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"Digital tools for architectural conception"

Alberto T. Estévez

Abstract

As brief description of the topic of study, this paper is about the presentation of 5 of the last Alberto T. Estévez's projects (with members of the Genetic Architectures Research Group & Office that he directs). And about the approach to the question, can be said that these 5 "case studies" are worked with digital tools and organic forms, on their fusion of biological and digital techniques, as access ways to the values of organicity, continuity, fluidity, dynamicity, plasticity, liveliness, complexity, diversity, unity & uniqueness, coherence, cohesion, harmony. Beyond biomimetics, (bio)learning from the lessons that the book of nature teaches us: with the environmental, empathic and humanization benefits that the biological brings, and the control, automation and manufacturing benefits that the digital allows (Estevez, 2015). In short, towards the efficiency and sustainability that entails. On the understanding that the objectives proposed and achieved are real projects, architectural designs to be solved from the conception, from the ideation, and from the fabrication with digital tools.

Keywords

graphic ideation; parameterization; biomimetics; morphogenesis; digital fabrication.

1. Introduction

This paper presents the research that has been done since 2000 at ESARQ-UIC Barcelona (the School of Architecture of the Universitat Internacional de Catalunya, Spain), by the author of this paper to develop digital conception (ideation) in architecture digital design strategies, i.e., "creative strategies used by designers during the design process" (Vissner, 2006), which is based on the trio of research & profession (Genetic Architectures Research Group & Office), and teaching (Biodigital Architecture Master Program). During the development of this trio, the following concept mentioned by Neil Leach (2009) has been corroborated: because digital morphogenesis is inspired by biology, it operates through a logic of optimization, i.e., it begins from the notion of architecture primarily as form-finding that privileges appearance; morphogenesis then places emphasis on material performance and processes over representation.

To this end, five of our last architectural projects were selected, which simultaneously, can be taken as case studies. The selected projects were the most relevant, largest, and representative of the different strategies that have been explored.

In fact, it will be noted throughout this paper that the tools of representation used, which have great graphic potential, will in turn become powerful tools for architecture conception (ideation) and even for project (design) and execution control. With these, an architectural language has been developed that can only be deployed with these tools and not with others.

Thus, to begin, it can be said that in a way, “we pursue the parametric design paradigm all the way, penetrating into all corners of the discipline. Systematic, adaptive variation, continuous differentiation (rather than mere variety), and dynamic, parametric figuration concerns all design tasks from urbanism to the level of tectonic detail, interior furnishings and the world of products.” (Schumacher, 2008).

2. Discussion

This section describes the results of the study. In addition, the goal is to present the results with clarity, even though the explanation requires brevity.

2.1. *Urban scene*, Bilbao: facets and digital subdivisions

The area where the project was implemented essentially encompasses two practical problems to solve in addition to all of the characteristics intrinsic to the architecture and characteristics that any project would certainly have (quality, harmony, interest, etc.). Both problems are related here to the same topic, which is accessibility: access to the different portals on the existing street, which currently is found in an abundance of sidewalks at different heights due to the slope of the place, and access to the upper street, which at present, is resolved only by a flight of steps.

From the beginning, an assessment was made of the need to find a geometry that would homogenize all of these issues and pre-existing elements that resulted from the sum of the small, isolated actions that did not fully solve the problems or take into account the street as a whole. Five different sidewalk heights, several steps to access portals, and many improvised ramps for the disabled were the elements that required unification.

Therefore, to provide a flexible, simple project idea, a set of faceted plans is used that recurrently adapt to existing portals and to the future topology encompassed by the entire project. The flexibility of a faceted pattern not only fully covers the street with inclined, accessible planes but it also absorbs the slope as it increases to form an “artificial mountain” that includes a staircase and elevator to overcome the height difference between streets (Figure 1).

Figure 1. Alberto T. Estévez - GenArqOffice, *Urban design*, Bilbao. Triangulated topography.

Figure 1 was created automatically with the Grasshopper plug-in of Rhinoceros 3D to reference the parameters of geometries created in Rhino and with an add-on, Weaverbird, operated within Rhino, for the subdivision tasks.

