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NATURE INSPIRED ARCHITECTURES AND JEWELS PARAMETRIC DESIGN

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Abstract. The concept of "geometric form" aroused from the observation of forms already existing in Nature. These can be sources of inspiration for artists. We present some design projects in which architectures and jewels are created in this framework, modelled using parametric processes and softwares.

Keywords: geometric forms, inspiration from nature, parametric design, math&art, architecture; jewel design

Mathematics Subject Classification: Primary 97M80; Secondary 00A67

0. Introduction. Mathematics for Parametric Design

New (and old) Mathematics have gradually become instruments and sources of inspiration for new forms of Art that aim at transcending the experiential world, rather than trying to reproduce it in a stereotypical way. In order to understand most of the new forms of Contemporary Art, one needs to understand their mathematical and technological roots. It is well known that Geometry was born out of much older knowledge as that part of Mathematics explicitly devoted to investigate shapes in Space and measure their "extension"; developed as a practical discipline since the Palaeolithic age [12], during the Greek age it became a formalized elegant tool of theoretical thought. The concept of "geometric form" did in fact slowly arise from the observation of forms already existing in Nature and more or less hidden in the structures through which the human mind tends to perceive the "Order of Nature". [19] The language that we use to understand "Kosmos" is indeed formed by a subtle intertwining of Numbers (the act of "counting", i.e. "Arithmetic") and Forms (the core of Geometry. [11] An infinite family of "geometrical shapes" that we like to call "forms without an age" since they have crossed the ages, from Prehistory to now, giving rise to what we call the "persistence of forms" [9]. Along with experimental developments that are still under their way, for many artists of XX Century the simple forms of Geometry – and more generally, the entire field of Mathematics - have again become a fresh source of inspiration for Art [19], in a kind of "travel backward in time", towards a renewed aesthetics of "simple forms": circles, straight lines, triangles ("without which we cannot intend human words" as Galileo said), as well as squares, pentagons, hexagons and other geometric constructions often found in Nature [6;7].
On the other hand, we have examined, during the previous Aplimat conferences, some examples in which, starting from Nature and simple geometric forms, contemporary artists and especially architects designed complex surfaces, often using a parametric approach [6; 16; 17].

The aesthetics related to the use of geometry is a topic in the field of theories of architecture gradually applied to the compositional process to draw plans and elevations according dimensional relationships, hidden but perceived at a deeper level, probably by virtue of a rooted cultural conditioning; also applied to polygonal modularity, up to the representation of buildings according to new geometries, to the topological transformations of surfaces and volumes, to the dynamic and kinematic parametric representations, and even with reference to René Thom catastrophe theory [6].
Mathematics and geometry represent the core of the architectural design process, in the age of digital parametric non-standard architecture. They have a central role from the initial stage of finding form, shaping form, generating form, to the process of manufacturing architectural elements. Contemporary computer technology allows the application of a number of tools for the design, analysis, simulation and manufacturing of complex architectural forms. In the process of design, today's leading architects as well as leading schools of architecture use different software packages and digital technologies, thus contributing to the formation of a new aesthetics of digital architecture. On the one hand, technical possibilities open up new horizons in architecture, while on the other, they give rise to new issues related to the disciplines of mathematics and geometry [21].
Parametric design is a process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between design intent and design response [13; 22]. Parametric design is a paradigm in design where the relationship between elements is used to manipulate and inform the design of complex geometries and structures. The term parametric originates from mathematics (parametric equation) and refers to the use of certain parameters or variables that can be edited to manipulate or alter the end result of an equation or system [4].
While today the term is used in reference to computational design systems, there are precedents for these modern systems in the works of architects such as Antoni Gaudí, who used analog models to explore design space [1; 18].
Parametric thinking introduces the shift in the mindset between the search for a specific static and defined formal solution, and the design of the specific stages and factors used to achieve it. It is the use of algorithms and advanced computational techniques not for the sake of drawing shapes, but rather for creating formal possibilities. It is not about producing a solution, but a family of possible outcomes [14].
Today many topics from different fields influence the design and mathematics can be considered as a tool of governance of finite element calculation. Former mathematical and geometrical algorithms, forms and structures are now visible and spatial understandable for architects and, therefore, usable. Using new technique architectural design has established computational design concepts such as: topological space (topological architectures), isomorphic surfaces (isomorphic architectures), motion kinematics and dynamics (animate architectures), keyshape animation (metamorphic architectures), parametric design (parametric architectures), genetic algorithms (evolutionary architectures) or fractal geometry (fractal architecture) [15].
In conceptual parametric design, it is the parameters of a particular design that are declared, not its shape. By assigning different values to the parameters different objects or configurations can be easily created. They are powerful owing to their ability to capture a high degree of variation in a few numerical values. Software like Rhinoceros offers such script editors for parametric design. Many architects have used it for conceptual design [21].

1. Projects

Within this framework, we will briefly present some of the projects realized during the last ten years by the SAO Schiavello Architects Office, in which nature and mathematics lay at the basis of the inspirational as well as design processes. SAO rely on principles such as Shape and Patterns and Form generation process, starting from the observation of nature and, in particular, on how form

and its varieties in nature are found. Patterns organize and define relationships in nature and can be integrated into design to substantiate and support visual communication. Since design's purpose is to create a relationship with the viewer, the language of pattern helps to frame what that relationship is before the message is read or even consciously processed [20].

