 2, Issue- March/April 2006p.35

In natural material systems, the materials which make up the structure and the control systems (which aid in growth and responsive stimuli) do not function in self-autonomy. Natural materials have an intrinsic property of responsive stimuli and adaptation to the changing environment as they are embedded with a genetic code (DNA). Over long periods of time as these material systems respond to similar patterns of changes in the environment, plants and organisms adapt and evolve. Development of synthetic material systems through bio-chemical processes which have similar properties to that of biological materials, have advanced to a great degree in contemporary material sciences. The synthetic materials developed are already in use in maritime, aerospace and medical fields.



a - Spongy bone tissue, Scanning electron micrograph of cancellous (spongy) bone tissue. Bone can be either cortical(compact solid) or cancellous tissue forming the interior. The cellular structure is highly differentiated forming an irregular network of trabeculae or rod shaped fibrous tissue. Open spaces within the tissue are filled with bone marrow.

b - Oysters (or mother-of-pearl) have a strong layer of armour called nacre . The substance is made up of tiny crystals pieced together like the bricks and mortar of a brick wall, as seen in this micrograph.Synthetic materials are developed from microplates of ceramic such as alumina joined by metal mortar which have a layered structure like that of natural mother-of-pearl. They are used in producing shatter proof glass and protective armours.

The synthetic spider silk is one such example of a bio- chemically processed synthetic material. Natural spider silk is five times stronger than steel of the same dimension and can elongate four times its length and can resume its original state by just absorbing moisture. This elastic behavior occurs in the spider's web to absorb the impact created while a prey is captured. Scientists are now developing synthetic spider silk which have similar elastic properties. Such variable- stiffness property in the material would find a wide application in building systems which require multiple states equilibrium to respond to the transient environmental conditions. The synthetic spider silk is produced through proteins in bacteria that can self–assemble themselves in room temperature, quite contrasting to the "Heat- Beat-Treat" processes, like that of industrial materials, where huge amounts of energy is expelled. The synthetic silk produced, are now extensively used in medical applications. There are synthetic silk messes and nano-tubes which are used in surgeries to replace torn tissues and replace ruptured arteries, also synthetic silk thread are used for stitching wounds.

Cellular materials are synthetically developed on the basis of the internal cellular structure of bones observed in nature. A wide range of foamed cellular metals and ceramics are developed, which are light in weight and can withstand high stresses. The cellular ceramics developed are implanted as bone grafts in surgeries.

2.0 CASE STUDY

2.1 THE GEOMETRY OF UNFOLDING LEAVES

H. Kobayashi, B.Kresling and J.F.V Vincent

Leaves of hornbeam (Carpinus betulus) and beech (Fagus sylvaticus) were modelled to a first approximation as plane surfaces, with straight parallel folds, using numerical methods. In both species the lateral veins, when the leaves are outstretched, are angled at 30^0 and 50^0 from the centre vein. A higher angle allows the leaf to be folded more compactly within the bud, but it takes longer to expand. This may allow the plant to optimize the timing of leaf deployment with ecological and physiological conditions.

The leaves of most plants are folded or rolled while still inside the bud. Leaves of hornbeam and beech have relatively simple and regular corrugated folding patterns and mechanisms, which can suggest ideas for the design of deployable structures such as solar panels and light-weight antennae of satellites, or for the folding of deployable membranes such as tents, clothes or other coverings.

Deployable structures have been studied for use in aerospace (Unda et al. 1994). A two-dimensional expandable array was proposed by Miura (1980) for a solar panel whose folding pattern has been called `Miura-Ori' (Miura & Natori 1985). A thin membrane wrapped around a central hub was examined by Guest & Pellegrino (1992) as a design for a solar sail. Several concepts of deployable aerospace structure have been described (Miura 1993).

A number of biological folding patterns have been investigated, concentrating on mechanisms for stiffening and deployment. A series of studies using a cylindrical shell model based on a biological structure (Calladine1978) was carried out by Guest & Pellegrino. The force required to fold the cylinder was examined theoretically and experimentally using a model consisting of identical triangular panels along a helical strip.

Wing folding of insects has also been investigated (Wootton 1981; Kesel 1994; Brackenbury 1994). The geometry and mechanics of wing folding of Coleoptera have been studied using vector analysis (Haas 1994). Although many folding patterns can be found in plant structures (Delarue 1991; Kresling 1991, 1995), there have been few studies from a mechanical point of view.

The unfolding of a leaf is described with a straight central (primary, main) vein and symmetrically arranged parallel lateral (secondary) veins that generate a corrugated surface. This morphology is relatively simple, so the description seems to be suited to the first step in the study of leaf folding. Numerical models with different angles between main and secondary veins were made to simulate the unfolding of such a corrugated leaf. Using vector analysis, angles of laminar element planes divided by creases and locations of creases, which correspond to veins, and the development of leaf area during unfolding, were calculated.

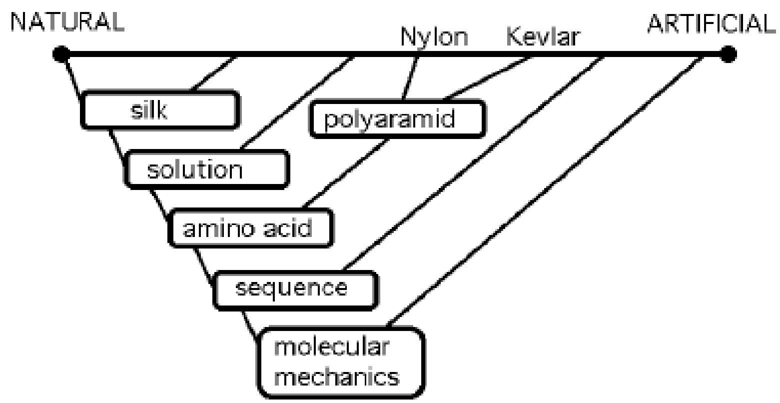
2.2 BIOMIMETICS OF DEPLOYABLE STRUCTURES

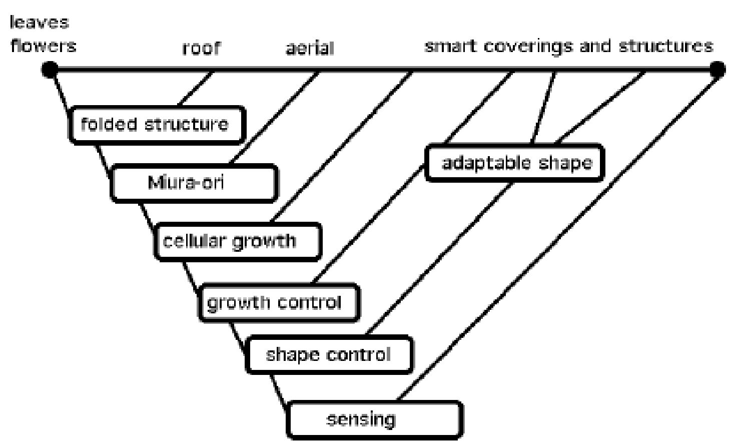
2.2.1 STRUCTURE - FOLDED PLATES AND TUBES

The research offers ideas for easily deployed roofing or umbrellas. Unlike the radial actuation of the traditional umbrella and its derivatives, a cover based on the leaf could be deployed and supported from a single extending strut. In a radial leaf, experimentation shows that it can be actuated from a single fold. Concepts based on folded insect wings would probably be rather more difficult to implement since the wing is actuated only from the base, so there may be inertial problems. However, some of the locking mechanisms, based on control of elastic buckling, may well prove interesting. They remain to be analysed in natural systems. The tube of the nematocyst offers some intriguing possibilities, especially in the medical world where a deployable tube could be used as a tent, which is a tube used to hold open a duct, vein or artery. Since the nematocyst tube deploys very quickly and without snagging, its geometry must be suitable for the sort of remote control which modern surgery demands.

