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The Natural Structures as a Source of Inspiration in Construction Engineering

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Summary

The specific shapes, volumes and structures of construction engineering are linked to the global evolution of different branches of research and creation. The new materials, technologies and computer design are a challenge in the re-evaluation of the potential given by the variety of natural forms, which can become the source of inspiration for technical creation.

The research and creation process has two distinct characteristics: the idea, the novelty of a concept, and its conversion into practice, its materialisation through a specific process. Nowadays, the materialisation of an idea cannot be finished without the use of computers. With the use of various software, one can create patterns of high precision which can be virtually tested for different real-life scenarios.

The aim of this paper is on one hand to show the steps of elaborating an idea – of searching for volumetric solutions – and on the other hand to show the transposition through an alternative method, preceding the computer model, the analytical drawing with free perspective. The free-hand drawing is the oldest method of visual understanding of the forms but not any type of drawing can mean fully comprehending the form. The analytical construction drawing can constitute a good method of understanding the essence of the structure of the form. Taking into account the fact that the aim of this study is to show the natural structures, the analytical drawing with free perspective are used to exemplify them. Those drawings are a research instrument, essential for the study of organic forms found in nature.

KEYWORDS: natural structures, natural patterns, inspiration, constructive-architectural patterns, creation

1. INTRODUCTION

The supporting structures found in nature are an inexhaustible resource for solutions, inspiration and for human creativity in the most diverse fields: mechanical engineering, construction engineering and design.

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Natural patterns distinguish themselves through their simplicity, structural gracefulness and especially for their extreme economy of resources and maximum of constructive efficiency. This quality can only be described as a remarkable, universal law of economy.

It is admirable how construction engineers and architects are getting closer and closer towards what nature can offer, as the challenges of the complexity of contemporary edifices are growing, and the solutions seem to be found in the simplicity of organic patterns. Those patterns can be distinguished as constructive-architectural patterns such as vegetal bolls or shells, which can constitute a model for the creative and research process, but one can also observe some less concrete patterns like sand dunes or the snow in a blizzard, alluviums or the structure of intersected soap-bubble spheres. The latter ones can surprisingly constitute a starting point in the creation of some constructions. One such famous example is the architect Zaha Hadid whose creations are inspired by the geometry of sand dunes.

Another distinguished example is represented by the works of the Italian structural engineer Pier Luigi Nervi. They are eloquent through the contribution brought in the transposition of natural patterns for creating constructive structures. His ceilings are famous. They represent architectural bays, [1], that can be observed on the Victoria amazonica water lily (Figure 1). This natural pattern is met, for example, when the ceiling of the Lanificio Gatti edifice was built [2] (Figure 2). In his creation, he was also inspired by the linear structure that partitions the spaces between the seeds on a sunflower disk.

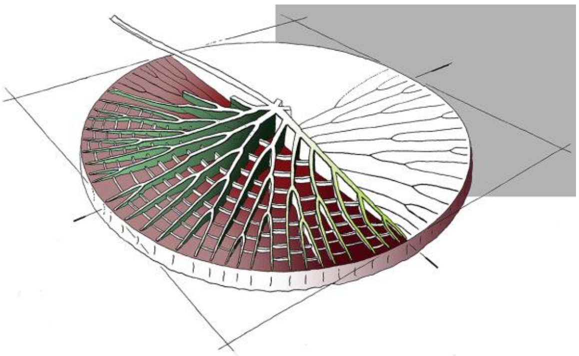

Figure 1 Victoria amazonica water lily – back side of the leaf

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Figure 2. Lanificio Gatti by Pier Luigi Nervi

2. DOMES

One of the oldest constructive elements, ever since antiquity, is the dome. A famous example is the Roman Pantheon. There is a great diversity of models for this constructive structure in nature. Some examples are the poppy boll, the shape of a flower or of a sea creature, but the easiest way to visualise and study this is represented by the rigid bolls which protect the flower seeds. The poppy head, (Figure 3), has a very simple, yet efficient structure and the perpendicular lamellae from the internal surface of the fruit are a specific feature.