1.1 The Earthquake Museum

The Earthquake Museum (acronym "MuTerr", from the Italian words Museo and Terremoto) is located in the major hypogean spaces of the San Domenico Convent in Soriano, in the Province of Vibo Valentia (Calabria Region, in the South of Italy), a religious XV Century complex which was partially destroyed by the earthquake of 1783. The Convent, formerly called "Casa Santa" (i.e. "Holy House"), has historically been the focus of the "Dominican Universe", having had the important support of many popes, cardinals and kings of Spain and Naples, ruling in the south of Italy (Fig. 1.). Since 1654, the "Holy House" has administered the County of Soriano and therefore its sphere of economical, cultural and social influence has greatly contributed to the development of the surrounding areas and settlements. Internally there were a guesthouse, a pharmacy, a print house and a well-stocked library, which still exists and that contains many prestigious volumes. For many years, the Dominican complex has been one of the most important symbols of the earthquake history and today it is reborn as a museum center, second only to that of Reggio Calabria, the biggest in the region. The complex also includes the Museum of Marbles (Italian acronym "Mumar") where of particular value is the Head of Saint Catherine of Siena, in Carrara marble, probably attributed to Gian Lorenzo Bernini. Besides the "MuTerr", other three museums are under construction in the same site: those of Ceramics, Sacred Arts and Contemporary Art Gallery.
MuTerr represents an attractive meeting and information place on earthquakes, not only of the Calabria Region, but of the entire Italian country. The earthquake phenomena are analyzed from different perspectives: historical, anthropological and architectural.
Thanks to this restoration, another important part of this complex, which remained so far "hidden" and never used, has been brought to light. All the ancient architectural spaces of the southwestern wing, commonly called the "Darks", testimony of what was once the most "deadly catastrophe" caused by the earthquake of 1783, are now accessible in the "MuTerr" and can be used for temporary exhibitions, different cultural events or conventions.

Fig. 1. The Earthquake Museum, San Domenico Convent in Soriano, Vibo Valentia (Italy).

The Museum has two distinct environments: the visitor is welcomed in a modern area, marked by the installation of a suspended monumental wooden ribs ceiling, created with digital processes of

parametric design and cut with CNC machines. The ceiling is a true piece of art that recalls the wave and fleeting movement of the earthquake and which visually envelops the visitor in an aggressive and dynamic place.
The ceiling was designed (Fig. 2.) by sectioning a "seismic wave" (Fig. 3.) in more than thousand pieces (Fig. 4.), snap-fit assembled by attacks and steel cables to the IPE beams which are anchored to the perimeter walls (Fig. 5.).

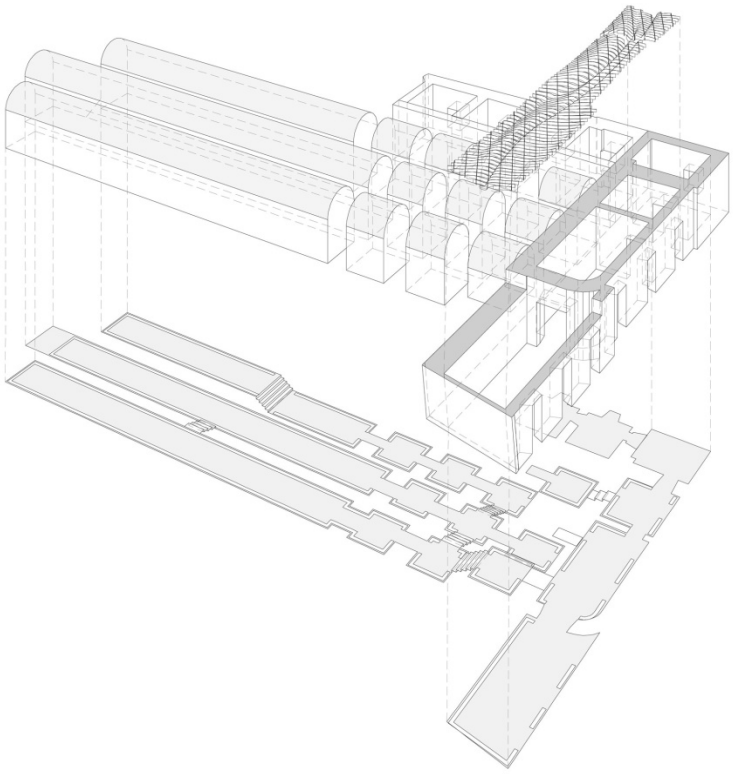
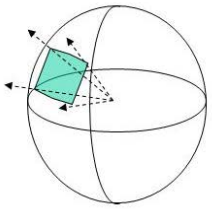


Fig. 2. Design of the ceiling

Principi fisici: energia delle onde sismiche

L'energia delle onde sismiche diminuisce con la distanza percorsa a causa di tre fenomeni:

(1) Divergenza sferica
(2) Attenuazione intrinseca (frizione)
(3) scattering



(1) Divergenza sferica: si consideri un onda sferica sinusoidale:

$$u(r,t) = A\cos(\omega t - kr + \varphi)$$

L'energia cinetica per unità di volume è:

$$E_c(r,t) = \frac{1}{2}\rho\left(\frac{\partial u}{\partial t}\right)^2 = \frac{1}{2}\rho\omega^2 A^2 \sin^2(\omega t - kr + \varphi)$$

L'energia cinetica si trasforma in elastica e viceversa: l'energia totale è: $E_{tot} = \frac{1}{2}\rho\omega^2 A^2$

e l'intensità di energia che attraversa la superficie unitaria è:

$$I = \frac{1}{2}\rho\omega^2 A^2 v$$

Data la simmetria sferica e la conservazione dell'energia:

$$I_1 \frac{4}{3}\pi r_1^2 = I_2 \frac{4}{3}\pi r_2^2 \qquad \text{ovvero:} \qquad \boxed{I_1 \propto \frac{1}{r^2}}$$

Sismica Applicata

Fig. 3. Seismic wave.

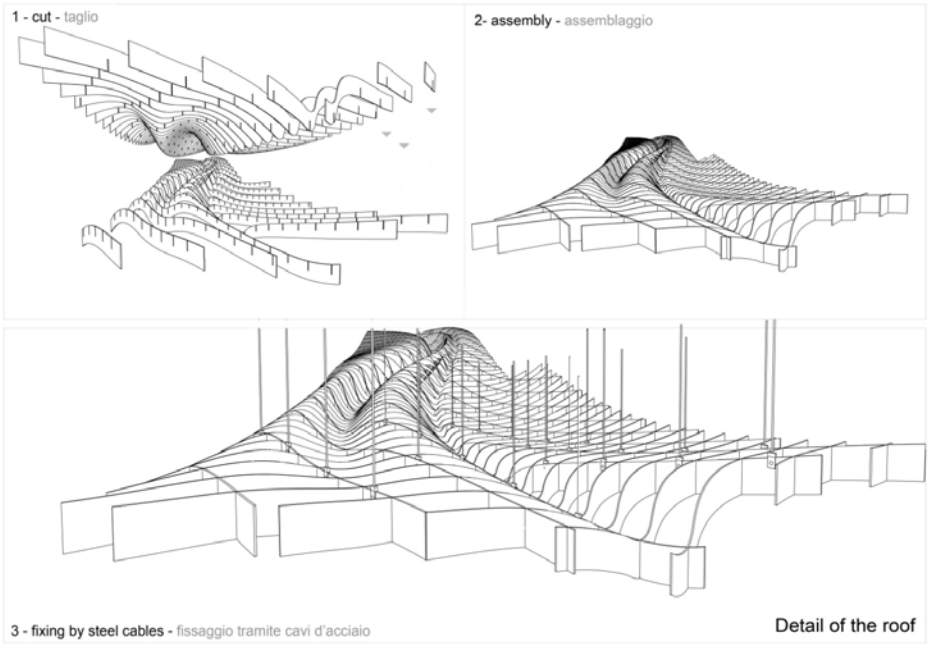


Fig. 4. Detail of the roof design.

Fig. 5. Installation of the ceiling.

Cutting and preparation for digital manufacturing have been created with Rhino / Grasshopper parametric software. Grasshopper (originally Explicit History) is a plug-in for Rhinoceros 3D that presents the users with a visual programming language interface to create and edit geometry [2]. Components or nodes are dragged onto a canvas in order to build a grasshopper definition. Grasshopper is based on graphs (see Graph (discrete mathematics)) that map the flow of relations from parameters through user-defined functions (nodes), resulting in the generation of geometry.

Changing parameters or geometry causes to changes to propagate throughout all functions, and the geometry to be redrawn.
From this bright area, the visitor is then conducted in the "Darks", characterized instead by a charming, calmer and contemplative atmosphere. Feature of this second room are the vaulted ceilings, whose charm has made it stand out from the white resin flooring. In order to highlight the direction of the vaults and of the opaque glass panels covering the channeling of the installation system, the flooring continues without any gaps. The long and complex reflection on earthquakes that the "MuTerr" proposes, between history and science, looks at the past but strongly interests the future, in the belief that a new shared culture of security of tenure can grow on these bases of knowledge on the earthquake phenomena.

