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Augmented graphic thinking in Geometry. Developable architectural surfaces in experimental pavilions

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Abstract

We will analyze how the incorporation of digital manufacturing in our schools is motivating a deep reflection about the need to be familiar with both the foundations of geometry as well as with more advanced knowledge. The reinterpretation of our inherited graphic design discipline in light of current digital tools can open up new fields of study and work, such as is occurring in the field of developable surfaces, warped surfaces and many others. In addition, through non-linear graphic processes and digital tools of parametric design, we can arrive at an "expanded graphic thinking" that we can place at the service of production and morphological research. Thus, the old descriptive geometry - geometry based on graphics – comes to serve a cybernetically enlarged mind.

We will present four experimental pavilions resulting from several workshops on geometry and digital manufacturing carried out in collaboration between the University of Seville and several Ibero-American Universities. Based on the deep geometric knowledge of developable helical surfaces and surfaces of equal slope, a guided exercise is proposed to approach the design, manufacturing and assembly phases of these architectural installations on a real scale.

Keywords*: Developable surfaces, Geometry, Graphic thinking, Pavilion, Ephemeral architecture, Worshops*

1 Introduction. Descriptive geometry and digital technologies

A great debate has arisen in recent years about the irruption of digital technologies in architectural graphic expression, provoking different reflections in an area of knowledge characterized by the diversity and complexity of its disciplines (Trachana 2012).

A large number of studies attempt to categorize this implementation of the digital in the processes of ideation essentially as *a posteriori* theorizing about a set of representative works. Another aspect of these reflections, closer to the graphic processes, attempts to understand how architectural ideas are conceived in contact with new instruments and the consequences that this entails.

In the construction industry, the main formalization processes of an architecture project are undertaken using CAD and BIM tools and products, and together with rendering and digital modeling, they are part of an unquestionable professional reality. Technologies based on the use of 3D scanners and drones in architectural surveys are becoming increasingly common in the practice of rehabilitation.

In the context of this technological revolution, which has caused an indisputable change in the processes of ideation and formalization of architectural projects, 'descriptive geometry' has been the most important forgotten process, to the point of almost disappearing from the academic curriculum of the architect. The reasons for this decline are complex (Migliari 2012). However, and paradoxically, the recent appearance of digital manufacturing laboratories has meant a paradigm shift evidencing the need for deep geometric knowledge based on graphic disciplines.

Robotic cuts by CNC numerical control machines, laser cutters, etc., presuppose - sometimes with excessive optimism - a deep knowledge of the fundamentals of geometry and the morphology of the elements to be designed, cut, mechanized, and subsequently produced through digital manufacturing (Garber and Jabi 2006). However, these and many other concepts are not being addressed in our schools today.

We focus the debate on descriptive geometry, a discipline that, on the basis of graphic expression, has traditionally been tasked with providing students with geometric knowledge and skills in their first years of study. However, today the discipline requires a thorough revision, in addition to adapting its objectives to the new role of the architect in society.

The obsolescence of the *Dihedral System* has meant the abandonment of *Descriptive Geometry* due to an ingrained - and false - idea that both concepts were related by an indestructible nexus in which the digital did not fit. However, *Architectural Geometry,* and *Architectural Computing,* have arisen without complexes as a transversal environment where it is necessary to produce concrete advances. Around them converge the most diverse disciplines related to mathematics, programming, calculation of structures, optimization of variables, etc., with the vocation of joining all of them with graphic visualization. A sort of visual result occurs *a posteriori*, as the final product of an extragraphic logic.

Thanks to these computational advances, we now enjoy optimized digital tools - new graphic environments in which to handle and control bodies on the basis of *a priori* graphic thinking, as the architect's mind has always required. It is precisely in this nuance that descriptive geometry differs from other disciplines: The construction of knowledge begins and ends in the purely graphic, without the need to rely structurally on a formal mathematical language.

We are pleased to see that the aims of this new descriptive geometry are directly linked to the production phenomenon (now digital manufacturing), following the same aims that Gaspard Monge enunciated in the prologue of his *Géométrie Descriptive*: to produce more efficiently, scientifically and less artisanally, according to the birth of an incipient industry (Monge 1803).

