

Graphic thinking and digital processes: three built case studies of digital materiality (COCOON/Colombia, BANCAPAR/Chile, SSFS/Argentina)

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Abstract

Thinking up a strategic articulation between computer programming, digital modelling, data, physical materials and numerical control manufacturing is an essential step to updating the discipline with new technologies. Our proposal involves articulating graphic thinking and digital processes, developable geometries and folded compositions. Its foundations are rooted in a broader kind of graphic thinking using multiple conceptual instruments that are already part of architecture's operational framework at the various stages of the project.

KEYWORDS: graphic thinking, digital materiality, temporary architecture

Graphic thinking and digital processes

The different systems of architectural representation generate, modify and/or confirm not only the ways of reading the architectural reality in relation to the mechanisms of perception but also the way of devising and conceiving architecture itself. By means of these systems of representation, graphic thinking – an evolving human construction – has allowed us to understand and explore the relationships between the design tools and the resulting architectural ideas, putting these into the context of the social-technical systems and the cultural paradigms out of which they unfold. It is hardly surprising that, throughout history, advances in the field of representation have had repercussions on the way that architectural space is conceived; the birth and codification of perspective drawing is one characteristic example of this. Similarly and more recently, other changes in the way of representing and conceiving objects brought about by digital processes are leading to significant modifications in our deepest structures of architectural creation.

In the context of these digital tools, the relationship between geometric knowledge and the exploration of architectural form broadens design resources through the rigorous geometric control associated with graphic thinking. Digital programmes have already resolved the problem of representation in instrumental terms, offering a wide range of automated graphic operations to control form, perpendiculars, tangents, angles, curve radii, etc. The architectural body is constructed in a three-dimensional space and moving two-dimensional projections appear on the screen automatically and effortlessly.

This subtle change of paradigm gets around the problem of representation ("building" a double projection was a real problem in the Monge system) – almost totally replacing it with the concept of the 3D object. The fundamental ideas, or geometric reasoning, take on, from the outset, greater importance than aspects of projection associated with representation. This by no means contradicts the objectives of the discipline of descriptive geometry, but rather takes it beyond the conceptual limits of the Monge system. In this way, graphic thinking (amplified by these new technologies) can be used to revise inherited geometric fundaments. Mathematical-geometric aspects can be understood, assimilated, resolved and strengthened through graphic thinking.

However, another instrument-related contribution must be added to this renaissance of descriptive geometry brought about by CAD, one arising from programming. We refer not only to mathematical programming but, fundamentally, to the programming of the geometric reasoning itself as a series of steps. The incorporation of parametric design adds a still deeper dimension to the problem of graphic thinking applied to the study of geometry. This new dimension concerns improving understanding of the graphic nature of a problem and also strengthening the creative processes since parametric programming offers not just one solution to the problem but a whole family of solutions. As we know, parametric design presents geometry from a mathematical-algorithmic viewpoint. Geometries are generated out of

the definition of an initial family of parameters and the formal relationships between these. In these design processes, algorithms and advanced computing resources are not simply used to represent forms but also to create dynamic and variable design possibilities. Interest in the strategic incorporation of the concept of parametric design into the design process is rooted in the possibility of taking up new instrumental resources that broaden response capacities in design disciplines (Chiarella, 2012).

In view of the above, we see that the fundamentals of geometry are strategically interconnected with graphic thinking through the use of tools that serve to speed up visualisation (and hence the capacity for synthesis) together with the capacity to programme such thinking into more demanding chains of reasoning. These tools are able to seek complex solutions from within an enormous family of possibilities, leading us on towards new paradigms in the exploration of architectural space and form.

Figure 1. Digital Processes: The Cocoon (Medellín, Colombia); Bancapar (Concepción, Chile); SSFS (Santa Fe, Argentina).

Digital Materiality

Digital materiality is an oxymoron. It is a conjunction of apparently opposing words, a supposedly contradictory conceptual construction and rhetorical figure that brings together both antimony and complementarity. At first glance, this impossibility comes across as a complete reversal of common sense with uncertain and provocative meaning, leading to questions that demand deeper reflection. Above and beyond the “representation systems” themselves, Gramazio & Kohler situate “digital materiality” in the existing and complex interweaving of computer programming, 3D construction (or digital modelling), data and physical materials at the different stages of the architectural project. Adhering to this concept, we understand this action, which begins as a digital process and incorporates materiality from the outset, as one aspect in a line of provocative thinking, both in terms of its expression and its production capacity; an action that establishes novel connections that broaden and enrich the relationships between conception, technology, manufacturing and the built environment.