1.2 Portonave Auditorium in Navegantes harbor

The "Portonave" (Company has opened a new area of the Harbor of Navegantes, in Brazil, one of the nation's largest private commercial ports owned by the Company itself. The Company bought the plot of land in 2005, starting its activity in 2007. Since then, "Portonave" has been employing more than 1,100 employees, contributing to restart the economy of the city.
In 2008, a new project planning has started. The aim of the company was to create a building hosting, on the ground floor, a company canteen, a library, a relaxation area and a dressing room serving its workers and, on the first floor, an auditorium and a large raised and covered square for events. Although they took a long time to start, works have been concluded in just 14 months.
The goal was to create a building acting as a new landmark in the area and open to the local community as well. As a matter of fact, the Company has started a partnership with the public administration aimed at promoting both cultural and social projects (health promotion, child and elderly care) and environmental initiatives (requalification of different areas of the city, awareness projects on environmental issues and other initiatives focused on sustainable development).
The "Portonave Project" is extended over a surface of 5,600 square meters and it has been carried out thanks to parametric processes.
The idea of the "Schiavello Architects Office" and the "Canhadas Bot Tarelli Arquitetura" studios was to give a strong, simple and innovative sign to the Project. The building shape reminds the form of a ship ready to sail and its surface was inspired by the geometrical texture of the so-called butterfly fish, belonging to the Chaetodontidae family and that can be found also in the Atlantic Ocean (Fig. 6.).

Fig. 6. Geometrical texture of the so-called butterfly fish (Chaetodontidae family).

The large, custom-made aluminum panels of different sizes cover an area of 90 x 40 meters; the high facade has been conceived as an urban and panoramic "promenade", shining at night. The building creates a sort of "path", structured on various levels and connected with ramps, staircases

and a raised square, with a view on the harbor. The external green areas are also distinctive elements of the Project (Fig. 7.).

Fig. 7. Portonave Auditorium in Navegantes harbor.

From a functional point of view, the working spaces are located on the ground floor while the upper part of the building hosts the most representative ones as well as the relaxation area. The connection elements - ramps, stairs and corridors, that link the different functional areas of the building, have been designed to have both a functional and an expressive and representative effect. The building is well placed in the context it belongs to.

1.3 Cheong-na City Tower: geometrical equilibrium

Project for the Cheong-na City Tower (Korea) International competition by the team Francesco Schiavello, Junseung Woo, Yeol Park is for an observatory of approx. 450m (1,480 ft) height, 200000 m^2, including exhibition, shopping area and entertainment areas. It is intended to be the sixth largest tower in the world, and the third highest observatory in the world.
This project aimed at achieving the representative aspiration and symbolic meaning of Cheong-na City and satisfy people's stable and grand visual experience to appreciate. Cheong-na is continuously changing, evolving to become a technological and cultural centre in the world, also through a precise strategy for an economically and structurally safe and sustainable development.
The Cheong-na City Tower is based on the mathematical principle of turning curves, which design results in woven structural conditions, in order to deal with its own stress and load. Mathematically generated circulating structure is related both to structural aspects than to symbolic meanings.

Its design has a reference to the Korean *Taegeuk* graphic symbol [3]: the interlocking-spirals, historically associated with Korean Taoism philosophical values, permanent circulation of cosmos, and is used in the flag of South Korea (Fig. 8.). It represents here the city tower idea as a symbol of a sustainable, economical and cultural agreement.

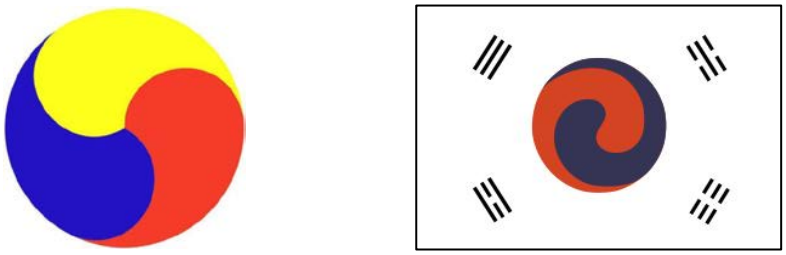


Fig. 8. Left: Korean *Taegeuk* graphic symbol; right: the flag of South Korea.