2 Extended graphic thinking and morphological exploration

At this point, where geometry and digital manufacturing meet face to face, we find the appropriate scenario to produce a true rebirth of the discipline, not only as knowledge adequate to productive purposes but also as a territory of morphological exploration. As a result of our experiences (Fig.1), we have verified how geometric surfaces can become a formal research field thanks to the symbiosis between the mind and the power of the machine, an idea shared by other researchers (Carazo and Martínez 2013). We have called this capacity "extended graphic thinking," and to reach it by overcoming the limitations - instrumental and conceptual - of the system of double *Mongian* projection should be one of the objectives of the new Geometry.

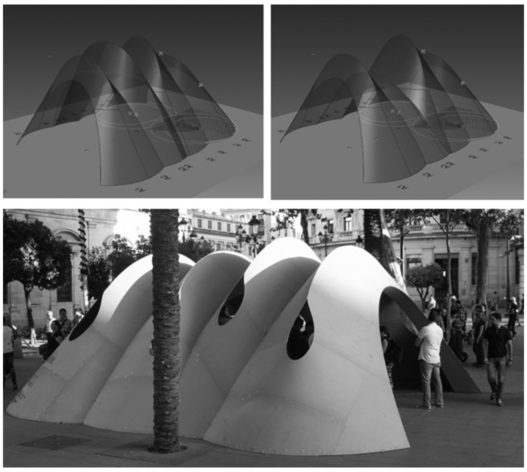

Figure 1. Parametric model and architectural installation with surfaces of equal slope. SSFS-Pavilion, University of Seville, Plaza Nueva, 2015.

Digital parametric design tools linked to graphic environments (such as Grasshopper-Rhinoceros) have allowed this revolution. Its application to the field of teaching offers possibilities that we are only beginning to explore (Coloma and Mesa 2012). Parametric design requires the "concretization" of a sequence of graphic reasoning from start to finish. As in pencil and paper geometry, precise commands go from the brain to the hand to execute the graphic construction. In parametric design, the same reasoning, which is geometric, is translated into a sequentially ordered line of commands within the visual programming environment. As a result, we obtain not one but several families of graphic solutions to the same problem by varying the initial parameters. The algorithm is built only once, being a powerful formal exploration machine that justifies all previous efforts to understand, in depth, the graphic nature of the object.

Another fundamental issue is the reinterpretation of the inherited discipline (manuals and treatises on geometry) in light of current digital tools. Only via a work of revision can we rescue many contents that, although present in the classic treatises, were never explained in the classroom, neither then nor now. We refer to the study of complex surfaces, developable surfaces, warped surfaces, and many others. The geometric knowledge relevant to design and digital manufacturing with these surfaces on the basis of graphic thinking is a particularly important work to be able to discern.

3 Geometry, ideation and digital constructed materiality

Based on these ideas we have launched different international workshops on design and digital manufacturing from 2014 to the present. This has led to the creation of seven ephemeral architecture installations in which the University of Seville has participated in collaboration with five Ibero-American Universities (Universidad Nacional de Colombia; Universidad Nacional del Litoral, Argentina; Universidade Federale do Rio de Janeiro, Brasil; Universidad del Norte, Colombia; Universidad del Bio-Bio, Chile). Developable surfaces was chosen as the main theme of these workshops, in part because these surfaces offer extraordinary possibilities in architecture and engineering because they allow manufacturing by CNC cutting procedures (Fig. 2).

In these workshops the design, manufacture and assembly of an experimental architectural installation at a 1: 1 scale is implemented, for which we have to apply in a concrete way the foundations of geometry and the knowledge of developable surfaces. We have found in the typology of the pavilion, or light architecture, the necessary scale so that the architectural object can be approached in its totality by the students from its initial conception to its physical materialization (Martín-Pastor et al. 2014).

Figure 2. Collaborative assembly of the Molusco-Pavilion. UniNorte, Barranquilla, Colombia, 2016.

The pavilions are conceived as an ephemeral architectural piece and composed of wooden skins, not very thick, that work together as a self-supporting structure. Being composed of developable surfaces, each of them can be made on the basis of the plane from smaller pieces, mechanized by digital manufacturing processes and CNC cutting. At the same time, different digital manufacturing laboratories have offered us the experience, the means and the technical and human support to carry out these projects.