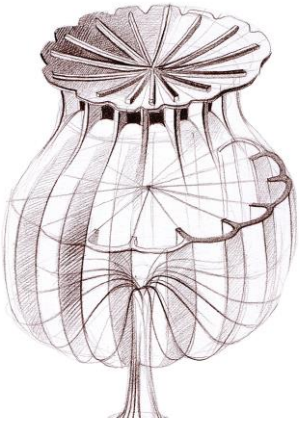

Figure 3. Poppy head

The lamellae start from the base, from the link with the stem, and converge symmetrically and radially towards the superior area where they are unified by a concave lid (a calotte), and in this intersection point, one can find small spaces, windows through which the seeds are freed. This constructive structure can be visualised through a transversal and longitudinal sectioning.

Another natural model which evokes the volumes of domes is constituted by the constructive structure of the cactus species Ferocactus – Barrel cactus, where the radial convergence of the tension lines can be observed very clearly. These perpendicular beams are obtained by folding the surface (Figure 4). Another similar volume can be observed in the Physalis fruit (Figure 5) and in the Abhutilon fruit (Figure 6)

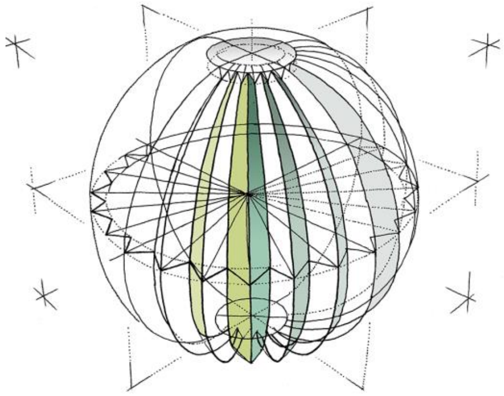

Figure 4. Graphical analysis of the supporting nerve in the Barrel cactus

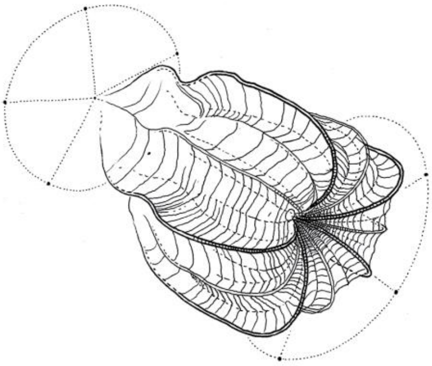

Figure 5. Graphical analysis of the supporting nerve in the Physalis fruit

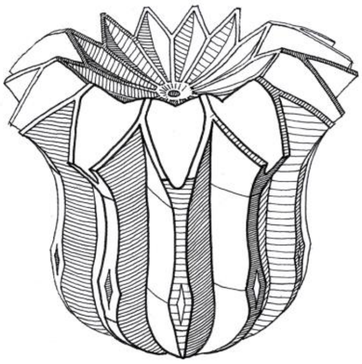

Figure 6. Graphical analysis of the supporting nerve in the Abhutilon fruit

At the beginning of the 20th century, Karl Blossfeldt, a pioneer in macroscopic photography, highlighted the structural-constructive characteristics of vegetal elements through the expressiveness of this art. The poppy boll and the Abhutilon fruit were part of his research. Blossfeldt used all his findings, which were materialised in a series of photos with the vegetal subject, as didactic materials in the work with his art students, in the lessons which had as purpose the study of shapes.

3. THE OVOID

Another constructive structure found in nature is represented by the ovoid volumes with intersected bays like the pineapple fruit or the pinecone. Their surface is modelled after those trabecular tension lines, which form a cellular pattern by converging (Figure 7, Figure 8). The edifice known as “The Gherkin” from London has a structure which was obviously inspired by the formerly mentioned natural elements (the pineapple, the pinecone) [3] (Figure 9)

Figure 7. Computer simulation of the pinecone structure

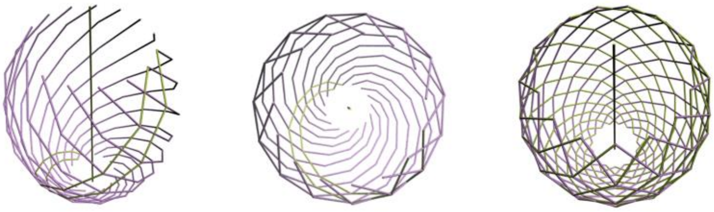

Figure 8. Computer study of the highlighting of the supporting lines in the pinecone