The topography is projected from the Delaunay triangulation on points associated with pre-existing items (doors, “mandatory” levels) and with maximum and minimum slope values. This ensures the greatest possible angles for each triangle, i.e., it maximizes the smallest angle of the grid and avoids narrow triangles that hinder the work. Subsequently, the starting points are subjected to a process of gradual elimination, and therefore, the lower planes are greater, which makes circulation easier and become progressively smaller towards the top to adapt to a more intricate geometry.

Once the planes are referenced, they are assessed on the basis of their area with processes that group them through conditionals (“area greater than”, “area less than”). These subdivisions are compared with the “standard”, and those that are still larger are then subdivided again through the conditionals.

The subdivisions of Weaverbird are run with the Split Triangles Branch component, which allows subdividing without losing slopes and original borders, which is similar to the system of triangular fractals.

Materials are then assigned to each triangle, “hard-soft”, according to a gradual emergence of plants from the bottom to the top. The process is repeated, though this time, a non-linear constant is applied. The sense of gradient is increased by filtering the results in a Bezier graph, which reinforces the beginnings and ends. In addition, the "hard-soft" is divided into variations of grey (including the bright tiles) and in triangles with different plants (Figure 2) randomly using a component of disorder in Grasshopper that allows real mathematical-harmonic control.

Figure 2. Alberto T. Estévez - GenArqOffice, *Urban design*, Bilbao. Section of the project. Geometry, pavement, illumination, and vegetation: from facets to gradients.

This is a digital subdivision and facet strategy that enables integration, control, and a method to solve, in a coherent, nuanced, and harmonic manner, the use, environment, pavement geometry, illumination, and vegetation that is enhanced with organicity, plasticity, and continuity values.

2.2. *Market*, Casablanca: pixelization and meshing

The project for this market (a temporary street market for certain days of the week) proposes a "special meeting place" with freestanding pergolas anchored with metal bars finished in wicker, as if from the local basketry, that welcomes (and expresses) the passage of people from nearby because it is also a public square next to a neighboring school. These structures have a double curvature, are parametric, and reinterpret Arabic patterns that, when digitized, can be controlled and manufactured with precision (Figure 3).

Figure 3. Alberto T. Estévez - GenArqOffice, *Market*, Casablanca. Top, overall view. Bottom, curvature diagram and lilies.

The pavement, which is made of colored artificial stone, is inspired by sets of Moroccan carpets and is the abstract translation of a painting by Paul Klee (Figure 4); to synthesize and ensure the pavement design is feasible, the work of Paul Klee underwent a pixilation process (of square proportions), which resulted in a set of pieces with solid colors. Because this is created using digital tools, everything is perfectly recorded for easier implementation.

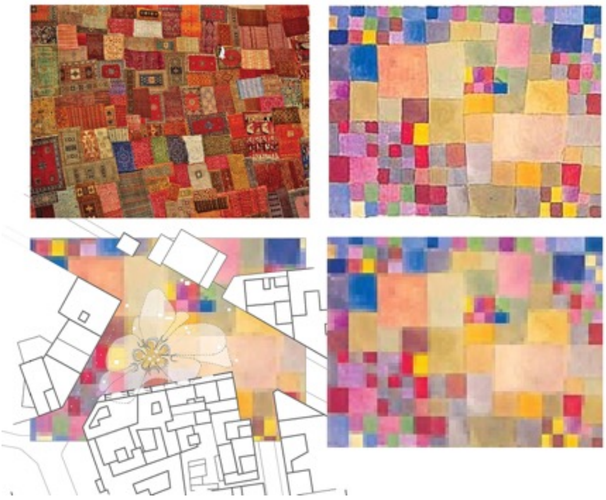

Figure 4. *Flora on sand* by Paul Klee (top right), its respective pixelization (bottom right), creation of the market pavement (bottom left), and set of Moroccan carpets (top left) (Arthus-Bertrand, 1993).

Thus, two strategies are combined:

1. Pixelisation of the mentioned horizontal plane and of the vertical plane of the neighboring dividing wall, which, with the same geometric scheme, creates holes in the facade alternated with plates of different shades of white and plant panels.

2. Cantilever pergolas, which are more resistant and remain lightweight due to having double curvatures, as different examples of nature (lilies, seashells, bones, etc.), that fold themselves and invert their curvatures (Figure 3). These surfaces undergo smoothing and reconstruction processes using Rhinoceros3D to avoid stress points in the curvature.

