Organic Reference in Design.
The Shape between Invention and Imitation

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Abstract

Historical treatises pursued the search for a rule in geometric laws that envisage the relationship between numbers and forms, fixing the articulation and the measure of architecture. Despite an inevitable inertia, architectural research always showed in formal and structural canons the concepts expressed by geometry, which like any science evolves in an attempt to explain increasingly complex facts, as the man's ability to observe the nature's world progresses. New geometries coincide with new space-structural conceptions that refer to inspirational models, which are based on the commitment of nature: on one hand it asks questions to explain, on the other hand it offers solutions to design problems.
The reference to the nature is a constant explaining the strong relationship between geometry and design. It finds a scientific reason in the perfect efficiency of biological equilibria, which men imitated first in the external forms of ornament, then in the balance of structures, and finally in the orderly control of chaos.

Introduction

Many historical treatises refer to the myth that the architecture was born from the imitation of the nature.
The reference to natural models actually evolved together with the knowledge of physical and biological phenomena and the mathematical laws created to describe and measure them. The different interpretations of the organic model reveal the implicit relationships between the evolution of mathematics and geometry, the knowledge of the natural world and the work of man,

emphasizing the relationship between the observation of nature - from which all sciences were born – the arts and the mathematics. With geometry, since the classical world, that was the first theoretical construction to explain natural phenomena, running together with the Western philosophical thought (ROSSI 2006).
Euclidean geometry actually is the essence of Western knowledge, the primitive origin from which first developed the science of numbers and then the computer science. In facts the mathematics has evolved by looking for ways to explain new problems that accompanied the increase in observation skills, constructing numerical or geometric models capable of quantifying and reproducing natural phenomena, as well as the refinement of the ability to observe them (PENROSE 2004). We can trace this evolution in artificial realizations, which always follow an intentional project. This is particularly true in architecture, which more than any other art expresses in the articulation of its design the synthesis of science and technology. In human activities we recognize many models that are differently inspired by nature, mediated by the mathematics in the game of drawing with numbers and shapes (FERRERO et alii 2009).
The organic model in architecture evolves along with the mathematics, developing new geometries alongside the Euclidean one. The last dominated until the Baroque, which exalted the achievements of Projective geometry in the complex structures that applied the study of the conics. A non-Euclidean geometry lies at the basis of Escher’s and Fuller's research. As well it is the reference to topology in the suggestions of Deconstructivist Architecture (WIGLEY 1993), up to the celebration of computer science in the dynamic reactions of last responsive structures. While new geometries explain increasingly complex phenomena, new forms shape architecture and design, which joining science and technology (ROSSI 2018). The concept develops the physical reference to a natural structure or phenomenon, which is copied into a non-mimetic imitation. Imitation is in fact an instinctive learning strategy and perhaps the first teaching method. Nature was the first model available, which has remained current because it is looked at with new eyes.
The artificial imitation reinterprets natural patterns and readjusts them to a different context. With the refinement of the knowledge it

concerned more complex aspects, which we can articulate in five successive phases:

1 - at the beginning, the focus was the *shape* with its properties resumed in the archaic articulations of the ornament (GOMBRICH 1979);

2 - with the birth of architecture, which reworked the formal concepts of everyday objects (SEMPER 1860), pointed on *composition*, pursuing balance and harmony among the parts;

3 - later the scientific method focused on *structures*, their mechanical behaviour and structural properties of forms (GALILEO 1632);

4 - after the explanation of the chemical-physical laws of natural forms (D'ARCY TOMPHSON 1917) the attention felt on the *relation* in transformation (growth) and the functional properties of organs;

5 - eventually the reference is the biological adaptation *processes*, associated with the topological relativity of apparently disordered forms (SPUYBROECK 2004).

Each approach corresponds to a different awareness level of natural phenomena, in particular life and, as we will see, find a motivation in the explanation and in the geometric-mathematical description of the same.

1 - The closed form (unit and decomposition)

Plato was the first who built a geometric model of knowledge. Through regular solids he referred the reality o a few physical elements, composed by only two triangles. He sensed the concept of the chemical structure of matter from the observation of regular forms in nature, such as crystals and elementary symmetries of many animal and plant organisms. Regular solids exist in the skeletons of the radiolarians and, but the dodecahedron, in the crystalline aggregates as well. In fact, the chemical structure of the molecules builds spatial lattices, which determine the regular shapes of crystals, such as snowflakes (KEPLERO 1619) as a direct consequence of the geometry of the molecular structure.