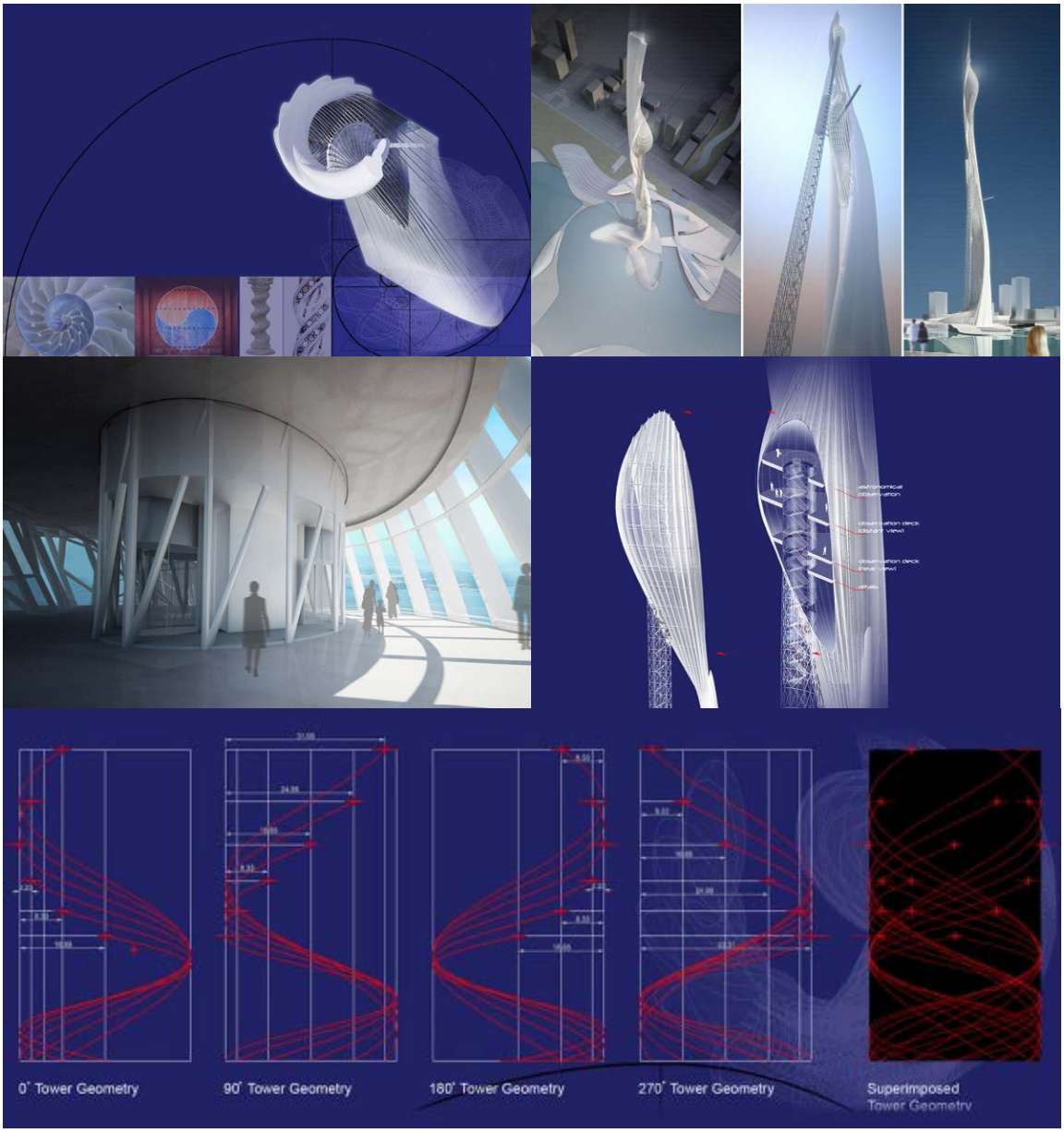


Fig. 9. Design and geometry of the Cheong-na City Tower

In the project, composite steel and concrete are provided along the perimeter of the Cheong-na City Tower at regular spacing. The bundle of the six tube structure is provided to maintain equilibrium under vertical loads restrain capability. Each of the tube structure is composted with embedded steel trusses. The tower is designed to meet three parts of major functions, corresponding to a turning angle, by steps of 90°: Observation level (90°), Entertainment level (180°) and Retail & Cultural (270°) (Fig. 9.). At a very simple inspirational level, and at the core of the project, there is an helicoidal staircase, a form that persists over the centuries [9], for example, in staircases and ancient cochlear columns, which also where used for visual storytelling purposes [8].

1.4 Metro station covering in Turin

Nature is always an infinite source of inspiration, especially when its forms reflect a mathematical harmony. In this case the inspiration came from the wings of the dragonfly. They show a particular texture and their functional morphology, with a considerable wingspan, has the property of not bending under considerable stress, despite their length [5].
The project by Francesco Schiavello and Yeol Park for the International contest for the design of covering of the Metro stations in Turin (Italy) indeed followed these principles. In addition, the pattern recalls the internal cupola of the mole Antonelliana Tower, the symbol of the City, which hosts the National Museum of Cinema.[1]
Turin, as a post-industrial city, has been trying to find a way to develop the city from the cultural point of view and, after hosting the winter Olympic games, has undergone a continuous transformation.. The main character of Turin is that it is surrounded by nature: the Alps mountains, covered with snow during winter, are a natural and suggestive frame to the city. The proposal for the roof intended to recall a pattern from nature. To obtain the fluid forms for the roof we generated a new geometry, which is based on an hexagonal geometry pattern, subsequently deformed parametrically (Fig. 10.).