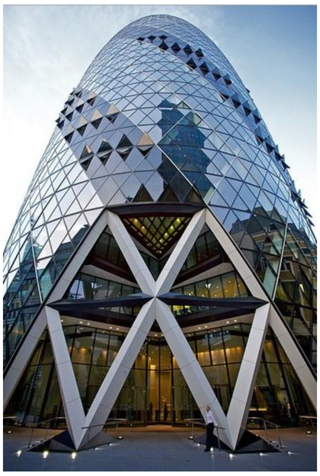

Figure 9. The Gherkin Building, 30 St Mary Axe, London

4. CALOTTES

An interesting example of calotte is the sunflower disk, where the seeds are set in a structure of isostatic lines which converge towards the centre. The trail of those seeds has the shape of logarithmic spirals intersected on opposite directions. This creates a size gradient, beginning from the centre and going towards the circumference. This type of structure can be found in Rome, at “Palazzetto dello Sport”, an edifice created by Pier Luigi Nervi [4] (Figure 10). It is important to highlight a certain aspect of the structure: the fact that the disk is not generated by a straight line in the longitudinal-medial section, but by a curved line, which contributes to the overall resistance of the shape (Figure 11, Figure 12).

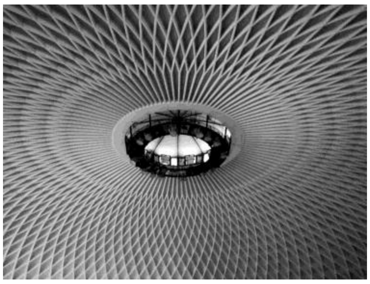

Figure 10. Palazzetto dello Sport by Pier Luigi Nervi

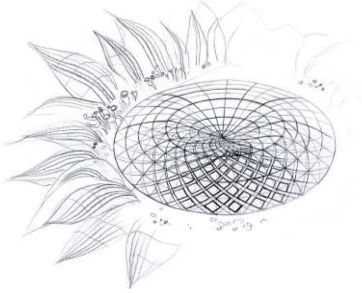

Figure 11. Graphical highlighting of the structural lines on a sunflower disk

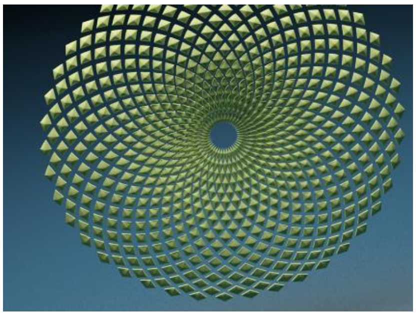

Figure 12. Computer simulation of the sunflower disk structure

A very ingenious concave surface can be seen in the seashell species Pecten jacobaeus. Even though it is a resistant structure like the surface of a lens, radially symmetrical, it doesn’t have a central point, but one that is found in the circumference area because that is where the joint, which opens and closes the shell, is situated. From this point, the tension lines are radiating, by curving the surface. A most interesting fact is that, as the size increases, in the joint area one can see a concave surface which seems to be drawing an “S” in the median section (Figure 13). As the veins radiate towards the exterior, the arcades of the sections are modified. They start to change from barely noticeable (Figure 13 – I) to highly visible (Figure 13 – III). In area III the geometry also changes through the apparition of some reinforcements (Figure 14).

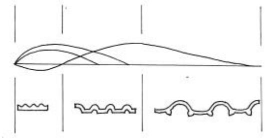

Figure 13. Drawing analysis of the structural line of Pecten jacobaeus

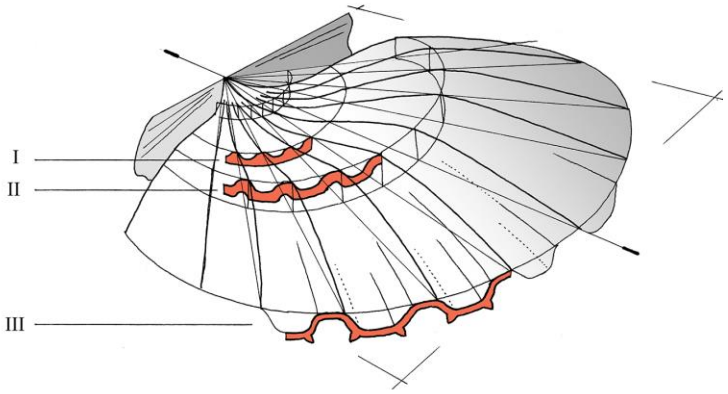

Figure 14. The differences of curvature in the longitudinal section in reference to the size of the shell and the evolution of radial veins

