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THE USE OF TWISTED SURFACES AS A SOURCE OF INSPIRATION IN ARCHITECTURAL CONCEPTS

Abstract: *In the creative activity of any field we rely on scientific, technological and artistic interdisciplinarity, through which any designer manifests itself as a creative being, capable of capitalizing and enriching nature. Nature, in turn, provides inspiration for various efficient structural forms The spiral found in various forms in nature is interpreted and applied to architectural concepts. These architectural concepts are adapted to technical and constructive thinking through descriptive geometry, developing other structural geometric shapes. This paper analyses the ways in which descriptive geometry, through helical surfaces, allows architecture students to create volumes and architectural spaces, and especially to understand the role they play in the development of spatial thinking, to understand the different geometric patterns we find in nature.*

Key words: *descriptive geometry, helical surface, education, architectural design, architectural space.*

1. INTRODUCTION

Nature astonishes us through the static lessons that it offers. Being in a continuous development for billions of years, only the most resilient structural forms have persisted. A large number of structural systems have roots and are inspired by vegetal or organic patterns, being structural, safe, effective and aesthetic forms. The acquisition, development and adaptation of such concepts provides a new vision for the development of new space concepts. Nature offers ubiquitous examples of helical architecture with various functions. Helix structures are also present at biomolecule level, being involved in the storage of genetic information. Among other numerous examples, shells with their helical form, are one of the natural forms whose functions are simple enough to be approximated by mathematical relations.

The study of this paper focuses on helical surfaces, their representation in descriptive geometry and the exercise through which these geometric shapes offer students at the Faculty of Architecture and Urbanism in Cluj-Napoca a source of inspiration and a starting point in the concept of architecture. Knowledge of descriptive geometry is required to design various architectural volumes. This discipline has the quality of developing three-dimensional thinking, forming a precise and logical spatial vision of the student. The training of students in the first year of study implies a substantial effort in their task of designing the tridimensional space.

2. OBJECTIVES OF GRAFIC EDUCATION

As Galileo Galilei (1564–1642) said, "The universe cannot be read until we have learned the language and become familiar with the characters in which it is written. It is written in mathematical language, and the letters are triangles, circles and other geometrical figures“ [1], the drawing is the compositional and essential language of architecture. This language is used to create a geometric matrix capable of satisfying both the conceptual strategy, the functional and structural determinations. All these stages are correlated with geometric thinking, and geometry-architecture relation is essential in articulating the shape of the built space.

In the first year of study the computer use in creation of architectural design is restricted, laying emphasis on the sense of proportion given by the drawing scale, sketching with free hand being the best way of developing the perception, and in the subject Descriptive Geometry, the drawing with free hand makes the learning process much more efficient. The start of this graphic research through descriptive geometry is crucial in the stages of completion of architectural drawing, therefore it certifies the necessity of a unit between geometric thinking and constructive thinking. The main objectives of architectural drawing are the viewing of space/volume and this skills is acquired by a very good capacity of perception. Abstract thinking of drawings represented in projections is the basis of day-to-day activity of architects. The objective is to provide tools for imagining and representation with precision and dexterity of expression of architectural tridimensional form, a repertory in continual change.

The main reason for the necessity of using the representations of descriptive geometry is the biunivocal correspondence between the finished product, architecture and drawing, which makes possible the checking of measurements and sizes. Such representations attest the whole system and the process which encapsulates the logic of projective geometry. On the other hand, this biunivocal relationship is determined by images and drawings which define the systems of lines, relations, sizes, exact positions in the land, surveying measurements, the position and form of structure/architecture, an assembly understood as projection at a certain scale, of reality, making everything possible by orthogonal projection [2].

2.1 How to communicate with students

At the beginning of any project there is an idea that materializes by drawing, and the shape catches volume with the help of descriptive geometry by searching for geometric schemes that synthesize the complex form of architecture. The student sees drawing as instrument of conceptual control and communication of the architectural process. Along with drawing, models take a significant place in student practice, the realization of models at small scale and makes them understand better the process. However, at the core of his practice are the drawings, from earliest conception right through the realization of project.