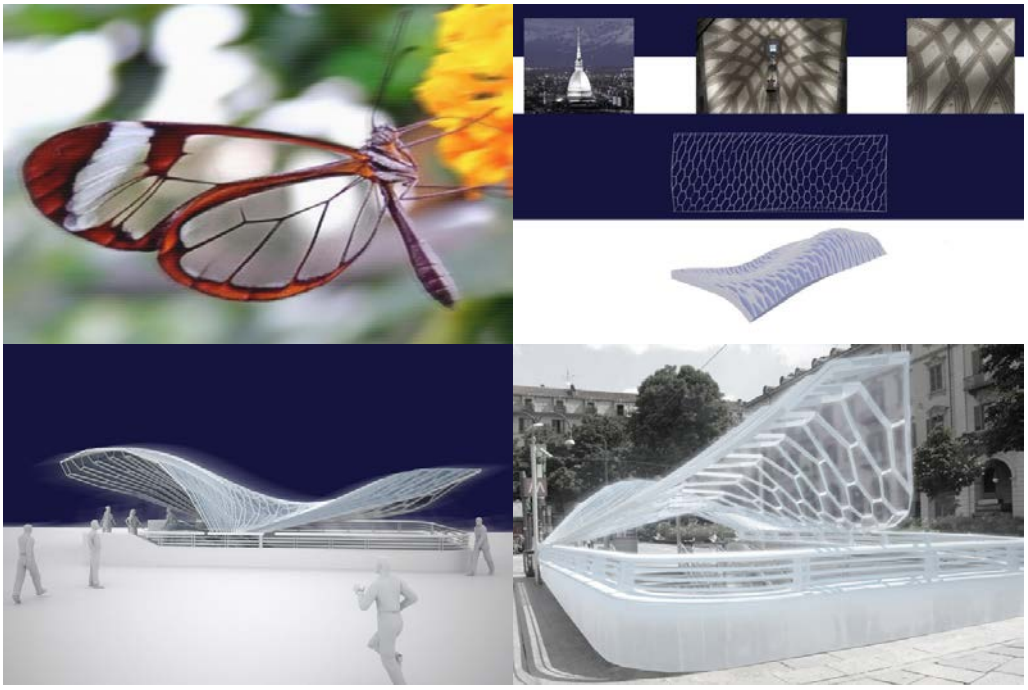


Fig. 10. Dragonly wings inspiration for the design of the metro station in Turin.

[1] Turin was the first Italian city in which the industry of cinema was born and developed, in 1896.

1.5 Be[e] Italy and Radiolaria Jewelry

A jewelry collection was presented for the first time during the second edition of the Trieste Mini Maker Fair, under the premises of the International Center for Theoretical Physics (ICTP), a research center that works on the basis of an agreement between the Italian Government and two UN Agencies and where studies and researches in physics and mathematics are carried out.
This project is indeed linked to the worlds of physics and mathematics; it also combines biology, these all merged through parametric design.
The goal is creating unique design jewels, starting from the study of natural phenomena, then using models that we can find in nature, and by means of software which create codes based on parametric processes. This process emulates biological models of construction, so far indecipherable codes, putting digital manufacturing at the service of architecture and design. The design of this creations in particular is inspired to forms and geometries which bees are able to create: endless configurations, characterized by the alternation of solids and voids and by the irregular Combination of 110 modules (honeybees parametric). This design process has been used to represent the Italian region's forms. Jewels which are dynamic by their very nature (Fig. 11-12.).
On the occasion of the Trieste Mini Maker Fair, SAO has therefore decided to present a project of innovation and design, while denouncing the problem of the widespread bees death. Beyond its aesthetic function design becomes thus also a sensitization and awareness raising tool.