Tape springs, which are something like the butterfly proboscis, are already widely used in aerospace for deployable antennae. This structure has not been arrived at by copying nature. One of the problems with the tape spring is its stability, since a structure which has been folded in this manner is in a high-energy, unstable configuration and has to be kept within a deployment mechanism which prevents it from jumping towards more stable configurations. Another problem is the deployment mechanism, which can be heavier and more complex than the antenna itself.

A bi-stable version of this mechanism has the tape of composite construction with fibres at 45 degree to the long axis relying on a strain energy minimum between the two states to keep each state stable. The biological version of this type of structure is stable in the coiled conformation and appears to require energy input to keep it extended. It can also be steered remotely and has terminal sensors.





The transfer of knowledge from nature to technology can be mapped to better understand the way in which it is conducted. The general concept of the map is that the natural origin is plotted top left, further down the more general and following these, more specific properties which relate more to materials. The map suggests that the more basic a property is within a structure, the easier it is to extrapolate that function into another area.

2.2.2 INTERNAL PRESSURE

Pneumatic structures, the closest technology to the hydraulic structures of plants and molluscs, have been studied for some 40 years. Despite the excellent insulation properties of air, minimal use of materials, light weight and cheap construction methods, they are difficult to design, non-linear, cannot take high loads and suitably strong, hard-wearing, fabrics are not available.

Early inflatable structures tended to be over symmetrical, repetitive in form and dull to look at and acquired a reputation for unpredictability. Modern computer techniques using finite elements, developed for the design of tensile structures, are opening the way for the design of deployable pneumatic structures which can be more exciting that the average bouncy castle. A concept which does not seem to have been explored, which occurs more frequently than one might think in nature, is using hydraulic pressure to store strain energy in an elastic component. This is the underlying principle of the Venus Fly Trap and very probably in other micro-mechanisms involved with pollination, for instance in orchids where a mechanism in the pollen-bearing part of the flower bends over and sticks on to the back of a visiting insect.

The elastic energy stored is the cellulose in the walls of the cells containing the pressurised liquid; the liquid is more or less incompressible. This approach has the advantage of power amplification, so that the strain energy can be accumulated at a low work rate and released suddenly. This would be useful to power an intermittently working deployment mechanism where power is at a premium, for instance on board a satellite.

PART TWO
ANALYSIS

3.0 PLANT PHYSIOLOGY

3.1 HIBISCUS ROSA SINENSIS

About 200 species of hibiscus are known to exist, and each species has its own unique kind of flower. The **Chinese hibiscus** (*Hibiscus rosa-sinensis*, family Malvaceae) is an evergreen shrub native to East Asia, also known as China rose and Shoe flower. It is widely grown as an ornamental plant throughout the tropics and subtropics. The flowers are large, red, firm, but lack any scent. Numerous cultivars, varieties, and hybrids have been created, with flower colors ranging from white through yellow and orange to scarlet and shades of pink, with both single and double sets of petals.

Hibiscus rosa-sinensis is the national flower of Malaysia, called the *Bunga Raya* in Malay and "Sembaruthi" in Tamil.

3.2 SCIENTIFIC CLASSIFICATION

Kingdom:	Plantae
Division:	Magnoliophyta
Class:	Magnoliopsida
Order:	Malvales
Family:	Malvaceae
Genus:	*Hibiscus*
Species:	H. rosa-sinensis

3.3 STRUCTURE OF FLOWER

Hibiscus belongs to the dicotyledons family. Being a bi-sexual flower, it contains functional male and female parts together. The stamens are composed of pollen producing anthers which are attached atop a stem-like filament. The filaments unite at their bases to form a tube called the staminal tube, surrounding the flowers long style. The hibiscus has many stamens. The staminal column at the apex separates into five style branches. Single bloom typically have five petals, five stigma pads, a five cell ovary, five teeth on the calyx and five to ten bracts. The style which emerges from the bottom of the sepals is the tallest part and supports androecium and gynaecium. The bottom of the style is the ovary.

The stamen is a simple structure with the filaments surmounted by the anther. A single vascular bundle runs through a filament and ends bluntly in the connective which is located between two anther lobes. The bundle of the filament is usually amphicribal and remains surrounded by vacuolateral perenchyma cells without conspicuous intracellular spaces. The ovules occur in the ovarion wall attached to the parenchymalous outgrowths, the placenta normally at the regions where the margins of the folded carpels meet.

The shape of the petal is that of one which is curled in spirals at the beginning of the blossoming process changes to expand and reverse curl. The flexible yet tight petal surface is an inspiration of self standing structure that changes its shape for its requirements. In the bud shape the flower by virtue of its form tries to occupy minimum volume. Later when required, for pollination it acquires a full blossom state for which it needs to expand to the maximum area and hence acquire reverse curl structure. Even when the flower dies, the vein structure of the flower collapses to add weight to itself causing it to fall.

The veins of the hibiscus petal form the structure to support the petal. It also carries food and nourishment for the cells in the petal. The arrangement of the veins is such that it is denser at the bottom of the petal. There the petal is strong while at the open end it needs to be flexible and hence veins are less dense. The thickness hence varies from maximum at bottom of the petal to minimum at the open end.

Structurally and developmentally the floral apex resembles the shoot apex in almost all fundamental features, slight differences that exist are due to the fact that the flower is a determinate stem with closely crowded appendages and very much suppressed internodes. It is at any rate assumed that the shoot apex is organized into the floral apex and the two are merely growth forms of the same meristem.

The accessory parts sepals and petals resemble the leaves in internal structure. The epidermis is normally made up of pappilose cells, often with intercellular spaces covered by cuticles. Trichomes and stomata may occasionally occur. Special cells containing volatile oils may be present in the epidermis of petals imparting fragrance to the flowers.

3.4 GROWTH OF FLOWER

The opening of a hibiscus flower is caused by faster growth of inner compared to the outer parts of the petal which is also supported by difference in turgor pressure across two sides usually in response to temperature changes. Though the opening and closing is influenced by temperature and atmospheric vapour pressure, the major factor is an internal clock set by daily dawn and dusk signals.