By courses, works and workshop exercises the students can follow historical, theoretical fundaments and the technical bases of projective geometry which will offer the bases of development of a specific vocabulary. That is why, the theoretical courses take the shape of debates and the practical workshop mean effective construction of models and representation of technical drawings, the very confrontation with built reality. This exercise takes place in the first year, providing a reliable thinking base for students, helping them to imagine and design more and more complex surfaces. Students depend on these drawings in the development of projects, localize the problematic areas and their resolution.

The drawing facilitates the thinking process and allows for interdisciplinary communication with all those involved in the constructive process of architecture [3]. The objective is not the quantity of information stored, but the creative potential and originality of architectural form from the perspective of determination of its structural, functional, aesthetic and cultural symbolic form.

2.2 Themes on design and graphics activities

Abstract thinking in descriptive geometry is a perfect environment for design in tridimensional space. The first-year students of the Faculty of Architecture and Urban Planning of Cluj-Napoca accomplish better this task by themes and tasks which are normally related to architecture. In order to accomplish this target we approached in the subject Architecture Design 1 a very interesting theme which proposes the realization of a temporary pavilion which will be located in the urban space. The object proposed, of small sizes, with an area of 100 m2, will have the destination of complementary space for cultural or entertainment events or will serve as support of the simple relaxation in the public space. This design theme correlated with geometric thinking will provide very interesting results and will maintain a high level of motivation, which is essential for the success of developing imagination and tridimensional thinking.

3. APPLIED DESCRIPTIVE GEOMETRY. HELICAL SURFACES

Helicoidal surfaces are ruled and are generated by a straight line moving such that every point of the line shall have a uniform motion around another straight line (axis), and at the same time a uniform angular motion about it. This can be cylindrical, conical or spherical.

In the family of helical surfaces, two main types can be distinguished [4]:

- straight, where the generatrix moves along two directing lines, a curve one - the helix and a straight one – the cylinder axis, in an angle of 90º;
- oblique (or askew), generated either by straight lines displacing along the two curves mentioned earlier at an angle < 90º, or by straight lines that remain permanently tangent to the points of the cylindrical helix and displace along two directing curves that are not situated in the same plane.

The helicoidal surfaces have applications in engineering in thread construction, obtained by moving a plane figure on the surface of a cylinder following the rules previously mentioned. Among the applications of helicoidal surfaces one can mention the square and rectangular thread, and among the oblique surface applications we can exemplify, the triangular and trapezoid thread.

Spiralled surfaces are found by the mixed motions of translation and rotation of a plane figure about a rectilinear or curved axis, or a real or imaginary surface, called core. The plane figure can be a triangle, square, pentagon, hexagon, circle, etc.

The helical surfaces are obtained by rotating a segment line called generatrix around directrices lines, respectively the spiral surfaces are obtained by composing simultaneously the movements of translation and rotation of a plane figure around an axis - which can be a straight line or a curved line, or around a real or imaginary surface - called core. The plane figure could be a triangle, a square, a hexagon, a circle etc.

3.1 Cylindrical helix and circular helicoid

The evolution of plants due to environmental changes has shaped some living organisms into geometric shapes, which are based on a circular helicoid. These spirals can be found in nature, both in plants and animals. An interesting example is the shrub, *Persoonia helix*, found in southwestern Australia (Figure 1). It has twisted leaves like a helix.

Figure 1 Persoonia helix [5].

In the descriptive geometry the helix is any curve drawn on the surface of a cylinder so that it intersects the cylinder generatrix at a constant angle. In particular, a plane perpendicular to the generatrix divides the cylinder by a curve that makes a right angle to each generatrix, Figure 2. This curve is a helix, called the right section. Generally, it is the only flat section that can be a helix. If the cylinder on which the helix is drawn is a rotating cylinder, the helix is called circular helix. If a helix meets each cylinder generatrix at multiple points, it will be called the pitch of the helix spacing between two consecutive points. The portion of the curve corresponding to a step is called the spiral of the helix. The helix can be traversed in two ways - directly or retrograde - on the surface of the cylinder [6]. The angle of the helix is the constant angle between the tangent to the helix and the plane of a straight section.