The incorporation of graphic programming in the architectural project not only offers the potential to develop multiple design alternatives (by a logical formalisation of the process, its conditions and the geometric relationships). It also gives the possibility of strategic integration through multiple analysis variables, increasing the efficiency of the project from out of its own materiality. By presenting our built experiences in this field over the last few years we will analyse the different interactions between the digital model, relating databases, programming algorithms and design parameterisation for assembly manufacturing of non-serial components. These three experimental experiences have risen from a kind of thinking that, far from tending towards more complex levels of morphology, have tried to seek simplicity in the idea that generates the form. This approach is manifested in the developable geometries, appropriable sections and/or folded compositions, culminating in a numerical control manufacturing in coherence with the design systems used. The works presented here are examples of an operative and conceptual connection between graphic thinking, digital processes and digital materiality. They were realized through joint research projects involving the Universidad del Litoral in Argentina, the Universidad de Sevilla in Spain, the Universidad Nacional de Colombia and the Universidad del Bio-Bio in Chile.

Case study: The Cocoon (Medellín, Colombia)

The experience is a collaborative work between the Graphic Engineering Department of the Universidad de Sevilla and the Universidad Nacional de Colombia. It places developable geometries in a transversal and practical position, focusing on the architectural project and digital materiality and thus filling the void that exists between technical possibilities and practical knowledge of the new computer design methods. By obtaining complex parameters of a geometric nature to create building elements, basic geometric knowledge becomes the central concept of the project. Mastery of these geometric fundamentals was essential for the digital design and fabrication of the Cocoon pavilion built by undergraduate students.

This pavilion is of shared authorship and takes its conceptual inspiration from The Caterpillar Gallery, realized in the Universidad de Sevilla in 2014. The project’s generating idea is to address the study of the “Theorem for the intersection of quadric surfaces” attributed to Gaspard Monge, from the basis of the CAD-CAM instruments and the parametric algorithms. Concretely, the theorem states that: “Two second-order quadric surfaces circumscribed around a third second-order surface (a sphere, the simplest such form) or inscribed within it are intersected by two second-order (conical) curves.” (Izquierdo Asensi, 1985). In our case we conceive a sequence of cones that are always circumscribed, in pairs, to a common sphere. In this way we guarantee that all the intersections are curved planes and hence that the surfaces are developable.

This international workshop is offered to undergraduate students (with support from UNAL teaching staff) as a large-scale work for them to undertake together. The challenge is to design, digitally fabricate and assemble a pavilion articulated with the aforementioned geometric structure to give it a unified form.

The geometry provides a path that connects the more theoretical aspects with the more practical ones. It serves as an exploration of the architectural form (incorporating size variables, environmental suitability and economic variables in terms of the number of panels used) and as a resource to resolve each of the conical intersections of the corbel planes in an automated way.

The workshop begins with the development of each conical surface and a study of the corbels joining the surface with the anchor bracket. The required panels are also broken down into component pieces to be digitally manufactured. The manufacturing process was carried out and directed by the team from FabLab Unal Medellín of the Universidad Nacional de Colombia. Lastly, the pavilion was assembled with joint collaboration from the students and teaching staff from the Manizales and Medellín campuses of the Universidad Nacional de Colombia.

The teaching and research work developed demonstrates once again the key role that geometric knowledge plays in an architect's formation. It is equally clear that the use of CAD-CAM graphic media is absolutely necessary to integrate the fundamentals of geometry with digital fabrication processes.

Figure 2. The Cocoon (Medellín, Colombia)

Bancapar (Concepción, Chile)

Bancapar ("*Fondart Regional 2013*" winning project) is a parametrically designed bench conceived as a public work of art. The project was self-managed with shared authorship and located at the entrance to the Faculty of Industrial Engineering of the Universidad del Bio-Bio in Concepción, Chile. The interdisciplinary work between university students and teaching staff and a group of researchers and teaching staff from the FADU-UNL in Santa Fe, Argentina transformed the proposal into a technological work of art without precedent in the region.