The phenomenon of the growth is not possible in non -living environment. The cell division process is multiplying and the end products resemble in shape and size to the original parent. But the change in volume can be used as a parameter to simulate. The bud is small in shape takes huge volume at the end of blossoming.

3.5 ANTHESIS STUDY

The duration of the blossoming of the flower is termed Anthesis. This period in the hibiscus species has been documented and the cycle spans over a period of seven hours. The intermediate stages have been captured in the form of images and inferences were drawn on the basis of the analysis of these stages.

3.5.1 SET-UP FOR EXPERIMENT

Three specimen buds were chosen for the experiment and were placed in water overnight. A camera mounted at a fixed position recorded the change in size of the flower, angle of spread and movement. The experiment was conducted under normal tube-light conditions in an interior environment, assuming that the factors of photo-nasty and thermo-nasty were constant over the entire period.

3.5.2 OBSERVATIONS

The following images depicts the changes recorded at regular intervals:

11:30 P.M JANUARY 8, 2007

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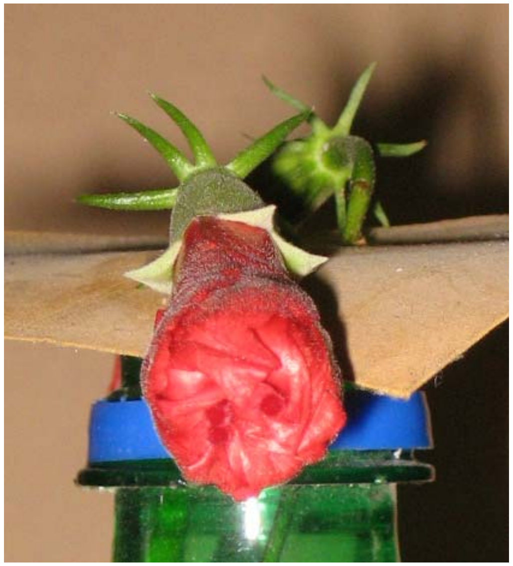
SPECIMEN 2



SPECIMEN 3

01:15 A.M JANUARY 9, 2007

SPECIMEN 1

SPECIMEN 2

SPECIMEN 3

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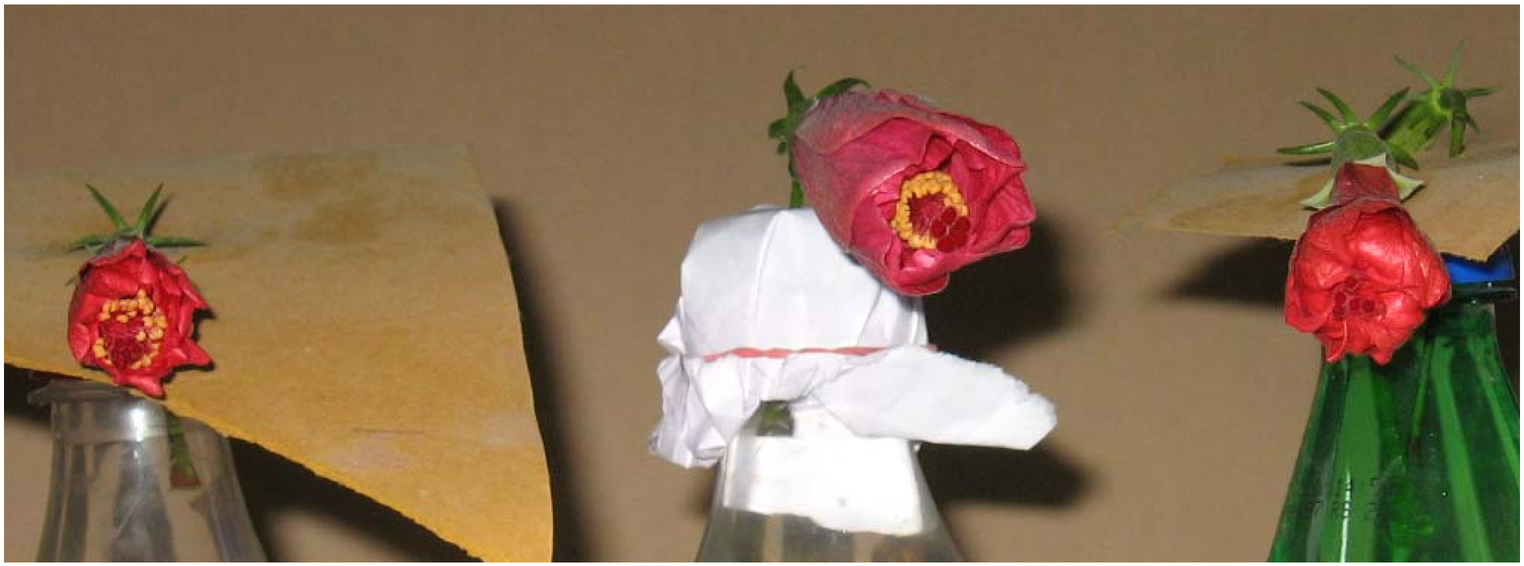

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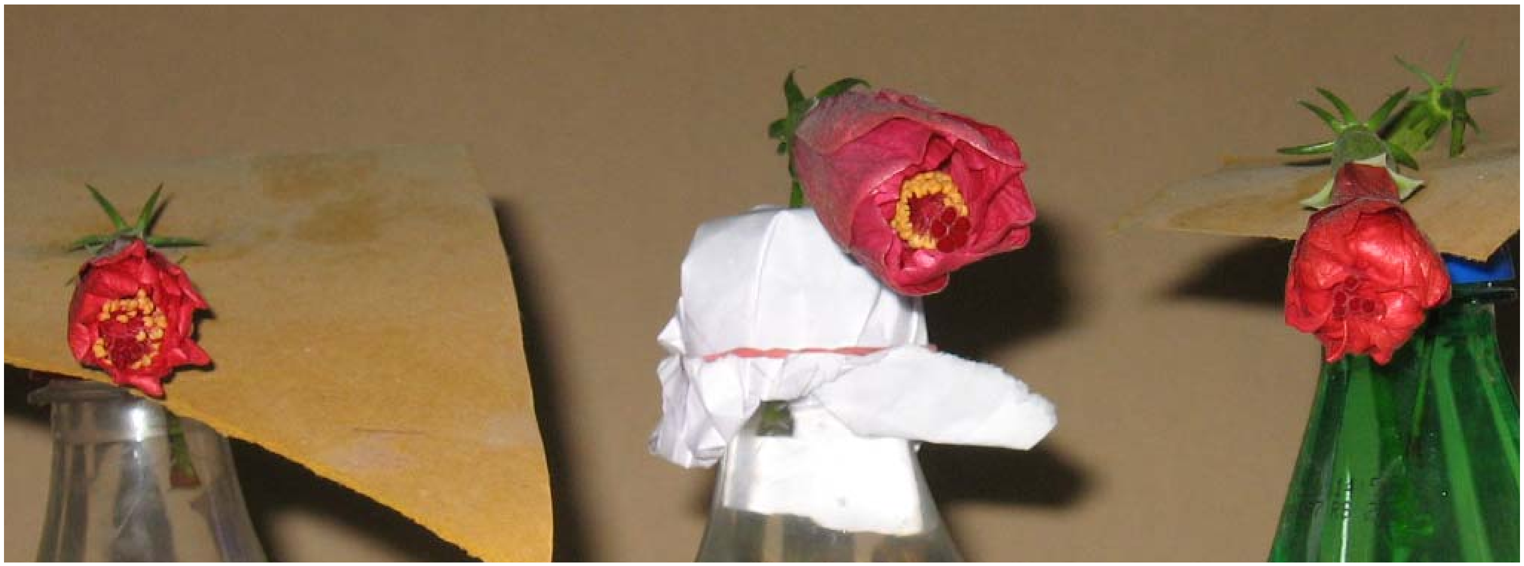