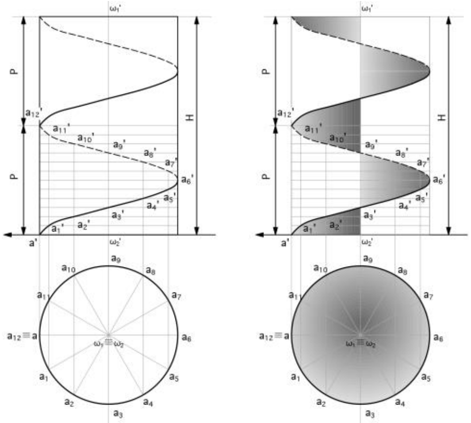
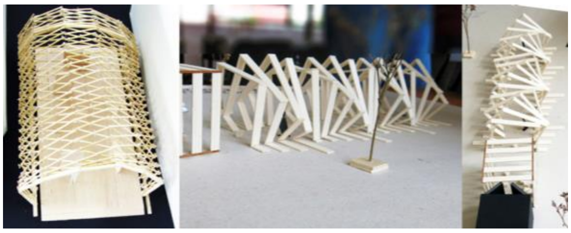


Figure 2 Cylindrical helix and circular helicoid.

3.2 Answers given by students

We want to present below the use of the helical surfaces and their implementation in models which surprise both the volume of architecture object and the indoor space, they were made by the first-year students of the Faculty of Architecture. The model, the tridimensional model of concept drawings, offers a very good visual support, being the most suitable communication pathway between the designer and beneficiary. According to the design theme of the first year – ”Temporary Pavilion”, students have a great liberty in choosing the architectural forms. Thus, some of them chose translation as a process of creation of space of architectural object, materialized by flat figures translated along an axis. In Figure 3a this structure of the shell was conceived by students as a self-supporting structure that uses wood as the basic material. Several cylindrical helices cross the two-way structure - directly or retrograde.



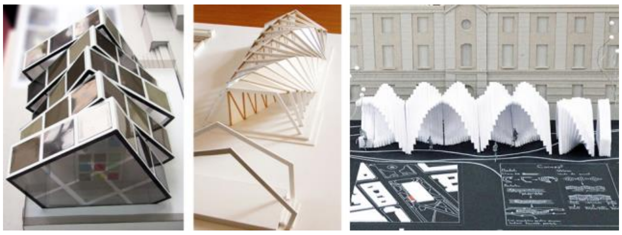
a b

Figure 3 Model made by student.

With the help of modern technology that offers flexibility wood joints, this shell structure can easily be achieved. In analogy to the nature of the sea shell structure, they could replicate the natural process and regenerate the sea-shell-like environment.

Using primary forms, an example is the cube, as a generator of architectural forms is one of the most common methods in design. Students can be attracted to circular or curvilinear shapes, and rotation as a method of generating a space can be one of the methods of obtaining it. Thus, in this project a roto-translation was adopted on a square along an axis, thus generating a cylindrical helicoid in combination with a black cube, Figure 3b. By materializing the cylindrical helicoid lying on a generatrix a single inconvenience appears, the indoor space resulted is longitudinal, thus the students are forced to add other volumes in composition.

The same way of obtaining the architectural space was also applied in the project of Figure 4a. Here the student combined a directly cylindrical helicoid with a retrograde one. The same result is also obtained in the Figure 4b the cylindrical helicoid is obtained by rotating a half hexagon. In Figure 4c an interesting space of modular pavilion has been achieved by positioning several cylindrical helicoids. Within the pavilion, a series of interconnected meeting spaces at multiple scales provide ultimate flexibility for assembly, while maintaining visual connections that establish connections outdoor-indoor and moments of surprise encounters.



a b c

Figure 4 Model made by student.