The ideation and materialization of the pavilions follow a complex sequence of work divided into three phases: design, manufacturing and assembly.

The design phase begins with the geometric conception of the surface that we are to work on and the search for the graphic reasoning that allows us to conceive and develop it. Once the (linguistic) rigors of the graphic programming and the creation of the algorithms have been overcome, we move to the exploration phase of the architectural form - a particularly important phase in the field of morphology because it enables, in a new way, other experimental strategies in the architect's resource palette. This complex design phase culminates in the digital formalization of the work and the creation of cutting files for production in the digital manufacturing laboratory.

The design process is completed with the creation of an 'Assembly Manual' where the assembly plan is explained in detail by a theoretical team (Martín-Pastor et al. 2017a).

All the pavilions share the same constructive system exhibited in Narvaez-Rodriguez et al. (2014). First, the machined parts are assembled on the floor with the help of overlaps fixed with screws, forming each of the large wooden modules. Once put together, they are curved in space until they acquire the final shape. The modules are stiffened against each other, sewn together by means of nylon flanges in the line of contact between them, and at the same time adjusted to the floor by means of brackets adapted to the curvature of the surfaces.

4 Developable surfaces in ephemeral architecture and light architecture

Developable surfaces are mathematically well known, belong to the ruled category and are usually classified into three groups: cylinders, cones and tangential surfaces. Their study is strongly marked by the mathematical progress of the seventeenth century and the figure of Gaspard Monge, who devoted much of his work to studying them in depth. Advances in this field are closely linked to the more intuitive character of the space that defined his *Géométrie Descriptive*, published for the first time in Spain in 1803.

Now their applications are being explored in the field of computing (Pottman et al. 2007; Lawrence 2011). However, sharing the opinion of Glaeser and Gruber (2007), the presence of such surfaces is not yet common in the context of architectural education or professional practice. This is not due to their complexity but, as mentioned above, to the recent emergence of digital tools.

To deepen geometrically in the study of developables, we rely on four works: [2]. Our approach was developed on the basis of graphic thinking, following the conceptual premises of Descriptive Geometry. The four works carried out are circumscribed within two subgroups of tangential developable surfaces that we consider especially interesting: developable helical surfaces and surfaces of equal slope.

We used the Rhinoceros-Grasshopper software to build the parametric algorithm that defines the surfaces. As a general consideration, we kept in mind that this software does not always correctly perform the automatic development of the surfaces. In these circumstances we developed a specific algorithm for this purpose.

5 Two developable helical projects: Butterfly-Gallery and Molusco-Pavilion

The developable helicoid is generally described as a surface of equal slope that rests on a cylindrical helix or that rests on an involute circumference, but we can also consider it as a type of tangential surface, a group to which it belongs.

These tangential surfaces are determined as the enveloping surface of the osculating planes of each point of the spatial curve (helix) that generates it. A simplified version of this formulation, in Glaeser and Gruber (2007, p. 63), determines the surface directly by the set of tangent vectors T along the helix; this is the formulation that we will use.

Once the correct functioning of the helix generation and development algorithm is guaranteed, we can create successive algorithms to combine different helicoids and intersect them. With this, a process of formal exploration of infinite possibilities begins (Fig.3).

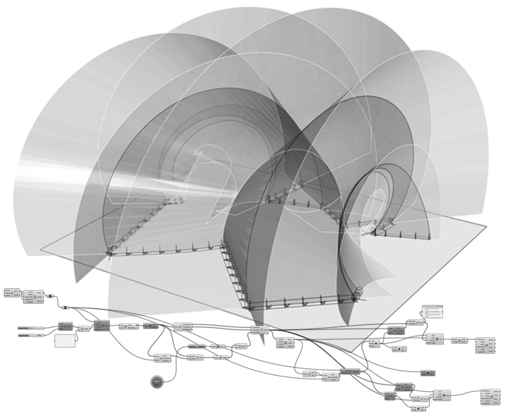

Figure 3. Generation algorithm of the developable helicoid and parameterization of the assembly formed by several helicoids.