In the experience, parametric formulas were developed in a manner characterised by collaborative design between teams from two universities in two Latin American countries. We can observe how this process has dissolved the concept of the author(s) and his or her work through the use of a parametric system from the outset, thus achieving independence from the idea of any predefined form. The appearance of new fields of collective creativity induced the initial designers to use their own inventiveness to broaden and strengthen the imagination of the others involved in the process. The parametric formulas served as communication tools speaking a universal language that strengthened this creativity and enabled the original designer to lose control of the design process while still maintaining the same basic shared objectives and structure. The design is based on the parametric combination of nine guiding curves that act as silhouettes for the user to sit and rest upon. Each of these guiding curves is made up of steel gussets that provide a basic gesture of containment and ergonomic support for nine different body postures (different heights for sitting with or without back support, lying down or leaning in a standing position). This basic connecting geometric logic, the original objective of the project, provided sufficient flexibility to be adapted to the context of the site and to changes to the initial manufacturing proposal at the configurative stage.

At the configuration stage, the physical construction (initially planned to be CAD-CAM fabrication) was adapted to the technological resources available in the region. The initial possibility of CNC Wire-Bending fabrication (proposed in the FONDECYT N° 3110025 project) was ruled out and the designers worked with printed graphic templates and manual-mechanical folding of each of the 106 pieces (5cm wide 6mm thick steel gussets). Three thousand kilos of steel was used, prepared for assembly, manually-mechanically folded, with each piece given a galvanneal finish. The result is a unique object with variable dimensions along its approximately 10m length and 2.5m width. Folding the steel gussets confirmed how the properties of the building material and the manufacturing and assembly process chosen are decisive factors in defining the final form. The manual-mechanical folding process has a greater margin for error than the Wire-Bending systems, thus resulting in a certain distancing of the geometry from the parametric curve found in the initial abstract model. Since all the sides of the individual components of the composition are similar, they give homogeneity and identity to the whole. Once the margin of error has been accepted, a new geometric character appears that has the advantage of generating a less abstract, more organic language not foreseen in the initial parametric composition. In contrast to regular geometric compositions, a perceptual reading of the Bancapar does not easily reveal its overall form from any single viewpoint.

The creation of continuous three-dimensional surfaces through folding and the geometric extrusion of appropriate sections enable a mathematical and operative connection to be made between the desired technological, perceptual and utilitarian conditions.

Figure 3. Bancapar (Concepción, Chile)

SSFS (Santa Fe, Argentina) Same-Slope Folded Surfaces

In this postgraduate didactic experience carried out in the Universidad Nacional del Litoral (in collaboration with the Graphic Engineering Department of the Universidad de Sevilla), the folded composition is presented as a formal construction, an operative action and a sense perception. The experience has been a clear demonstration of the use of collaborative design. The initial graphic thinking (USevilla) was nourished by the strategic use of same-slope developable geometries to achieve manufacturing and assembly (UNL) of a temporary folded composition in a single working day.

The developable surfaces belong to a little-studied architecture typology that has proved very effective for manufacturing and assembling folded compositions. In this project we worked with same-slope surfaces. These are a subseries of developable surfaces engendered by the movement of a cone along the length of a directrix – in our case, elliptical arcs – with the surface determined as the final outer envelope of all the cones.

The form's generating idea consists in a same-slope surface support on an elliptical directrix (Gentil, 1989; Izquierdo, 1986). This initial module was taken from graphic thinking to parametric formulation, thus permitting an exploration of different formal combinations until our design objectives were reached. The geometric exploration itself led us to the knowledge of a series of totally unique points on the geometric surface that we present, as well as other special properties such as the natural progression from a continuous surface to a folded surface.

The design was created in the Graphic Engineering Department (USevilla) and the digital fabrication processes were simulated with a 1:8 scale model in FabLab Sevilla. Lastly, two modules of the full size pavilion were put to test by students from FADU-UNL (Masters in Architecture/Design and Digital Construction).

The result is a single, self-supporting, continuous envelope with high structural resistance. It covers a distance of about 8 metres by means of a physical deformation applied by folding the material. Studies were made only from graphically parameterised variables with no rigorous technical information available on the material used (multi-laminate sheets of *guatambú* wood with three 6mm thick layers), which has so far resisted gusts of wind of over 50 km/h (the *pampero* winds in the Litoral-Centro region of Argentina).