3.3 Conical helix and conical helicoid

Seashell are one of the most commonly real cases of conical helicoid. But we want to present a very beautiful plant with the shape of a natural fractal and of course a conical helix, *Romanesco broccoli*, Figure 5.

Figure 5 Romanesco broccoli [7].

The inflorescence (the bud) is self-similar in character, with the branched meristems making up a logarithmic spiral, giving a form approximating a natural fractal; each bud is composed of a series of smaller buds, all arranged in yet another logarithmic spiral [8].

The conical helix Figure 6 in the descriptive geometry is the curve described in space by a point that executes a uniform translational motion on the generatrix of a straight circular cone that is in a uniform rotation motion around its axis, the trajectory of the point being proportional to the rotation angle [9]. In order to construct a helix, on the right circular cone with a circle base, the center in Ω and the vertex in S, both the cone's circle in the horizontal projection and the pitch p in the vertical projection should be divided into twelve equal parts. With lines of order it is determined in horizontal projection 1, 2, 3 ... 12. Draw a circle with a radius of 1s until it intersects with the generatrix $s1_1$ and determine 1_0. Similarly, the other points of the helix will be determined.

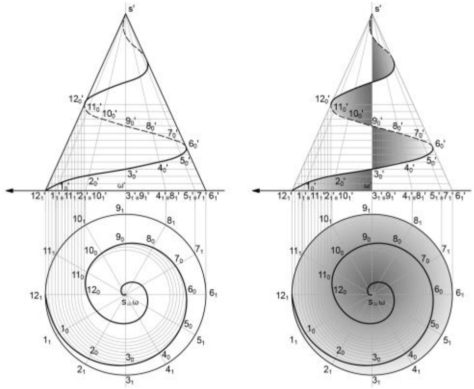
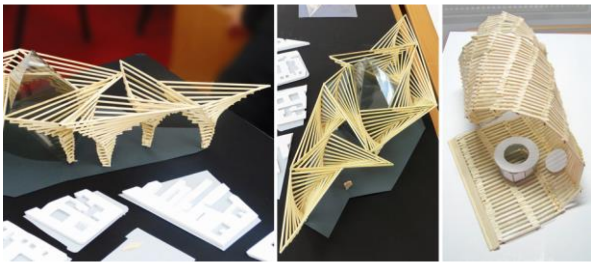


Figure 6 Conical helix and conical helicoid.

3.4 Answers given by students

In Figure 7a, 7b the project presents the materialization of conical helicoid thus the wood is woven tightly together in a huge spiral shell. The form changes dramatically depending on where it is located in the site. As the shell curves upwards the pavilion becomes an amphitheatre for impromptu events and gatherings, at its narrowest a place for intimate discussion. Light and shadows, reflection and refraction will be added, turning the pavilion clockwise throughout the day. Can accommodate a café, as well as a program of art, architecture, music, film and dance.



a b c

Figure 7 Model made by student.

The next project Figure 7c. attempted to reproduce the shells in an abstracted form and of course the conical helicoid. Through an atypical cone settlement with the top down, resulted in interesting coverage where visitors are invited to enter and explore the installation. But, of course, the interior also appears to some as forest-like due in part to the fact that the structure is woodand due to the many joints and overlapping elements. Additionally, the shapes formed by the elements form arches, which evoke a somewhat Gothic character as well.

3.5 Spherical helix and spherical helicoid

Countless globe-shaped flowers among them include dahlias, or conifer cones, being a good example for the spherical helicoid. *Araucaria cunninghamii*, Figure 8, is a conifer, evergreen tree, up to 45-60 m tall. Rough bark, peeled in thin layers, under red or brown bark, with spirally arranged leaves. The cone produced by this conifer has cone scales develop exactly in the direction of the spherical helix [9].

Figure 8 Araucaria cunninghamii [10].