The Butterfly-Gallery (Fig. 4) is an ephemeral installation 6.2 m long by 3.6 m high generated by 6 developable helical surfaces, whose horizontal axes are not parallel or coincident with each other.

Figure 4. Architectural installation made with helical surfaces. Butterfly-Gallery, UFRJ, Brazil, 2015.

The Molusco-Pavilion (Fig. 5) is inspired by the shape of the marine mollusk *Bolinus brandaris*, proposing a geometric approximation from four *developable* helical surfaces, which reach 4.3 meters in height in a self-supporting structure.

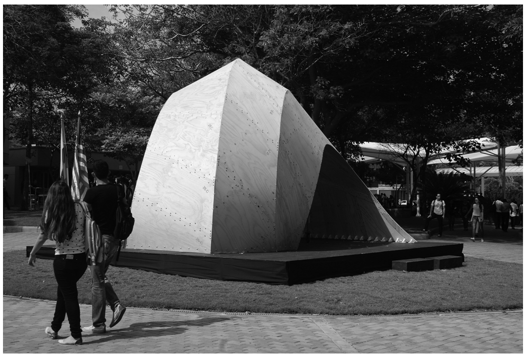

Figure 5. Architectural installation made with helical surfaces. Molusco-Pavilion, UniNorte, Barranquilla, Colombia, 2016

6 Two projects of surfaces of equal slope: SSFS-Pavilion and Pavilion Bio-Dune

Surfaces of equal slope also belong to the group of tangential developable surfaces. It is not a typical surface in architecture, although its generation does appear in both Descriptive Geometry texts as well as in Izquierdo Asensi (1985), Gentil Baldrich (1990) and others close to *Architectural Geometry* such as Pottmann (2007). Despite being a tangential developable surface, we do not know *a priori* its backward edge. Unlike the helicoid, the generation must be formulated from a different curve on which to impose the angular conditions.

This new formulation contemplates two possibilities that correspond, in turn, to two ways of interpreting this type of surface.

The first consists in conceiving the generation from the bottom up (Fig. 6). In this way, we determine a flat guideline on which a set of segments (the ruled ones) that maintain a constant angle with respect to the plane of the curve rest perpendicularly. In our case we have chosen as guideline an ellipse contained in a horizontal plane. The surface generated by the set of ruled segments is a surface of equal slope that cuts itself, forming a ridge between two points of singularity.

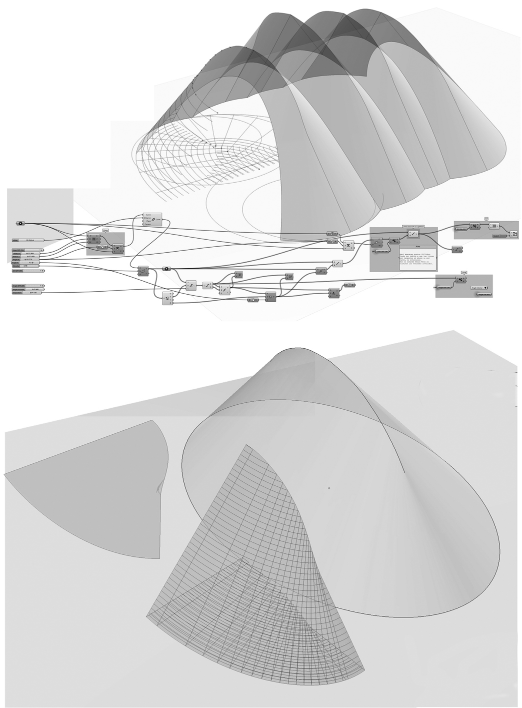

Figure 6. Surface of equal slope generated by a set of rulers that rest perpendicularly on an elliptical directrix and form the same angle with the horizontal plane. Above: Parametric generation law to intersect several surfaces with each other.

The SSFS-Pavilion is a set of equally sloping surfaces that rest on elliptical arcs contained in a horizontal plane. The parameterization of each module has been made from two semi-ellipses tangentially linked at the ends of the major axis, which they share. This same module is repeated four times, having a parameterized set of 8 semi-ellipses defined by four major axes and eight minor axes.