To achieve this, the original surfaces (NURBS) are processed in 3D meshes, allowing them to be processed with the EvoleTOOLS plug-in. Geometric options are generated by combining several mesh reordering commands. Then, one of the options is chosen based on its compositional quality and relationship to Arabic motifs, and a second modification is done to the mesh using EvoleTOOLS; however, this time, it is related to the curvature and surface stress similar to what was done previously. The optimization of the mesh produces an exploded view that can be densified or lightened based on parameters; the vertical parts or those with greater curvature will have more density in the pattern, and for the edges of the overhangs, which is where the structural requirement is minimal, the length of the bars will increase up to three times. This optimization must be ran several times until the changes in geometry are negligible.

Due to the nature and weave geometry of the patterns, the popular techniques of wicker baskets solve the structure of the patterns of the project and provide economy, lightness, and flexibility for a large-span structure.

2.3. *Park*, Cornellà: force fields

A gradient area is revitalized through “force fields” and attractors, which are defined by mathematical equations of the computer program used to define, measure, and control the following proposal: a landscape of bands of native aromatic plants alternating with pedestrian and track circulation bands, or “flows”, which express connectivity, fluidity, and continuity. All of this originates from a law that creates “force fields” based on electromagnetic simulations (Figure 5); these fields must comply with certain conditions to configure the project:

Figure 5. Alberto T. Estévez - GenArqOffice, *Park*, Cornellà. Force fields, vegetation, activities, and flow bands.

1. The fields require key points that are positive or negative charges, whose power varies according to their importance. For example, charges close to the pre-existing station or that originate from main streets will have greater value than those from secondary streets or entrances to the surrounding buildings.

2. The fields set a path of smooth curves that follow the daily flows of people and that get connected or separated, which represents the functioning and intensity of the place.

3. The fields define bands to separate uses, activities, and parking.

To select the electromagnetic lines, the polyline that limits the lot is subdivided in n points, and the minimum and maximum widths of the bands are assessed. The assessment is done particularly on the areas where forces from different loads converge and draw the central path, which will ramify between the loads (Figure 6). The fields are defined by a total of eleven loads with three levels of intensity:

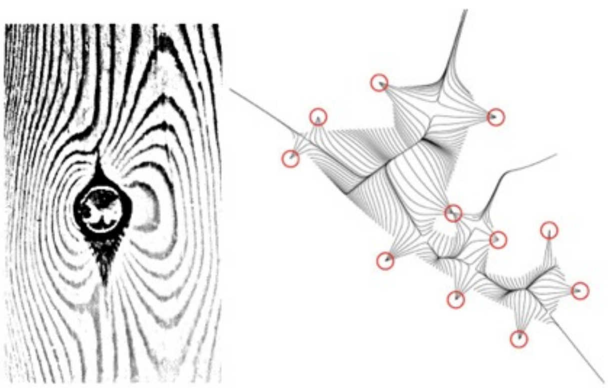

Figure 6. Wood grain and resulting magnetic fields of the park design.

The force lines are modelled by taking advantage of the vectorial components of the ‘fields’ tools of Grasshopper. The different loads in the same field are merged, and an assessment is made in the field through the points that result from dividing the perimeter into an adequate number of points; the process requires adjustments in the value and position of the loads to obtain the softest curves possible that are not under great stress due to the proximity of the loads.

Due to the definition of the fields, there will be points where the meeting of lines tends to infinity, which produces overlaps that will require a cleaning post-process. When the set of lines is well delimited, it will be sufficient to add thickness (for example, apply curve piping) and cut with the surface that is the plane of the park.

Finally, with random processes and certain functional selections, an activity or class of vegetation is assigned to each band according to two values, color, and aromas, i.e., roads, rosemary, picnic area, thyme, parking, and lavender.

2.4. *Tower-antenna building*, Santiago, Chile: fractals

This project is about a building-lookout to support antennas, which is “an urban landmark” for which a new typology of tower antennas will be defined (Figure 7); this antenna is energetically self-sufficient (spherical solar capturing, BetaTorics) and contains hollow tubes with fans and filters to promote clean air, which represents a symbol against pollution. The building is raised from a fractal structure, which is a metaphor of trees and dandelions planted in the surroundings, which gloss its special recreational and medicinal properties.