Thus, in the descriptive geometry the spherical helix can be considered as the intersection curve between a sphere and a straight helicoid, which has as its axis a diameter of the sphere and whose step is equal to the radius of the sphere [11]. It is usually used only the upper hemisphere and it is considered in the place of spherical propeller defined above, a spherical spiral Figure 9. easy to construct by dividing the 0-12 quarter circle from the vertical projection into 12 equal parts. These divisions correspond to 12 level circles, whose rays are transported in horizontal projection over the radius 6ω. The apparent contour of the sphere is also divided into the same number of parts.

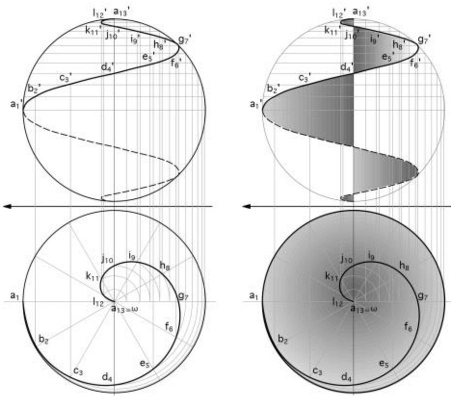


Figure 9 Spherical helix and spherical helicoid.

The horizontal projection of the curve is an Archimedes spiral, tangent to the point a of the apparently horizontally outline contour and in ω radius of aω. To plot this spiral in horizontal projection, the corresponding segments of the radius 6ω will be measured in each radius. The vertical projection of the curve tangent to the apparently vertical outline in a', g', m' and shows a symmetrical branch with respect to the diameter defined by points a' and ω'.

3.6 Answers given by students

The project in Figure 10 materializes the spherical helicoid and presents the idea of how this natural form can be materialized as an architectural volume. Each form displays a virtual quality of architecture and is ready to be further developed into a real architecture with an adequate selection of the material and the structural system. The design for the pavilion was inspired by sunflower. It will have prefabricated wood planks that will be interconnected to form curved structural elements. The top of the pavilion is covered with semi-transparent fiberglass strips, allowing the light to be filtered while protecting the underside.

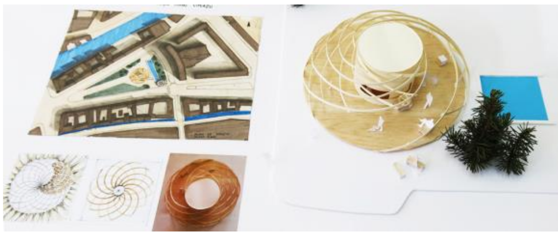


Figure 10 Model made by student.

4. INTEGRATION OF THEORY AND PRACTICE: EXAMPLE IN COURSE

Practical examples motivate the students to actively participate in the realization of models at small scale and makes them understand better the space and form. The application of helical surfaces in architecture and engineering involves organic forms, plants, fruits, animals, humans-from the natural environment, can evoke primordial forms in a new, avant-garde manner. Designers are inspired by everything that surrounds us, nature being an inexhaustible source of form, functionality, adaptability.

4.1 Circular helicoid. Fields of use

The present paragraph discusses the geometry of several twisted, rotated buildings, seen as reference points in the contemporary architecture of the last decade.

The torsioned tower called Turning Torso from Malmö, Sweden is the first high rise building in the form of a spiral ever built in the world. The tower was designed by the Spanish architect Santiago Calatrava, who was inspired in his work by his own sculpture; it was called the Twisting Torso and it mimics the twisting of the human body [12].

Figure 11 Torso Tower, Malmo [13].

The Turning Torso, Figure 11, is the highest building in Sweden taking the third place in Europe with its 190 meters. The irregular pentagon in plane has a rotation of 90° between the first and last level. The building is made up of nine modules twisted around a core. Every module has the upper basis twisted by 10° relative to the lower basis. The first plane of the upper module overlaps the last plate of the lower module and a certain volume is left between them. The 54 floors host 147 private flats, relaxation and spa rooms as well as a winery.