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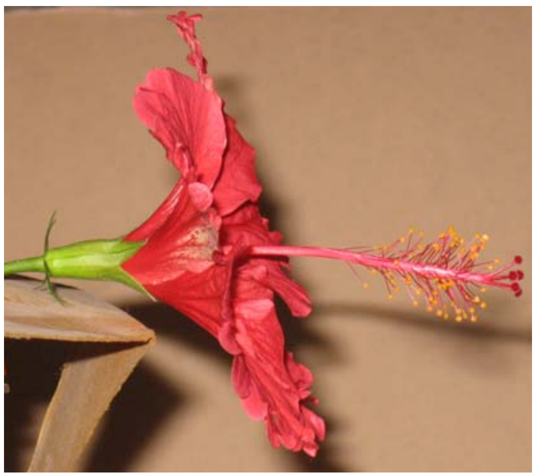
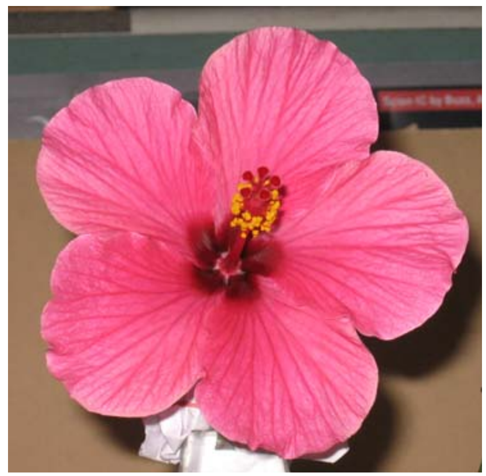


SPECIMEN 1



SPECIMEN 2

SPECIMEN 3

3.5.3 INFERENCE

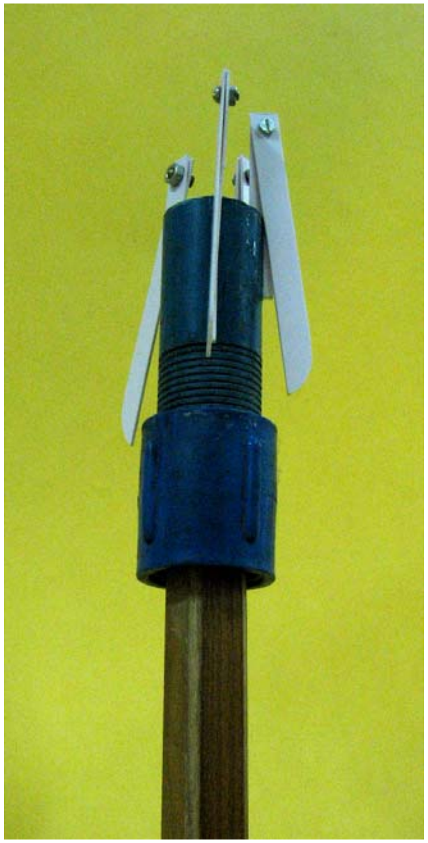
- The petals at the bud stage are entirely inside the sepal. They are small in size and tucked underneath the stigma.
- The sepal growth stops at one stage, while the petals keep growing.
- At the beginning, they are curved and enveloped in a spiral manner, overlapping each other.
- Later stages of growth witnesses the area of the petal at the apex to increase and the flower petals start opening.
- At one stage, when sufficient lighting and temperature conditions are reached, the turgor pressure increases causing veins to stretch and open the flower.
- The increased water content in petals brings the freshness and beautiful look to the flower.

4.0 MECHANISMS

4.1 TWISTING AND OPENING MECHANISM

The opening of a flower witnesses the telescopic twisting of the central core to push it upwards and the same action releases the petals that are tucked underneath the style. The spiral motion of the flower aids releasing of each petal, one after the other to bends outwards.



4.2 HYDRAULIC MECHANISM

The petals are released from the bud posture and attains the open state by means of hydraulic pressure that build up with in them. The pressure variation forces the flower to open and attain full blossom.

4.2.1 TURGOR PRESSURE:

Many plants are capable of movement. Like those seen in petals of flowers that open and close and tracking of the sun by sunflowers. Rapid movements are more visible, such as the closing and drooping of leaves when *mimosa pudica* is touched. In all these examples, movement and forces are generated by a unique interaction of materials, structures, energy sources and sensors.

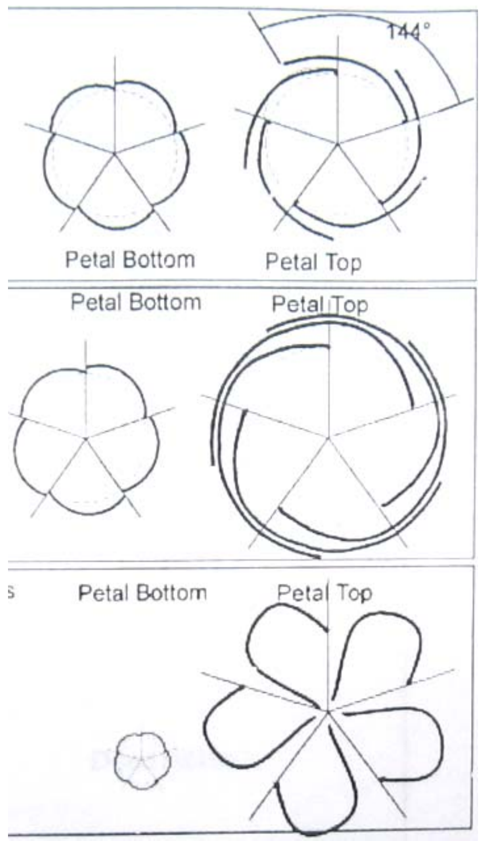
Movements that are reversible in plants are produced by pressure change within special cells. These parenchyma cells are flexible in bending but stiff in tension. When a cell takes in water, the size of neighboring cells increases due to the elasticity of its walls and builds up pressure. If the pressure of the neighboring cells increase at the same time, the tension results in deformation of the whole tissue, which causes movement of that part of the plant. The arrangement of cells of different sizes and orientations constraints the movement in the direction that is needed. When the osmotic pressure within the cell slowly decreases, the movement is reversed. A common example of this mechanism is the daily lifting and lowering of leaves in a day/night cycle. These material systems are essentially working as networks of interacting mini-hydraulic actuators, liquid filled bags which become turgid or flaccid and which, owing to their shape and mutual interaction, translate local deformations to global ones and are capable of generating very high stresses.