The first form of imitation was the copying, sometimes with symbolic abstraction, which implies a conceptual reference that is mediated by reinvention. Geometric motifs of natural inspiration with realistic or stylized shapes are common in ornamental

decorations since pre-historic cultures. The ornament is a secondary aspect, but it is significant because the decoration is integrated into elementary shapes, which respond to the function and workmanship of the simplest artefacts, enhancing their purity through geometric references (axes, orientations, isometries…).
The two archetypes are the closed form and of the divisions of unity in regular polygons, hence cyclic or dihedral symmetrical scans. They are still the base of the design theory (basic design) and of ornament, which bases on the regularity of Euclidean symmetries. (GOMBRICH 1979). In its primitive stage the imitation therefore concerned the most evident: the form and its organization, according to the fundamental references to spatial orientation through the fundamental entities of geometry.

2 - The harmony of the parts (repetition and multiplication)

The architecture articulates in composite forms enclosing complex spaces. According to the classical theory, the drawing gives harmony to the whole by controlling the relationship in between the parts. The Alberti's principle of *concinnitas* lies in the correct proportioning of the whole, in which nothing can be added or removed unless for worse. The concept expresses the Vitruvian triad, *firmitas*, *utilitas*, *venustas* which defines the conditions for a good project. The Classicism explicitly called the nature as a model of harmony. The proportioning, regulated by shapes and numbers, refers to the divine perfection through the golden ratio. It is recurrent in the architecture as well in the living organisms. The *concinnitas* sums up the logic of form: "*Concinnitas is the fundamental and most exact law of nature. Artificial beauty must imitate the model of nature, creator of the best forms.*" (LEON BATTISTA ALBERTI 1485)
The imitation of nature appears in the structural conception of architecture, which is rich in aesthetic and formal values: the architectural order is the main case of theory, but it is only the most evident example since all human creations base on the observation and imitation of natural ones. As well in the ornament, the search for beauty is related to the presence of signs in harmony with the shape. The decoration of the architectural order recalls the original wooden constructive matrix: the imitation is pretty direct. It re-elaborates the

form that is expressed by the Vitruvian *utilitas* in the adaptation to the stone construction.
In fact, nature works with materials of a predetermined size, like masons. The concepts of harmony, order and rule are related to the relationship between *form* and *number*, which are the recurring terms in the search for beauty through the application of universal laws, mainly the golden ratio. In the articulation of organisms, however, other concepts of geometry also appear, such as symmetry, addition, multiplication, division. The counting unity, strictly linked to number, expresses the central importance of the concept of *module*.
The formal archetypes refere to the repetitive juxtaposition of equal elements, according to the elementary symmetries in a modular lattice with rational proportions, which may grow to the infinite in the three directions of the Cartesian space.
In general terms, the form is defined by absolute or relative magnitudes in the different directions, and it depends from the chemical and physical laws of matter.

3 - The balance of forces (order and symmetry)

Modern science is born from the systematic observation of nature after Galileo stated that the book of nature is written with the characters of Geometry: "*Philosophy is written in this grand book, the universe ... It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures"* (DRAKE 1953). Descartes reconciled numbers and forms with the Analytical Geometry. The understanding that the scale of quantities is a discriminating factor and in nature it is not possible to increase a shape beyond any limit, keeping proportions and materials unchanged. Construction science and mathematical calculation take the place of the geometric sizing of the structures. The existence of thresholds in a form's growth because of mechanical, technological or constructive problems, is frequent the application to architecture.
The formal archetype is the intrinsic equilibrium, with the determination of its static centre of gravity, underlined by the articulation of the architecture itself.
D'Arcy Thompson showed that the form articulation is the effect of the physical forces of the system. It is due to molecular pressure in the cell, to mechanical stress in bigger structures. The force of

gravity controls the shape of the bigger organisms and the activities of superior beings, while in the field of the infinitely small it loses importance compared to the surface tension, which induces the semi-fluid bodies to assume spherical shape. The natural shape of the cell keeps the least external surface with respect to the internal volume, but the external forces induce transformations to balance the system according to the maximum efficiency, which is typical of nature. In higher organisms, the skeleton's mechanical structure performs static functions.
Galileo explained the mechanical principle of resistance by form and his observations allowed the scientific method and the science to born. Even in the eggshell, which is the model of thin-structure domes, resistance is in relation to size. The hollow shell is suitable for small animals, in the larger ones it is stiffened with ribs as in tortoises. This fact is well known to structural scientists, whose solutions often take the shape of bone skeletons, where the substance thickens in the most stressed points.