In Figure 12, one gives the generation in 3D Max of the volumes forming the tower. It is noticed that, the horizontal projection of every module is twisted by 10o with respect to the previous module and that finally, the rotation reaches 90° [14].

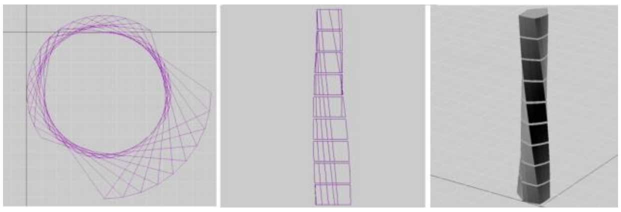


Figure 12 3D generation of the Torso Tower.

4.2 Conical helicoid. Fields of use

The following example is a wedding chapel Ribbon Chapel designed by Hiroshi Nakamura & NAP Architects, Hiroshima, Japan was conceived as a double spiral, consisting of two separate ladders Figure 13.

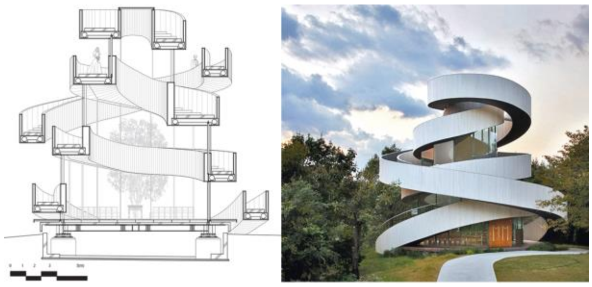


Figure 13 Ribbon Chapel designed by Hiroshi Nakamura & NAP Architects, Hiroshima, Japan [15].

These two curving staircases which encircle the exterior have the shape of conical helicoids, meeting at rooftop platform that overlooks the Hiroshima coastline. The architects say: "The chapel is configured as a double spiral formed by two stairways. Starting from different locations, the stairways slowly spiral upward to become one—a device symbolic of the bride and groom’s path of marriage and formal union as one” [16].

4.3 Spherical helicoid. Fields of use

The Reichstag dome is a glass dome, constructed on top of the rebuilt Reichstag building in Berlin. It was designed by architect Norman Foster and built to symbolize the reunification of Germany, Figure 14. The steel and glass structure allows viewers to look directly into the chamber of the German Bundestag. The passage of natural light highlights the transparency of government and its openness to its citizens. The light is directed by 30 rows of mirrors. Each row has 12 mirrors directed into the chamber 10 metres below. A movable, computer-controlled shading element made of aluminum panels, deflects direct sunlight. The dome itself consists of 24 major steel ribs, which are supported on a lower ring beam and tapered to an upper ring beam [17]. The observation deck is accessible over two interlocked, co-rotating spiral ramps made from spatially shaped as spherical helicoids.

Figure 14 Reichstag, Berlin, Germany, Norman Foster.[18]

5. CONCLUSIONS

In this paper we analyzed several architectural volumes and how complex surfaces in descriptive geometry are easy to materialize if they are known under the analytical aspect. For the purpose of engaging the critical capacity of students, it is necessary to blend the real/practical experiences with geometric analysis and with descriptive and constructive methods. These exercises are very important in the professional training of the architectural student, which thus reveals the diversity of architectural forms in direct relationship with their structure. This procedure generates a greater independence in making decisions, an overview and adoption of the most suitable strategies for solving various design and structural problems. The combination and manipulation of these geomeric volumes can lead to generation of more complex architectural shapes. Last but not least, translation and rotation along an axis generates helical surfaces and thus the motion sensation, in this way the architecture can be perceived as dynamic. It is not only a new chapter in architectural aesthetics, but also plays a very important part in improvement of a building's functionality. The imagination of the architects and their desire to produce unique works is today possible as high performance materials and equipment are used in constructions and as computer aided modelling is a support instrument.

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