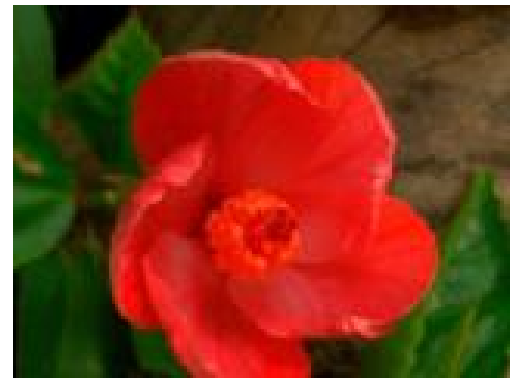
The same mechanism is used within the tissue of the leaf, where the stomata regulate the respiration of the plant. Stomata open when the air is humid and close when it is dry. Even in petals that emerge from buds to catch sunlight, the packing of the maximum surface area of material in the bud and expanding it rapidly and efficiently is the result of very clever folding geometry osmotic pressure and growth.*

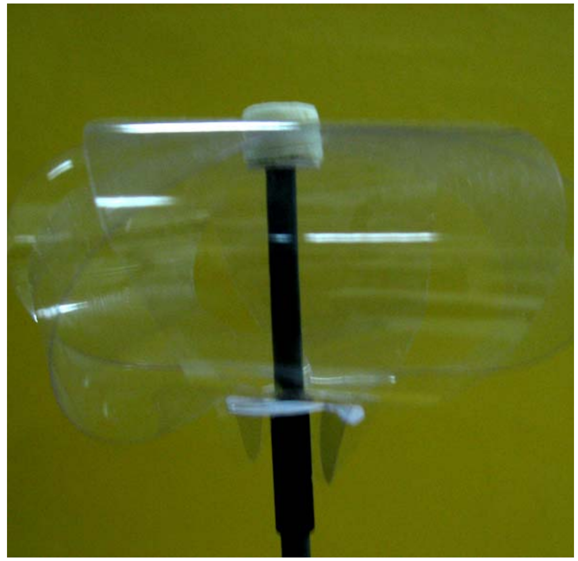
***Jeronimidis,George**- '*Biodynamics*'- Emergence: Morphogenetic Design Strategies-Architectural Design Journal edited by Michael Hensel, Achim Menges and Michael Weinstock, Academy Editions, London, Vol. 74 No 3 Issue –May/June 2004.

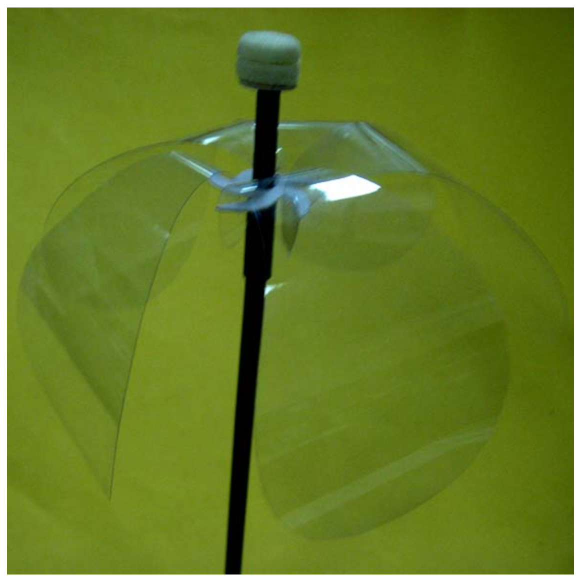
4.3 OVERLAPPING OF PETALS

The five petals of hibiscus are arranged on the receptacle in a spiral manner overlapping each other. This helps the bud curl its petals to attain a compact form.







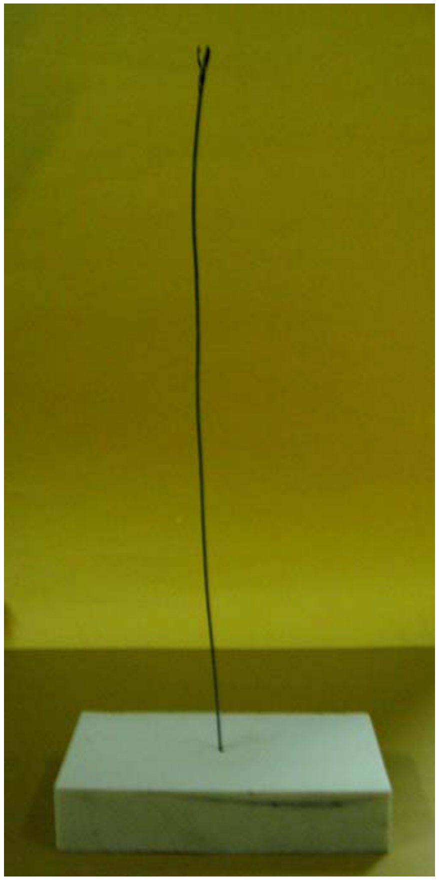


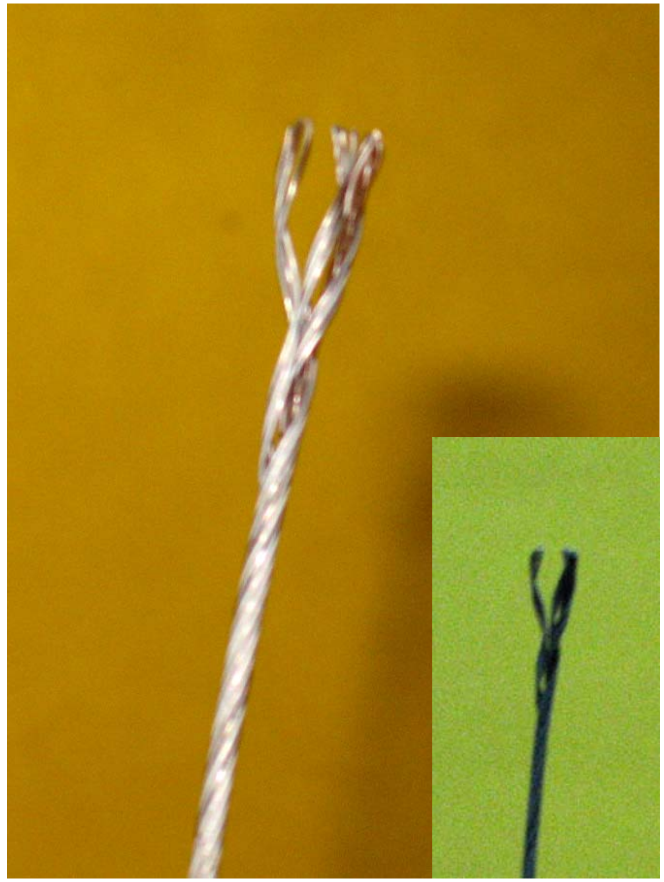
The model interprets the overlapping of petals in a spiral manner and twisting to release each petal one by one.