The necessary interactions between the digital model, the programming algorithms, the design parameterisation and the conditions of numerical control manufacturing have led to the need for maximum simplicity in terms of the idea generating the form, in order to ensure that any complexity is limited to the resulting form itself and not the production and assembly process.

In SSFS-Santa Fe, the various groups of FADU-UNL students have faced problematic situations arising from the experience of assembling external designs. These have arisen due to the interaction generated by the collaboration processes in the workplace itself and following the critical analysis of the first USevilla proposal. Thus, once the assembly work was finished, each group was requested to draw up a possible solution for, improvement to or assessment of the original proposal for the SSFS Pavilion. In this way, they acquired a commitment to go beyond a mere construction contribution to find their own critical viewpoint to solutions to any problems they observed. The experience of the collaborative workshop was carried out in a theoretical-practical way, alternating video conferences and in-person activities to provide a good level of exchange between teaching staff.

The whole pavilion was built on the researchers' European Night (Seville, 25th September, 2015) and named the SSFS Pavilion FabLabsevilla, part of an activity titled: "Developable geometries for building temporary pavilions".

In this experience, several determinants lent the project further complexity. The first was the limited budget available to realize the four modules in a larger structure and the second the impossibility of perforating the pavement of the chosen location, the Plaza Nueva in Seville.

The first determinant meant choosing the lowest cost material on the local market (with all its limitations): a 5 mm thick 2440x1220mm MDF panel. The second obstacle, the impossibility of anchoring the pavilion to the pavement of a public square, opened the debate on how to counterbalance the structure's horizontal forces where it met the hard surface of the pavement. As a solution, transition gussets were placed on the surface along the length of two tied horizontal metal strips.

It was possible to prove empirically that, thanks to the geometric form and the morphology of the fold, the structure was completely self-supporting and undeformable in its final state, despite not being anchored to the pavement surface.

Lastly, the various experiences shared have been translated into an open, non-linear procedure model to generate temporary pavilions with different solutions adapted to each specific context. This model

receives constant feedback from the reflections, analyses and production experiences of each stage in the process.

Figure 4. SSFS Pavilion (Santa Fe, Argentina)

Conclusions

Graphic thinking with digital processes broadens available resources, incorporating the notion of digital materiality into the fundamentals of geometry. Our recent experiences test ways of thinking and procedures that are not habitual in traditional architecture teaching and that derive from the strategic use of digital materiality in the creative processes. The ancestral inertia of architectural subjects together with the inability of traditional building materials to take on the demands of current spatial and conceptual quests are challenges to be faced if these post-industrial design and simulation technologies are to exist alongside industrial and pre-industrial building technologies.

In this way, numerical control machines, widely used in industrial design, are slowly being incorporated into the field of architecture with the promise of fabrication without intermediaries. These new architectural production techniques face the challenge of accompanying the complex projects generated by informatics tools, ensuring the complexity lies only in the geometries themselves and not in the production process. Digital materiality arises out of graphic thinking with digital processes, proposing new relations between the architectural object and its representation.

The slow implementation of the numerical control manufacturing systems attempts to redefine the instances of prefiguration and representation by rethinking the possibilities of a progressive transformation of some of the fabrication and construction processes in architecture. Rethinking and modifying the operational methodologies with digital fabrication in architecture forces us to abandon autonomy and a certain determinism in graphic thinking, which has for years been subject to an obsessive almost stylistic control of the designed object and a spatial structuring inspired by Cartesian logic.

The success of a creative process should not only be reflected in the ability to understand the complexity of every dimension of the architectural phenomenon in order to offer a suitable and flexible response to concrete situations. It should also contemplate the discovery of new conceptual and operational tools that broaden the very possibilities of design thinking.

Our proposal to articulate graphic thinking and digital processes, developable geometries and folded compositions, has its roots in a broader kind of graphic thinking and uses multiple conceptual instruments that already integrate the operational framework of our discipline. Strategic articulation between computer programming, digital modelling, data, materials and numerical control manufacturing at the various stages of the architectural project is key to achieving this end.