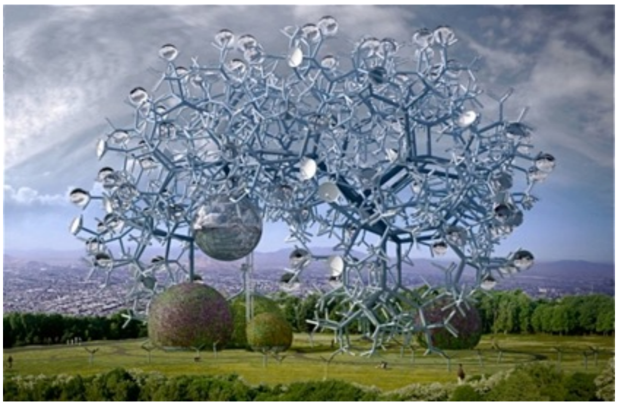

Figure 7. Alberto T. Estévez - GenArqOffice, *Tower-antenna building*, Santiago de Chile. General view.

The building is created digitally through a fractal geometry (L-System), which makes it easier to control its parts and is “automatically” harmonious, organic (organized), formal, and conceptually understood as being without interruption; the building is generated by a coherent system that resonates in all parts of the whole in an agreed symphony similar to trees (Figure 8).

Figure 8. Alberto T. Estévez - GenArqOffice, *Tower-antenna building*, Santiago de Chile. Top, the "dome". Bottom, the fractal system.

The fractal system was developed in Rhinoceros3D, Grasshopper, and Rabbit with L-System and Turtle as the primary components. The selected L-System meets the requirements for developing the project with greater functional and structural ease.

The system is therefore defined by a succession of bars that are multiplied by three in each of its eight generations and reproduced through a system of 60º angles. This forms an almost spherical shape that functions as a dome when a number of its ends begin to intersect.

It is equally important that the generation of nodes is always constant and that they can be resolved with the same piece: a bar that is split into three pieces with 30º angles in relation to the plane perpendicular to the original bar and with 120° angles between them.

A constant system of colour proportions and gradient is introduced; as the recursions increase in the fractal, the length and thickness of the bars decrease. All of the generations produce 3,276 bars with diameters between 0.34 m and 1.06 m. The last generation of bars (2,187 in total) receives the antennas and the elements for energy self-sufficiency.

2.5. *Multifunctional building and park*, Hard: Voronoi structures and distribution

Due to baseline requirements and to obtain the desired continuity, unity & uniqueness, the Voronoi cell system is used in this project. Additionally, due to its automaticity to generate or resolve situations and needs using a simple geometry (points that mark the center of each cell) with controllable patterns, it is possible to create breakdowns that are elongated, linear, large and with an “orderly” appearance or patterns that are more heterogeneous and extensive, e.g., a plaza or something similar (Figure 9).

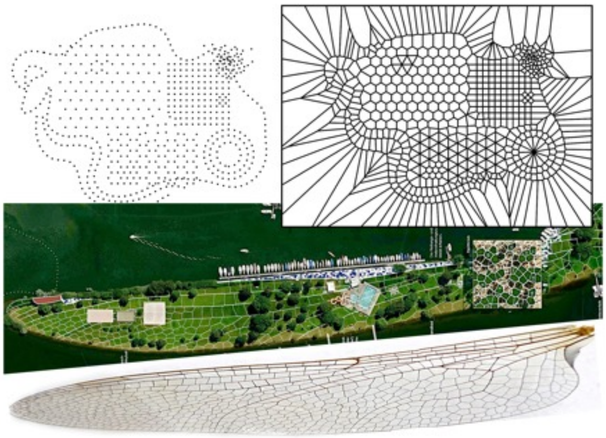

Figure 9. A possible breakdown adapts to any homogenous pattern (square, triangular, hexagonal, etc.): subdivisions within those same patterns, merging of different patterns, linear paths with or without parallel paths, different densities, radial systems, edges, or a random point distribution.

The study of Voronoi patterns, e.g., dragonfly wings, reveals the quality that results from capturing the differences between conditions of the structure, edge, and others.