4.4 ENTWINING STRANDS

Hibiscus is a bisexual flower in which the androecium entwines over the gynoecium. The stamens entwine in a spiral manner around the pistil with the style, which is a conduit. The thin member stands on itself because of the structural stability attained through this form.



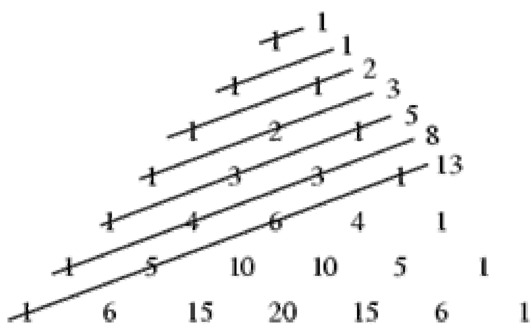


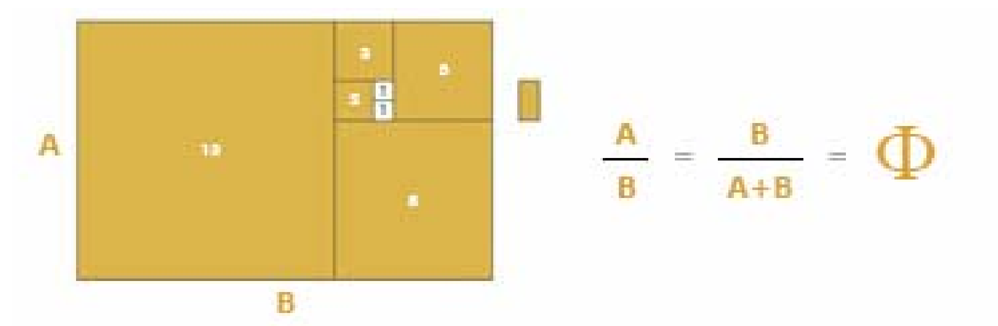


The style has evolved to be a structurally stable configuration by reducing the bending moments efficiently with optimum usage of material. This avoids linear bending by twisting into a helix.
The model interprets the same quality by use of the typical GI cable which has these very inherent properties.

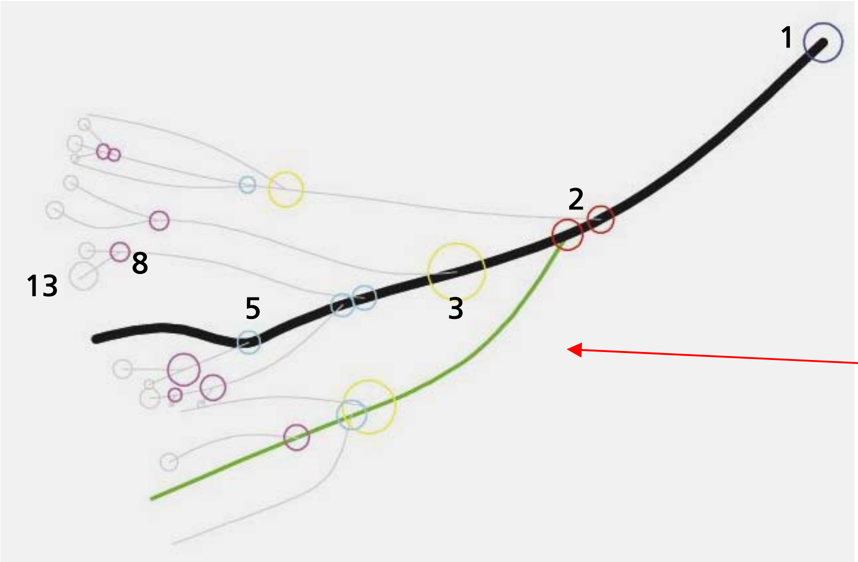
4.5 SPAN OF PETALS

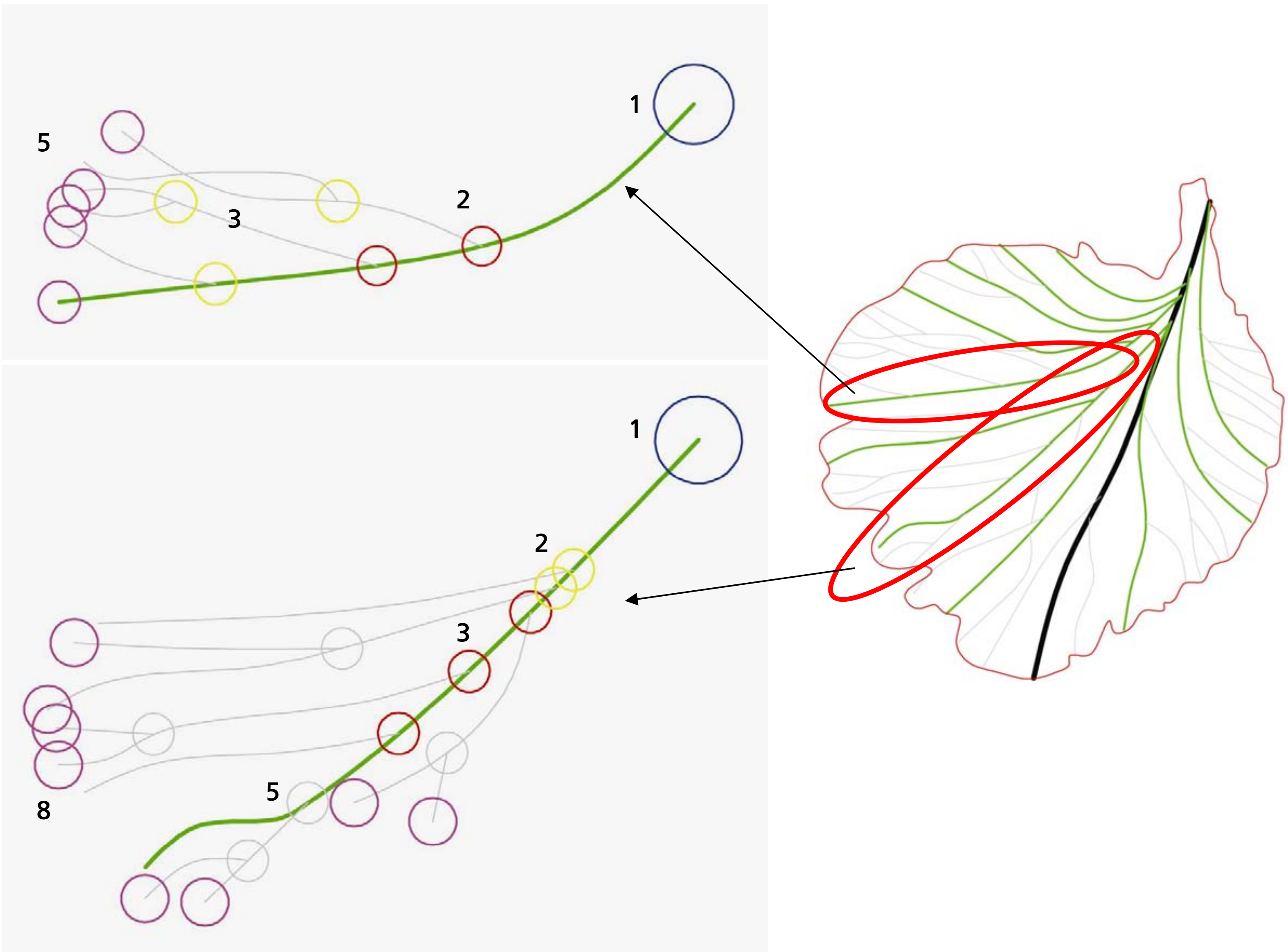
The petals attain the span by means of veins that spread through the petal and support it. The petals of hibiscus by means of its particular vein arrangement attains a frill pattern across the edges. The veins branches to follow the fibonacci series which allows the required multiplication of the veins across the span, which in turn allows the petal to attain the furled edges.