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COCCON:

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SSFS PAVILION. SANTA FE:

Project design: Andrés Martín-Pastor, Roberto Narváez-Rodríguez. Parametric co-design: Juan Expósito Bejarano. Academic coordination: Masters degree in Architecture, FADU, Universidad Nacional del Litoral (Professors: Rodrigo García Alvarado, Mauro Chiarella). Production and assembly: students and teaching staff from the Masters degree in Architecture. Consultation: Paulo Chiarella. Collaboration: Graphic Engineering Dept., Universidad de Sevilla, ETSIE, Fablab Sevilla. Records and editing: Federico Cairolí. Performance action: Ariana Beilis; Felicita Cersofio; Carla Tortul. <https://vimeo.com/135685179>

Bibliography:

- CHIARELLA, M.; GARCIA ALVARADO, R. (2014). *Folded Compositions in Architecture: Spatial Properties and Materials*. Nexus Network Journal. Springer.
- CHIARELLA, M. (2012). *Folded Geometries in Architecture. Parametric Design and Digital Manufacturing*. The 9th international, interdisciplinary Nexus conference for architecture and mathematics: Relationships Between Architecture and Mathematics. Milan, Italy.
- IZQUIERDO ASENSI, FERNANDO (1985). *Geometría Descriptiva Superior y Aplicada*. Editorial Dossat. [on p.309 the author discusses same-slope surfaces on a horizontal elliptical platform]
- GENTIL BALDRICH, J MARÍA (1990). *Método y aplicación de la Representación Acotada*. Cuadernos EGA 2-1989 [on p.137 the author describes the inclined surfaces of the ellipse directrix]
- MARTÍN-PASTOR, A; TORRES-HOLGUÍN, J; NARVÁEZ-RODRÍGUEZ, R; GALINDO-DIAZ, J. (2014). *Los workshops de geometría en Cad3d y prefabricación digital como estrategia docente en la enseñanza de la geometría para la arquitectura*. *Geometría y proyecto*. p. 213-216 . In: *Proceedings of the XVIII Conference of the Iberoamerican Society of Digital Graphics: Design in Freedom*. Montevideo.
- NARVÁEZ-RODRIGUEZ, R; MARTÍN-PASTOR, A; AGUILAR-ALEJANDRE, M. (2014). *The Caterpillar Gallery: Quadratic Surface Theorems, Parametric Design and Digital Fabrication*. *Advances in Architectural Geometry 2014-2015* (Editors: P. Block; J. Knippers; N. J. Mitra; W. Wang)
- SÁEZ, N; CHIARELLA, M; GARCÍA ALVARADO, R; GARCÍA LARA, L; DALLA COSTA, M; VEIZAGA, M; GRONDA, L. BANCAPAR. (2014). *Objeto Paramétrico de Arte Público con Diseño Colaborativo y manufactura no industrializada*, p. 527-531. *Proceedings of the XVIII Conference of the Iberoamerican Society of Digital Graphics: Design in Freedom*, São Paulo.

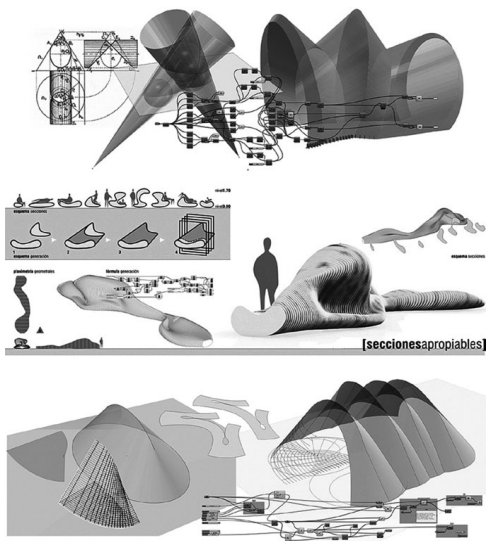


Figure 1. Digital Processes: The Cocoon (Medellín, Colombia); Bancapar (Concepción, Chile); SSFS (Santa Fe, Argentina).



Figure 2. The Cocoon (Medellín, Colombia)



Figure 3. Bancapar (Concepción, Chile)



Figure 4. SSFS Pavilion (Santa Fe, Argentina)