4 - The organism (growth and transformation)

The crucial fact is the transition from the inanimate world to life. The border seems to be due to the form geometry: the breaking of the symmetry as a factor of balanced stability, which implies imbalance, therefore movement or changes.
In the organic model the most important change is growth that is implicit in life.
The archetype is the spiral, an open and continuous form that associates the linear aggregation and the radial lattice, geometrically expressed by the gnomon in the golden rectangle, on which rivers of ink have been spent, above all in relation with architecture. In the spiral growth, the cells alignment takes place by moving the upper layer with respect to the lower one with a rotation with respect to the vertical axis and sometimes even with a shift with respect to the reference plane. The geometry of this form is a logarithmic function that grows without changing of shape. Each increment is similar and similarly located with respect to the previous one. The same result by adding what Aristotle call *gnomon*, which is the part you shall add for self-similarity, analogous to that of fractals.

The principle of growth is connected to the evolutionary concept of transformation, which characterizes the interpretation of the organic architecture of the Modern Movement, focused on formal and functional analogies between the architecture and living organisms. The growth process demonstrates the importance of the system balances and it was the basis of the brilliant intuitions of R. Buckminster Fuller and of P. Frei Otto. The first with geodesic domes, the other with tensile structures, they pursued the maximum efficiency through the imitation of organic model.
Fuller's domes are light structures with a regular organization. This is inspired by the shapes of radiolarians, supported by an exoskeleton that distributes the forces over the cell surface. Their shape is the goal of a research, which started from the study of the balance of forces and from the properties of regular polyhedra (FULLER 1975). That allowed him to transpose the principle of cell balance into a greater dimension. The solution derives from regular geodetic divisions of the sphere surface, inspired by geographical projections and the microcosm of single-celled individuals. Fuller himself points out that his experiments investigate the balance of nature, trying to learn its secrets.

5 – The dynamic system (transformation and responsiveness)

The identification of the mathematical relationships linking form and growth explains the formal evolution. D'Arcy W. Thompson explains that biological processes manifest asymmetries in the balance of system forces, with lines of less resistance along which the development is faster.
The forces that alters the growth in the different parts of the same organism, determine diversifications in the forms. In the small the balance responds to the surface tension on the cell's membrane, in the great to the force of gravity. Asymmetry is the main difference between vital and non-vital phenomena. Pasteur stated that the production of exclusively asymmetric compounds is a life's prerogative. It manifests itself in ordered organisms, in which symmetry reappears as a factor linked to cellular multiplication. Cells' proliferation means controlled growth, which is geometrically

organized but not uniform and has some stopping points. The shape therefore adapts to external conditions.
Organic growth means a change of dimensions, sometimes even of proportions and shape. In organic tissues the increase occurs through repeated cellular multiplication, with the tendency to be placed in linear series. Histological aggregates present repetitive formations of similar cells. The arrangement is linked to the optimization filling the space and induces adaptations of the tendential sphericity of the cell into a squared or a hexagonal lattice (cubic or tetrahedral in 3D). Variants and invariants between species have been explained with deformed Cartesian diagrams that highlight formal homologies also in species that are not close in their evolution. In morphologically similar individuals, the deformation of a two-directions grid that connect corresponding points, measures in its deformation the adaptation of the same organization to different growing conditions. Lines assume different curvatures maintaining the same topology in their functional layout.
Contemporary evolution of Deconstructivist Architecture gave new vitality to organic design. Today visual computation allows the imitation of life-responsive processes for the computerized search for optimized and therefore environmentally sustainable solutions. New organic forms derive from the simulation of complex and apparently disordered phenomena, regulated by recursive algorithms, which underline the maturity of computation in design: '*Computers outgrown their servile function in the digital drawing room, where the real design was still done far away from the machines, sketched by hand, guided by genius…*'. (SPUYBROECK 2004)

Conclusions

The principle of nature as the main inspiration of the project accompanies the theory of architecture from its origin. The digital computation granted the success of Organic Design as a sustainable approach inspired by natural organisms.
Today the imitation of the nature pursues the optimization in the search for the best solution in the project. Nature, which the ancients considered perfect in its things, pursues the maximum efficiency of its systems with a continuous evolutionary process and therefore remains the best model.