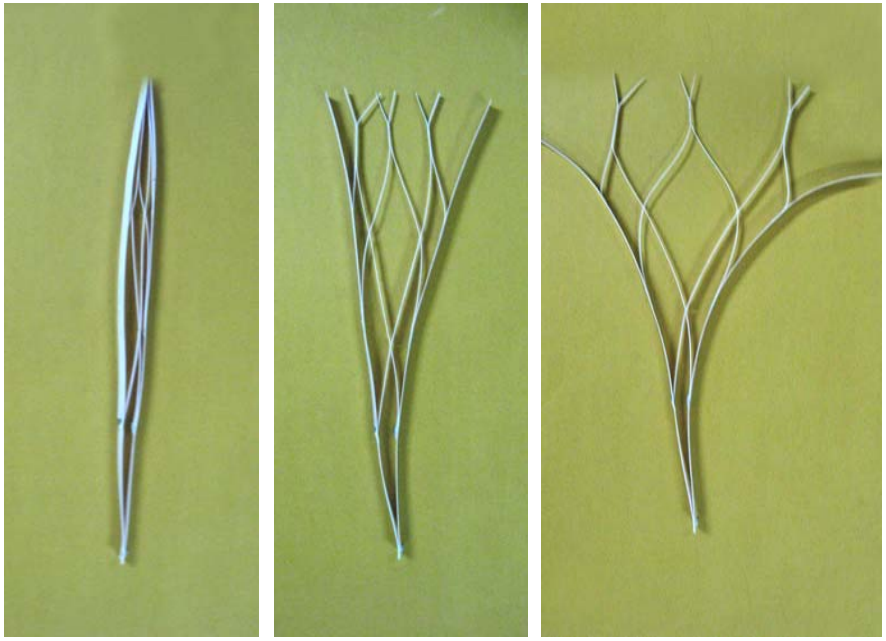


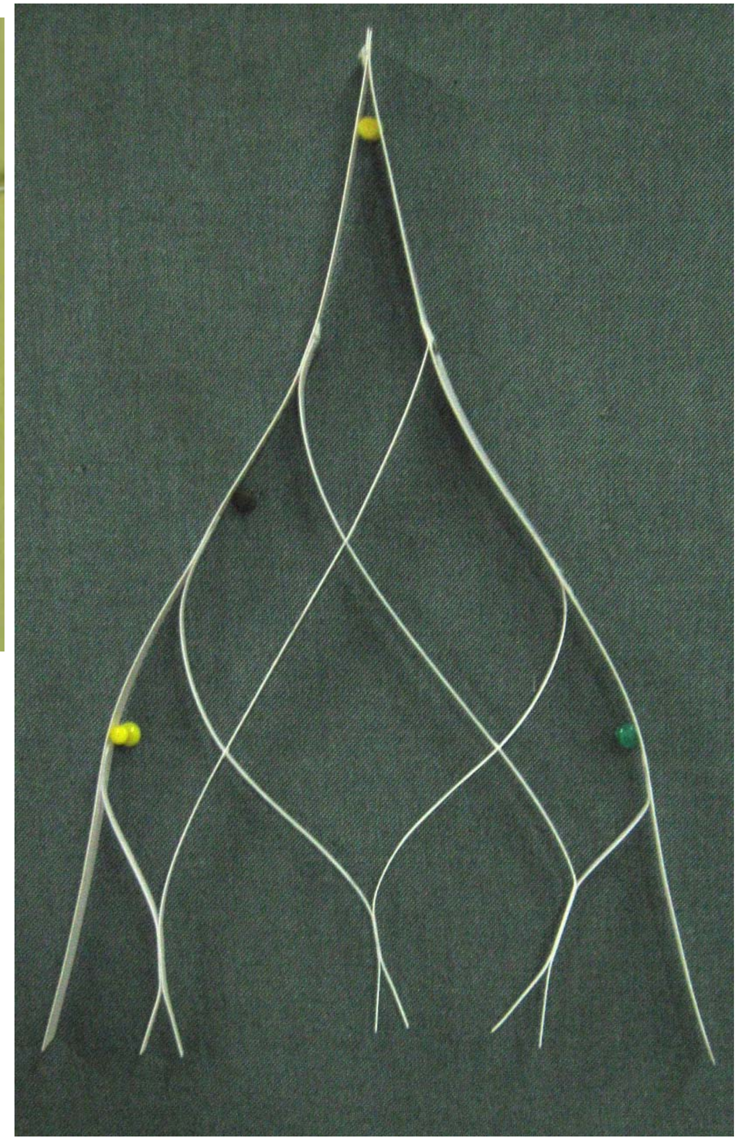


The primary, secondary and tertiary veins are extrapolated to analyze the occurrence of Fibonacci series.