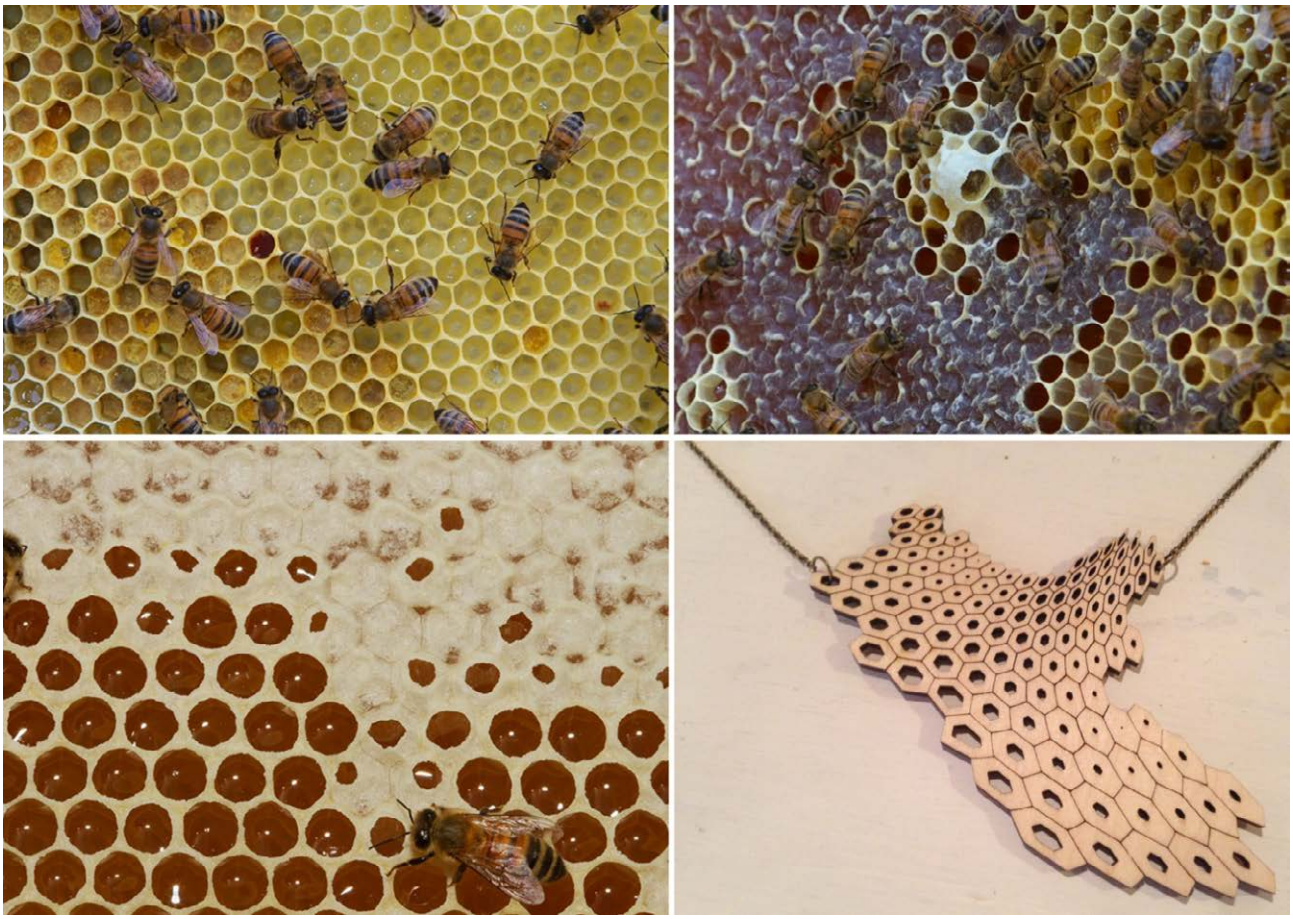


Fig. 11. Inspired by nature Be[e] Italy Jewelry.

Fig. 12. Be[e] Italy Jewelry.

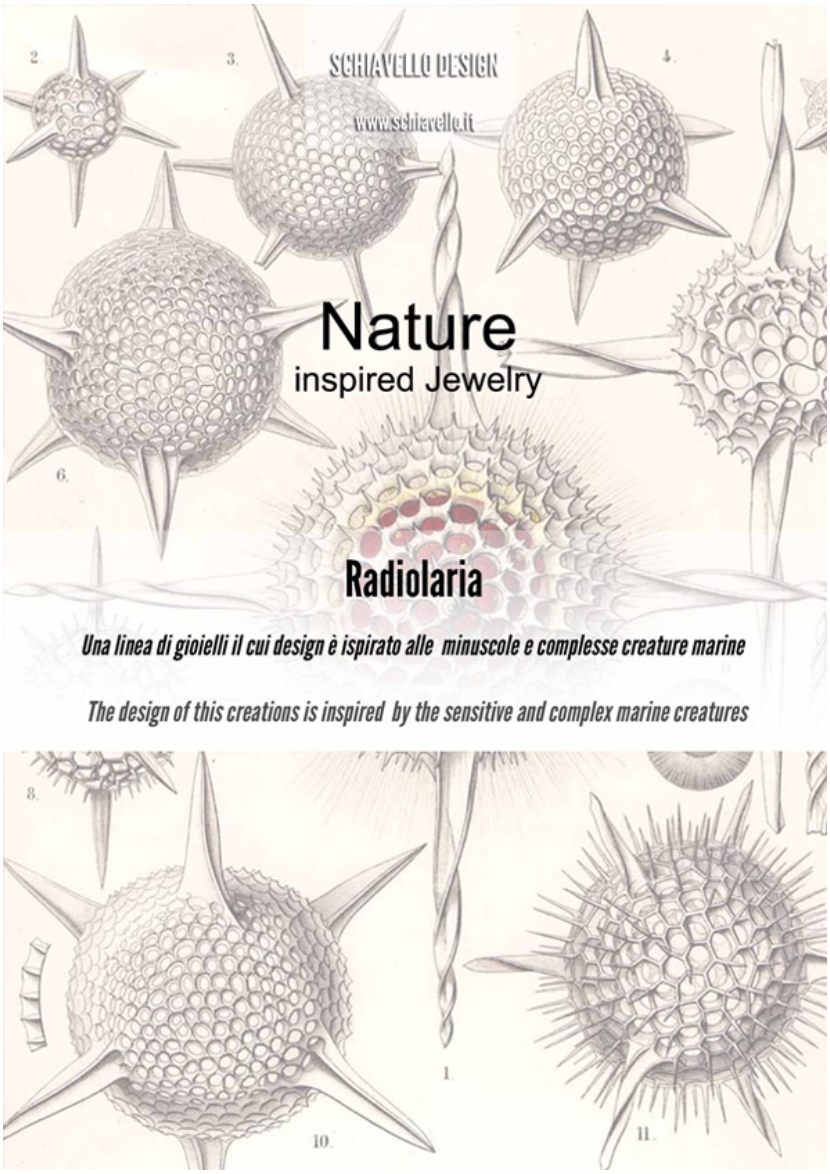


Fig. 13. Radiolaria Jewelry inspiration.

The necklace comes from the decomposition of the design of the radiolaria: a protozoon characterized by a siliceous skeleton. The linear dimensions of this protozoon are most often between hundredths and tenths of a millimeter, but there are species that reach or exceed the millimeter. Schiavello, combining design and biology, has enlarged the design of a protozoon and, by modifying its shape through digital processes of parametric design, has created a unique piece of jewel, with a fluid, harmonious and dynamic shape.