In the evolution of the imitative concept of nature we recognize 5 steps. Each new approach keeps the previous principles by adding new design references in a more sophisticated interpretation, from the exterior appearance to the adaptation processes:

1 - the essential geometry and shape references;
2 - the composition and the parts sizing;
3 - the structural functionality in the relationships pattern;
4 - the growth of the organism and the law of transformation;
5 - the responsive system in the relationship between cause and effect.

Each of these phases exemplifies a step in the development of a computational model that optimizes the variables of a problem, solving it through recursive algorithms, scripting the process code. Taken together, they show the design intent that governs the concept layout of artefacts.

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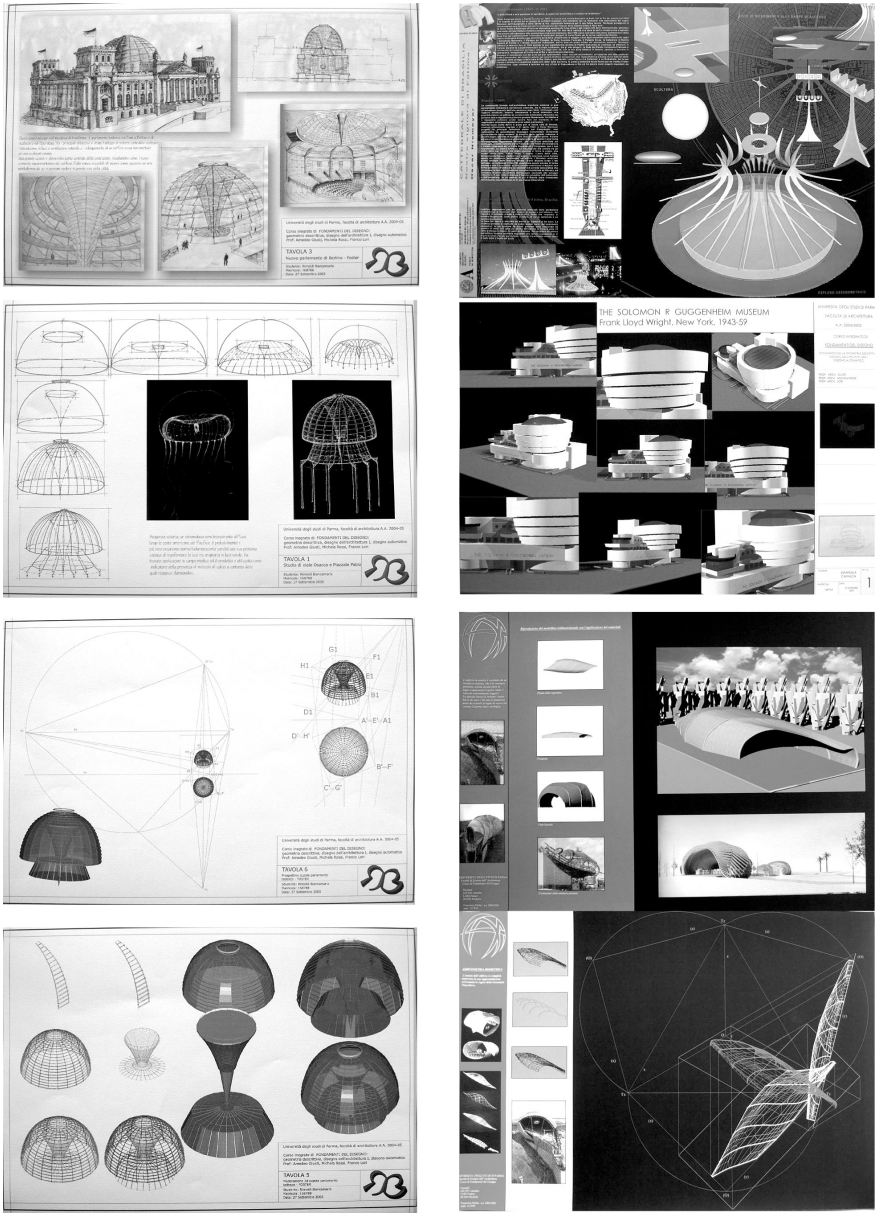

Organic references in contemporary architecture, form and geometry. Students' drawings.