Voronoi levels that are subordinated to each other are drawn, which allows continuous lines (of greater width, as they form the main path) that are defined by a succession of points that define parallel curves.

The Voronoi pattern organizes the paths of the park and divides areas according to use, which creates a degree of virtual privacy. The cells in more urban areas with hard pavement are subdivided in three successive fractal levels until the small scale of the tile is reached. Alternatively, the cells will grow and form kiosks in the second subdivision level or banks in the third level. The transition between urban spaces and green areas contains gradients between the cells of the second level.

The tiles, which can be one of three colors (blue, grey, and white) and are randomly controlled by a computer, are a reference of the casual tapestry of the canvas of boats in a port.

Continuing the Voronoi fractal, a multifunctional building-atrium is planned (restaurant, cafeteria, offices, changing rooms, stores, facilities, etc.) with an entrance to the park from the promenade, following the Voronoi rules in a three-dimensional manner: the corners of the cells are the structural elements, and the faces serve as a facade, floor, or roof (Figure 10).

Figure 10. Alberto T. Estévez - GenArqOffice, *Multifunctional building and park*, Hard. Detail of the multifunctional building-atrium.

The program to be executed is solved by closing or opening the faces of each three-dimensional cell. To achieve this, the different faces are evaluated based on the z value to classify them as either a roof, pavement, or facade; certain faces are made of glass with a Voronoi lattice, and others are made with a wooden floor.

The computational effort consists in subordinating cells within others (nesting the structure within itself three times using the *Voronoi Groups* component) or adapting cells to irregular perimeters. For this last requirement, it was necessary to run Boolean evaluation components to delimit the overlapping regions (Region Intersection) of two domains: a Voronoi pattern greater than the total and the limits of the project.

To reinforce the cell concept, the inside angles are rounded, and their radius is made dependent on the cell size. This emphasizes the organic nature, values of continuity, unity & uniqueness, and of the fluidity and dynamism.

These aspects were elaborated with greater complexity in a final project not included in this paper (*Passive solar housing block*, Innsbruck) after learning of the microscopic structures analyzed with an electron microscope. It is understood that in these designs "differentiation is achieved by the differentiation of Voronoi tiling of a parametric surface that provides a multi-functional performative design approach to the structural surface pattern" (Oxman, 2017).

3. Conclusions

In conclusion, after presenting these five projects of real programs, it can be concluded that with the tools presented here, it is also possible to provide functional and efficient alternatives, and with values "in every design project creativity can be found, if not in the apparent form of a distinct creative event, then as the evolution of a unique solution possessing some degree of creativity" (Dorst and Cross 2001).

This paper is thus an expression of the search for paths and strategies, where the influence of the tools of representation and ideation are decisive in the resulting architecture, which can only be represented by such tools. Regarding these projects, it can now be said that "software is a tool for the mind" (Reas and Fry, 2014). Digital tools and organic forms are "beyond being another tool for modelling complex forms, parametric design was presented (…) as a unique and distinctive model of creativity and innovation in parametric design thinking" (Oxman, 2017), in the conception (ideation) of the design.

In fact, as Neil Leach (2009) also declared, the programs used in the preceding examples reveal the true potential of the digital world, which influences the design process and opens fields of possibilities. The computer then emerges not only as a prosthetic device that extends the range of architectural imagination but acts as more of a calculator, i.e., as an optimization tool that offers a more rigorous search for potential options.

Just as it was mentioned at the beginning of this paper, throughout these pages, it has been seen that these projects have been worked on using a "fusion", so to speak, of biological and digital techniques as means of access to values of organicity, continuity, fluidity, dynamism, plasticity, liveliness, complexity, diversity, unity & uniqueness, coherence, cohesion, and harmony. This goes beyond biomimetics and towards (bio)learning the lessons that the book of nature provides. It also has the environmental, empathetic, and humanization advantages provided by the biological aspects and the advantages in control, automation, and production that digital technology allows (Estévez, 2015). In conclusion, the use of this fusion seeks effectiveness and sustainability.

Finally, all of this has only confirmed that "despite the importance given to drawing within architecture, the influence of the development of representation systems and the different tools used by architects during the design process have shown that there is a fruitful relationship between drawing and project, between graphics and architecture" (*Call for Papers*, XVII EGA International Congress).

4. Acknowledgement

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