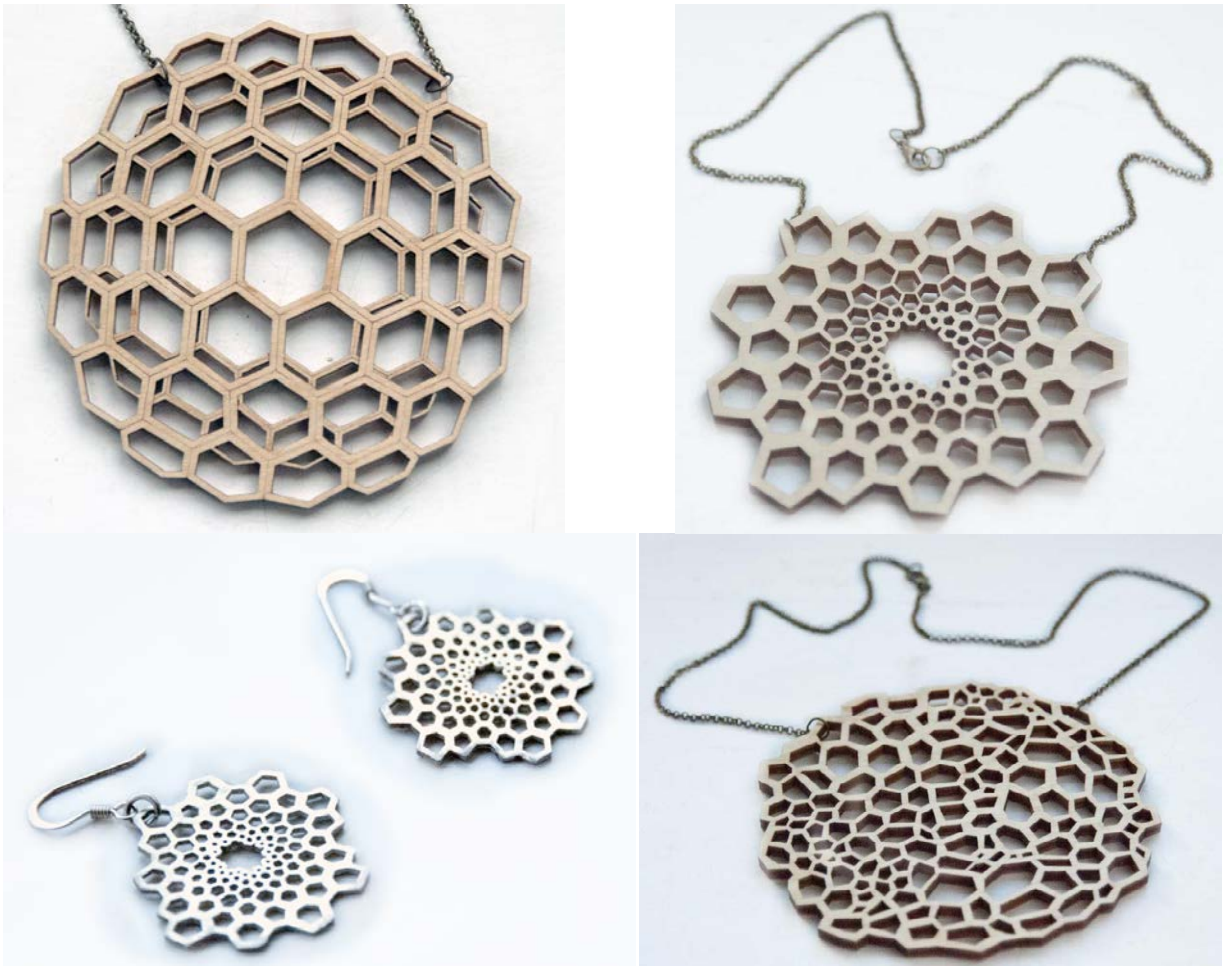


Fig. 14. Radiolaria Jewelry.

2.0 Conclusions

Mathematics pervades nature in its various forms, which can become an infinite source of inspiration for the artist, the architect, the designer. The process of design itself benefits from various parametric software that have a strong mathematical basis. Machines for cutting and 3d printers make these design become real objects.

Epilogue

In the brief epilogue, Thompson D'Arcy [10] writes that he will have succeeded "if I have been able to shew [the morphologist] that a certain mathematical aspect of morphology ... is ... complementary to his descriptive task, and helpful, nay essential, to his proper study and

comprehension of Form." More lyrically, he writes that "For the harmony of the world is made manifest in Form and Number, and the heart and soul and all the poetry of Natural Philosophy are embodied in the concept of mathematical beauty" and quotes Isaiah 40:12 on measuring out the waters and heavens and the dust of the earth. He ends with a paragraph praising the French entomologist Jean-Henri Fabre who "being of the same blood and marrow with Plato and Pythagoras, saw in Number 'la clef de voute' [the key to the vault (of the universe)] and found in it 'le comment et le pourquoi des choses' [the how and the why of things]".

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