5. STRUCTURAL VEINS THROUGH CREASING OF SURFACE

The stems that support very big leaves, stems of banana trees in the case of this study, are a very interesting pattern which exemplifies the assurance of rigidity with a minimum of material and a maximum of efficiency. The stem has a cross-section shaped as a “U”, which is very well highlighted and the curvature softens progressively and proportionally with the decreasing weight that it must support until it reaches the apex of the leaf (Figure 15). In the creation of the structures

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made by men, one can see the summarized usage of this organic section prototype in profiles with the cross-section shaped as a “U” or, through symmetry, in those shaped as an “H”.

Another excellent and edifying example for its structural veins obtained through creasing is constituted by the palm leaf of the species Washingtonia robusta. Its form is the result of creating a flat surface in zigzag and then combining all the tension lines in a convergence point in the same way as in forming a paper fan (Figure 16). This (structure) is the unfolding of the symmetric-radial structure on a flat surface which can be observed at Ferocactus glaucescens – Barrel cactus (Figure 16). This palm leaf is a good example because of the clear and visual way in which the principle of stiffening with a minimum of material and a maximum of efficiency is exemplified.

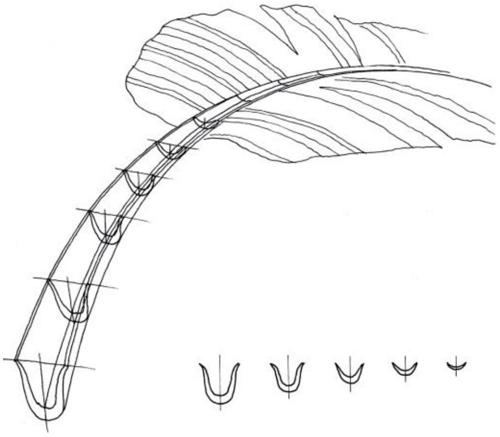

Figure 15. Drawing analysis of the transformation of the “U” section in the banana tree stem

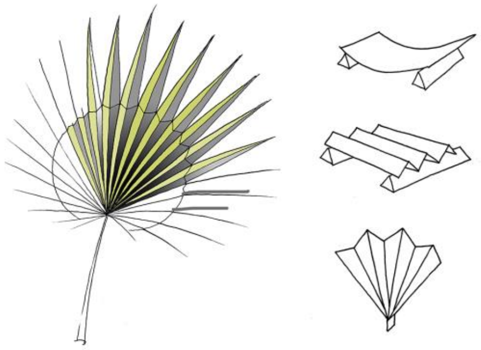

Figure 16. The leaf of the palm tree Washingtonia robusta – similarities with the stiffening process through the creasing of paper

Thus, a simple piece of paper, supported by two parallel structures, will fold, but it will constitute a rigid surface on the direction of the veins by creasing it in a zigzag way. This stiffening possibility is used for creating the roofs of industrial halls, in a zigzag way or by corrugation.

6. STANCHIONS

By observing the solutions that nature has brought for the shape of the structure, it seems like it has an indisputable answer: the tube, the pipe. The more fragile the materials are on young stems, in the reed plant for example, the bigger the empty area is, compared to the solid mass, therefore, the support is given by the wall, not by the core. This is the difference that can be seen between the pipe (the tube) and the wire (the cylinder). In relation to the length, the wire is more easily malleable, while the pipe opposes resistance to bending. The stems have circular and smooth cross-sections in the exterior, but in numerous cases, the presence of creases and veins on the longitudinal direction, which increases the resistance, can be noticed.

An entirely special case of structural ingenuity, present in the cross-section, is the Dutch rush (scouring rush) Equistem hyemale stem. This aspect is also emphasised by Karl Bloomsfeldt in the photography of a stem portion, [5].