1
5
2
3
1
2
3
8
5

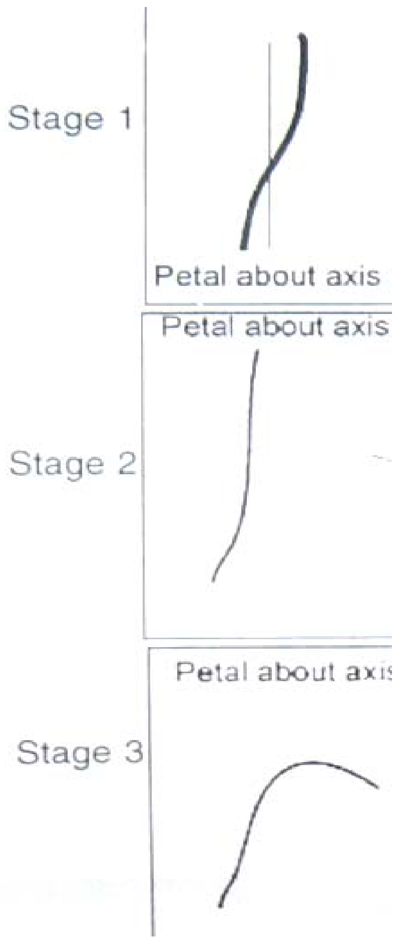




The model interprets the division of the veins across the surface of the petal indicating the ratios acquired in the division of the main veins to the subsidiary veins

4.6 CANTILEVER OF PETAL

Each petal is supported at the base where it is relatively narrow and thick. Further from the base, the petals are broad and thin. This variation in cross section helps the petal to cantilever from the base. The surface behavior of the petal, which by virtue of the doubly curved surface is strengthened by the veins in the lateral direction.

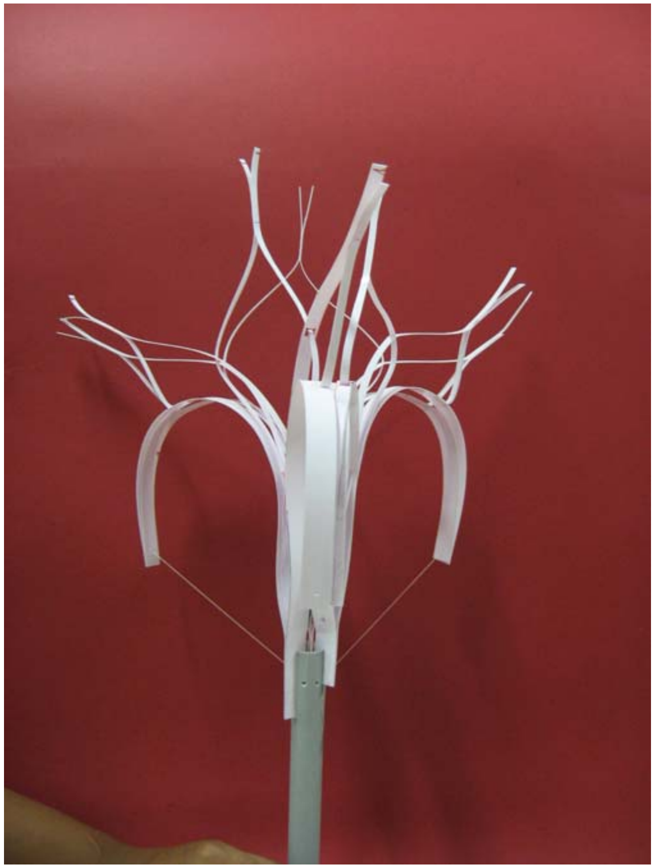


PART THREE
SYNTHESIS

5.0 PHYSICAL INTERPRETATION

5.1 MODEL 1

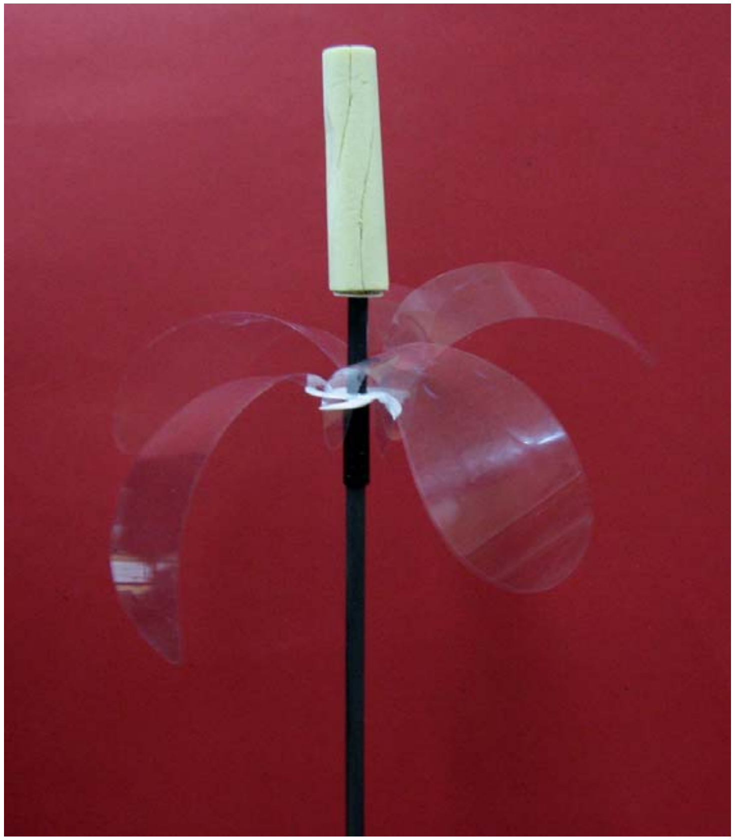
The flower is interpreted as an extension of Mechanism X , which is the Span of the Petal. The members have been multiplied along the central axis to form a full blossom flower when opened.



Open and close position to depict compact bud till full blossom stage.

5.2 MODEL 2

The flower is interpreted from Mechanism X to form the Overlapping of the petals entangled in a spiral manner at the Bud stage. This twists along the central core to release each petal one by one to acquire the fully curved profile which is observed during the full blossom.



Open and close positions to depict the spiral overlapping of the petals twisting to full blossom

6.0 CONCLUSION

Bio-mimicry as studied covers a wide arena of application in the field of design. The project focuses on the core essence of the approach of “Interpretation”, where one has tried to draw nuances from the geometry, structure, form and movement of the Hibiscus flower. The final outcome has dealt with looking at the hibiscus flower emphasizing on two mechanisms out of the innumerable underlying principles involved in this wonderful phenomenon.

The journey was enlightening with a complete thorough understanding of all avenues of Bionics in man’s life, right from ancient civilizations to its impact in useful applications in the field of medicine, design and engineering. An investigation into the differentiation of the approaches to understand and interpret the principles in nature, concretized our understanding of this field and helped in deriving the five major areas of application. One could however concentrate into how these 5 areas of bionics have contributed to the field of Industrial design in particular.

The need to focus on one commonly observed natural phenomenon such as the blossoming of the flower was sensed as critical to our study in Bionics. This exercise involved the study of the physiology of the Hibiscus, the detailed analytical documentation of the phenomenon and the inherent mechanisms responsible for the blossoming of the flower. The mechanisms were further interpreted into physical models, which also dealt with the area of “Simulation” to a certain degree with the abstraction of the qualities of the flower creeping in.

Owing to the time constraints, one has tried to focus on individual mechanisms to bring out the complete essence of the entire phenomenon. However, a more interesting and challenging approach would be to derive a holistic model that captures an “integrated” concept of the various mechanisms fused to enhance the nuances of this natural phenomenon. At the same time, there is enough potential even in the understandings of single mechanisms for successful application development at the functional level.

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