The second formulation consists of conceiving the generation of the surface from the crest (upper curve) downwards (Fig. 7). The formulation attempts to determine, in a rough manner, the envelope surface of the displacement of a cone along the ridge. The generatrices of the cone (being an equiangular surface with respect to a reference plane) determine the slope of the surface.

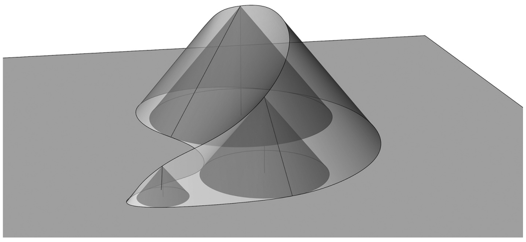

Figure 7. Surface of equal slope generated by an envelope surface of the infinite cones that rest along an upper curve or peak.

The Bio-Dune Pavilion (Fig. 8) uses the dune as a source of inspiration. Said surface is theoretically developable because it is formed by the envelope of the natural slope cones of the terrain that move along the crest of the same, being, therefore, a surface of equal slope.

Figure 8. Architectural installation made with a surface of equal slope. Bio-Dune Pavilion, University of Bio-Bio, Concepción, Chile, 2016.

A natural dune would be geometrically developable if we disregard the bagging of material at the bottom of it, the effects of wind and other natural actions. In our project, this property is used to design an artificial dune, hollow and developable, formed by a thin layer of wood.

By way of conclusions

The knowledge of the deep geometry of things is directly related to the processes of architectural ideation, evidencing how the field of morphology demands to enter into the most rigorous aspects as part of the creative process.

We believe it is essential to review the geometry we have inherited in our post-digital era. A new type of graphic thinking - enhanced by the machine's power of calculation - is already present in our work, in which new instrumental resources enhance new cognitive abilities and facilitate the understanding of a superior geometry.

This 'graphic thinking,' increased cybernetically by the power of the machine, is an opportunity with which to overcome the instrumental and procedural limits of the previous paradigm, where graphic control was based on double projection.

Nonlinear graphic processes - the programming of complete sequences of graphic reasoning and the feedback of results in a single visual interface - open the door to a new way of assimilating geometry and also provide the opportunity to design our own exploration algorithms. This graphic thinking, cybernetically enhanced, takes us in turn to distant or almost unknown territories in which the tool, apart from being an instrument, serves as a laboratory of geometric research in which to continue investigating.

Within the field of morphology, this logic of exploration places us in a new paradigm where a single form does not prevail but rather a whole family of formal solutions, which represents an important qualitative leap in this discipline. In this line of thought, we also reflect on the deep relationship between the reinterpretation of the past and the creation of meaning and innovation, which is an absolutely central issue in artistic theory, especially in contemporary art, and which may be very close to these graphic and geometric processes, certainly exploratory.

Digital manufacturing is an opportunity to establish the teaching of the foundations of Geometry according to a practical, productive and innovative purpose. In this sense, the Geometry and Digital Manufacturing Workshops can be suitable scenarios for carrying out new activities and launching experimental or teaching innovation projects Martín-Pastor, A. et al. (2017b).

Finally, the Geometry-Digital Manufacturing binomial opens a new debate in the development of the project and the role of the architect, engineer or designer. At first, the CAD tools brought us a world rendered on the screen that other professionals had to reproduce, often with craft techniques. Currently, the concept of *constructed digital materiality* involves the architect of the project from the beginning to the end, having direct consequences on the production processes (Chiarella, M, et al. 2017). In this new scenario, the importance and responsibility of the designer increases, while the intermediaries and constructors begin to disappear, delegating the manufacture to machines. This leads us to understanding the architect of a project, above all, as a process designer.

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SSFS PAVILION–FABLAB SEVILLA: Design and project: Andrés Martín-Pastor, Juan Expósito Bejarano and Roberto Narváez Rodríguez; Manufacturing: Fablab Sevilla; International coordination: Mauro Chiarella; Production Chief: Daniel del Valle; Assembly: Tutors and stu dents of ETSIE, ETSA and Edificalab; Collaboration: Noche Europea de los Investigadores, Dept. of Graphic Engineering, Universidad de Sevilla, ETSIE

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