The cross-section is truly fascinating. At a first glance, it has all the data and qualities of an industrial product. The wall of the stem is hollow and it is made of two concentric tubes that are connected by several flat surfaces, symmetrical lamellae, placed in the direction of the radii that converge towards the centre – towards the axis of the stem. In this way, the lamellae, which anchor the external and internal tubes, form a comb-like structure and generate grooves on the external wall surface (Figure 14). Those are longitudinal veins and are very similar to those found on the columns from the ancient Greek temples.

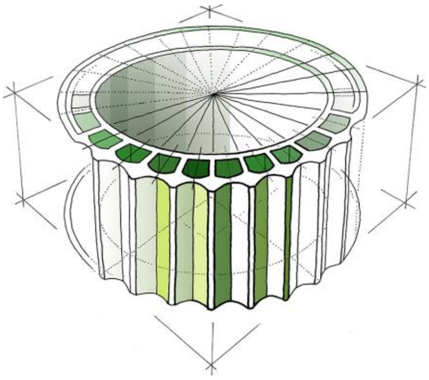

Figure 17. Drawing analysis of Dutch rush, Equisetum hyemale stem, cross-section

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In this way, one can ask wonder whether their role is purely aesthetic – of optical elongation – of aesthesis or suppleness – or if their role is functional and they ensure the resistance of the column at the level of the external surface.

Another aspect of Equisetum hyemale that deserves to be underlined is the fact that the young branches on the main trunk have a number of grooves which is smaller to those on the trunk, but are equal in size. This aspect can be geometrically translated by the fact that the new branches have creases, veins which are bigger, resulting in a highlighted stiffening of the branches (Figure 18)

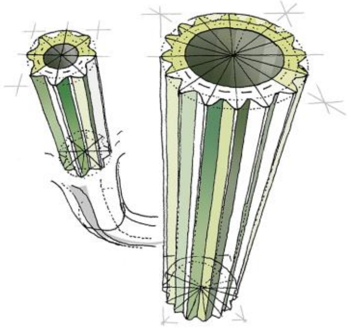

Figure 18. Dutch rush, Equisetum hyemale, section in the main and secondary stems

The bamboo stem is another stiffening example, specific to the tube structure. Its characteristics are the circular knots which are constituted from the entry elements placed at approximately equal distances. The knot is formed from two conical rings with a diameter which is slightly bigger than that of the tube. The two rings are connected by a smaller diameter, the middle knot (Figure 19). On top of it being the prototype of a structural element – the pillar, ideal for its flexibility and resistance to breaking – the bamboo stem is a utilised element, integrated into the creation of structures.

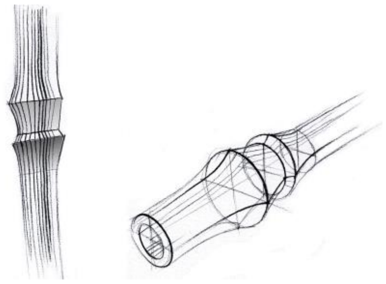

Figure 19. Drawing analysis of the bamboo stem, the knot

The main rod of the bird feather is an ingenious tubular structure where we can observe the progressive transformation of the cross-section, from a circle in the intersection area to a rectangle which has concavities, and an increased resistance because of the creases, [6]. This geometry of the rod answers the needs which appear for a different reason. Thus, the connection area, of maximum resistance, has a slightly ovoidal section, which decreases and transforms progressively into a rectangle to facilitate the connection of the elements that construct the surface as well as to obtain an optimum degree of elasticity towards the top. From the point of view of functionality, the different forms of the sections answer the needs for every specific segment, especially during the flight. The main needs are minimum weight, the stability of the feathers' positions during movement, flexibility, elements which reduce the maximum muscular effort and ensure optimal air load-bearing capacity (Figure 20). One geometrical solution, present in a natural form, can be seen in Pier Luigi Nervi's pillars for the Italian Embassy in Brasilia [7] (Figure 21). The pillar is continued by four arms on the superior side which creates a connection with the horizontal plane. Those arms have, as a geometrical solution, a 90° spin of the rectangular surfaces which correspond to the insertion of the pillar with the horizontal plane. In the inferior connection area of the pillar and the arms, the surface is a vertically orientated rectangle which through progressive transformation becomes a horizontally orientated rectangle [8] (Figure 22). At Palazzo del Lavoro, which was also designed by Pier Luigi Nervi, there is another type of pillar whore cross-section, which has the shape of a cross at the base, progressively transforms into a circle in the superior part.

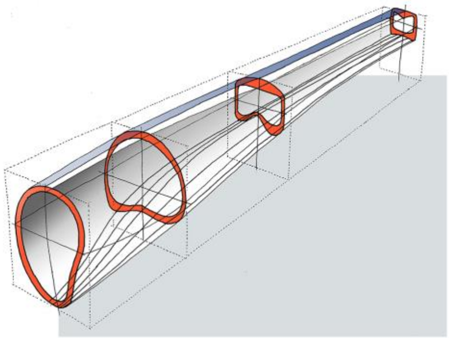

Figure 20. The evolution of the feather section, drawing analysis

Figure 21. Italian Embassy in Brasilia by Pier Luigi Nervi [9]

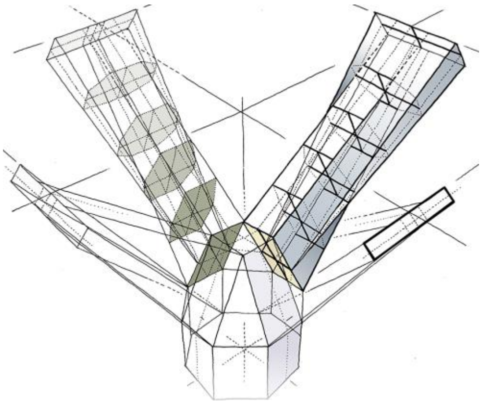

Figure 22. Pillars for the Italian Embassy in Brasilia – Pier Luigi Nervi, drawing analysis

6.1. *Reinforcement, coupling, pillars, beams, arcades*

By watching the curvatures of the secondary stems of some vegetal species, like the banana tree, the date palm tree or Washingtonia, one can observe that those are formed by a perfect coupling between the main vertical (the axis – the pillar) and the maximum point, the highest of the curvature, the point from where the curvature descends. In the case of this kind of structure created by men, this point seems to coincide with the support point of the horizontal beam. This natural pattern, which is expressed through the coupling curves between the pillar and the beam, has been used in the 19th century in the metal skeleton of the commercial halls, industrial halls or of train stations (Figure 23). The Eiffel Tower seems to be another manifestation of this property because of its vertical position, the four couplings which support the axis – the pillar – and the ground which represents the beam area.

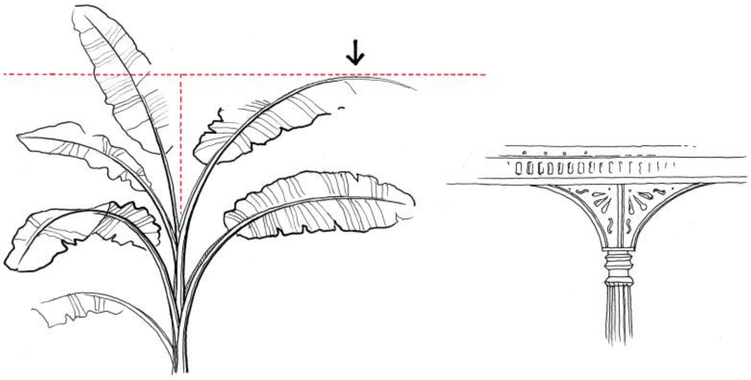

Figure 23. Banana tree, secondary stems
– natural patterns for the coupling pillar – the beam

7. PATTERN MODULAR STRUCTURES

7.1. Bays

The bays represent a fundamental constructive element used by men in their structures and they can be identified as stiffening lines. They can be seen in the support structures of bridges, hall roofs, high voltage poles, extraction wells, constructive elements of cranes, etc. A very interesting natural pattern is represented by trabecular lamellar bone tissue (trabecula latina – small girder). (Figure 24) This can be observed especially on the superior part of the femur. The role of these tension lines is to reinforce the femoral head which sustains a very high pressure.

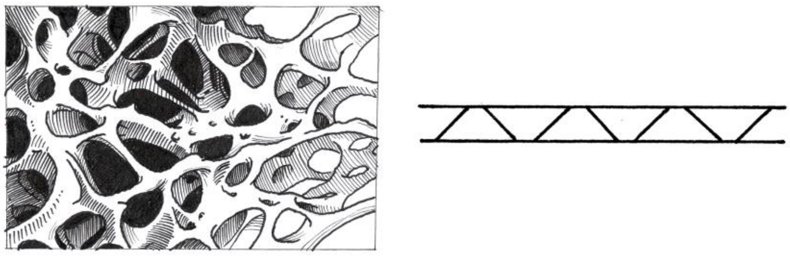

Figure 24. The trabecular structure of the bone, a natural pattern of reinforcement

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7.2. The nest

The bird's nest, created in different constructive varieties, constitutes a symbol for natural structures achieved by following an authentic plan which seems to be consciously thought and designed. In appearance, it is just a random construction, but one can observe right from the choice of the construction place, of the size and of the shape, that it is created with special rigour. The nest is created following the modular principle – the branch constitutes a resistant line and a brick at the same. This pattern can be found in wooden houses where the overlapped and combined girders are at the same time supporting elements and the wall. Some modern edifices use linear structures which seem random. One example is the "Beijing National Stadium" also known as "The Bird's Nest" which was created for the 2008 Summer Olympic Games from Beijing, China.

The sphere is a nest's general prototype, but it is most often built in the shape of a hemisphere or of a calotte. In terms of functionality, it perfectly answers the need to protect the centre where the eggs and then hatchlings are situated.

Some unique constructive solutions can be observed among Village weaver – Ploceus cucullatus – nests. They have the shape of a tear (an ovoid) suspended on branches and is made from blades of grass. Another example is the spherical nest of Hornero Furnarius – the potter bird. It is created out of wet mud and the wall becomes rigid after drying.

7.3. Spherical structures

The spherical constructions (geodesic domes) have represented a structural-constructive challenge, usually being destined for art galleries, greenhouses etc. This kind of structure is created through a modular polygonal pattern, which divides the sphere surface into lines and planes. The natural patterns that exemplify this are the coral species like Goniastrea aspera (Figure 25), or the distribution of dandelion seeds.

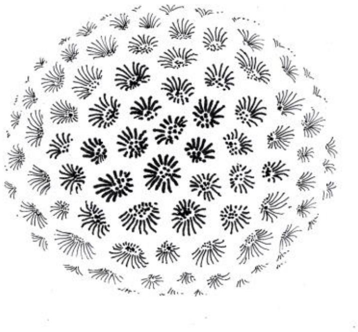

Figure 25. The spherical structure of the Goniastrea aspera coral

7.4. Linear pattern structures

The way in which the seeds of wheat are distributed on the stem of the wheat stalk is a unique organisational structure created through arrayal. In the superior area, the stem forms a zig-zagged line, stiffened by the knots which support the seeds. Both the knots and the veins of each module ensure an excellent reinforcement (Figure 26).

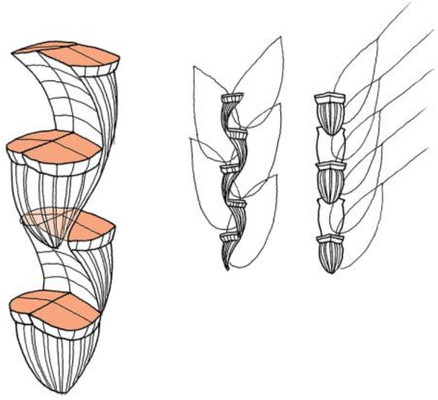

Figure 26. The way in which the wheat seeds are distributed on the wheat stalk through the linear modular structure (string), drawing analysis

8. CONCLUSIONS

The rational organisation of natural structures reveals the fact that it is the result of a rigorous thorough ideal plan. Thus, the harmony one feels while admiring and studying these forms combines principles from the strength of materials, the ingenuity of structural and functional solutions, mathematical calculations and physics. In this sense, the sequence of Fibonacci has symbolic value for the study of the composition of nature, both in terms of rationality and harmony, through the golden ratio.

Nature shows that the optimal solution for a functional requirement generates beauty and harmony. Today’s evolution and performance of study and research equipment, curiosity and the researcher’s intuition highlight the fact that natural patterns will forever be a truly great study and creative partner. This study wanted to highlight the fact that the design, intuitively-free, according to the models and structures encountered in nature can offer solutions and ideas in the elaboration of the structures. Thus, the drawing, summary drawings or elaborate - analytical drawings are a continuation and deepening of the observation of nature. Observation is the first step, essential to knowing and understanding phenomena.

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