# ALGORITHMIC THINKING IN DESIGN AND CONSTRUCTION

*Working with parametric models*

A. PETEINARELIS AND S. YIANNOUDES
*Technical University of Crete, Chania, Greece*
*ng5ten@yahoo.com* | *soc.yiannoudes@gmail.com*

**Abstract.** This paper examines the parametric model in algorithmic design processes, using the outcome of an educational digital design and fabrication course as a case study. In its long history, algorithmic design as a form-finding method, allowed designers to manage complex non-standard associative geometries, suggesting a shift from the digital representation of form, to its systematic representation into a parametric model through code. Rather than a style or a tool, the parametric model is best defined in mathematical terms; in practice it incorporates the organizational logic of the form and the topological associations of its parts, so that a change in its constitutive parameters will invoke a concerted update of the entire model, and, iteratively, formal and structural variations. In a series of design experiments that took place at the School of Architecture of the Technical University of Crete in the spring of 2015, we used parametric models represented into visual code, from the initial conceptual stage to fabrication. From the experience and outcome of this course, we deduced that, compared to other digital formation methods, parametric models allow the designer to constantly interact with the model through the code, producing discreet variations without losing control of the design intentions, by "searching" into a wide range (albeit finite) of virtual results. This suggested a shift in culturally embedded patterns of modernist design thinking.

## 1. Introduction: Parametric Design

Although the term "parametric design" can be traced in many recent publications on digital design (Woodbury, 2010; Jabi, 2013), the term "parametric architecture" was coined for the first time in the 1940's by Luigi Moretti, who, in his writings, pointed to the study of architectural systems by "defining the relationships between the dimensions dependent upon the various parameters”, to produce variations of the form of buildings (Bucci & Mulazzani, 2000). In line with Moretti and since buildings and cities have always taken shape according to changing parameters, either environmental, cultural, constructional or functional, we could easily argue that architecture and design have always been parametric (Aish & Woodbury, 2005; Gerber, 2007; Hudson, 2010). However, Patrik Schumacher, a few years ago, introduced the term “Parametricism”, to refer to a “new great style” and suggest the advent of a new paradigm in architecture after modernism (post-modernism and deconstruction being only transitional stages), along the lines of a new research program (as defined by Lakatos in the philosophy of science), with certain methodological and stylistic rules (Schumacher, 2008; 2010). Of-course, Schumacher’s view, who, in our opinion, mostly showcases the architectural style of his practice Zaha Hadid Architects (ZHA), is very prone to criticism, because several emblematic buildings of modernism, like Villa Savoye, can and have been parametrically modelled. But as we will show, rather than an architectural style, parametric design is concerned with the management of the relations between the parameters that define a geometric structure in the design process, and the best definition for what we will refer to as “parametric model” comes from mathematics.

### 1.1. THE PARAMETRIC MODEL

In his doctoral dissertation Daniel Davis, instead of “parametricism” or parametric design, talks about “parametric models” based on the definition of the parametric equation in mathematics. Parametric, in mathematics, is a set of quantities expressed as an explicit function of a number of parameters, such as the formulas that describe the catenary curve: $x(a,t)=t$ $y(a,t)=a \cosh(t/a)$. Hence, “A parametric model is set of equations that express a geometric model as explicit functions of a number of parameters” (Davis, 2013). This mathematical definition of the parametric catenary curve, characterizes the inverted suspension models with strings and birdshot weights used by Antoni Gaudí to automatically simulate -by analogue means- the route of the forces and thus the multiple variations of the form of his Colònia Güell chapel, according to the set of outcomes that derived from the parameters (string length, anchor point location, birdshot weight). Similar analogue methods for parametric calculations were later expounded by Frei Otto at the Institute for Lightweight Structures (ILS), who used several experimental form-finding and optimization techniques, as documented in the ILS publications. These methods are currently revisited by contemporary practices that make use of parametric and algorithmic design, while Otto’s legacy has recently been further investigated (Peteinarelis, 2015; Fiorakis, 2016).

Davis will conclude that "…a parametric model is unique, not because it has parameters (all design, by definition, has parameters), not because it changes (other design representations change), not because it is a tool or a style of architecture, a parametric model is unique not for what it does but rather for how it was created. A parametric model is created by a designer explicitly stating *how* outcomes derive from a set of parameters" (Davis, 2013). Thus, the use of parametric models in digital design, allows designers to describe the geometry of their model (either orthogonal or curvy) with flexibility, and create dependencies between the components of the model, using specific rules and constraints. Designers can use current parametric modelling software like Revit to manage complex and associative geometries, i.e. they can associate dimensions and parameters with the geometry, so that a change of a part, a rule or a constraint that describes it, will affect and update the entire model.

To create parametric models, designers use algorithmic editors that usually incorporate visual programming languages (like Grasshopper/Rhino3d, Max/MSP or Revit/Dynamo), to overcome the constraints of the interface, and to design directly, managing not the form (with the design tools provided by common software packages), but the code that generates the form. In this way the designer can formulate the associations of the parts of the parametric model into code, so that a change in the parameters that describe it, will cause a coordinated overall update – thus observing the variations of the generated results. This allows freedom and flexibility to deconstruct the problem and thus represent it with precision and control, into code (Burry, 2011). Understanding the parametric model in the form of code in the context of algorithmic design is the rationale of the postgraduate course discussed next.

## 2. From Code to Fabrication

The postgraduate course "Advanced Digital Tools in Design and Construction" runs at the school of Architecture at the Technical University of Crete. Central to the course is the concept of code and its representation for the creation of parametric models. In the spring of 2015 we examined form-finding techniques with algorithmic thinking, emphasizing the unified use of the digital model, from the initial abstract diagram (body-plan) to fabrication, according to the properties of the materials used and the capacities of digital prototyping machines.

Apart from the historical precedent and the theoretical aspects of parametric design, we reviewed several current practices in parametric and algorithm design, more or less experimental, to gain insights from their design approach for our design course process. For example, Lisa Iwamoto and Craig Scott designed a structural skin parametrically correlated to changes in building stress and strain for their Jelly Fish House (2005-06), and Tom Wiscombe (Emergent Architecture in Los Angeles) used the patterns of dragonfly wings to model the variably patterned structural envelope of his Paris Courthouse project (2006). Most importantly however, Archim Menges and his team in the Institute for Computational Design at Stuttgart, proposed a design methodology, on the basis of biomimetic principles as well as Manuel DeLanda's neo-materialist thinking, foregrounding the properties of the construction materials as morphogenetic information, simulated in the computational process, from concept to robotic fabrication. The ICD/ITKE Research Pavilion 2010 is a characteristic achievement of the team's method.

Drawing on these biomimetic attitudes that start from the structural characteristics of form, in our design course we asked students to analyze a natural form of their choice, determining its geometric and qualitative characteristics, in order to describe, using diagrams, the rules that express, and the code that organizes its structural complexity. The aim was to finally restructure these diagrams into a new code, a genotype that would incorporate the basic design choices for novel form-finding, in particular, for the design of a utilitarian object – namely a lighting fixture. Students would choose the structural characteristics that would be parameterized, and then transfer this new code into the environment of graphical algorithm editor Grasshopper3D for Rhino. They would thus be able to form a parametric model of the object that they would design and build.

We used two qualitatively different prototyping methods, which affected both the form and the fabrication instructions incorporated in the parametric model. The first method was 3D printing, which builds complex geometric forms by successive layers of plastic (additive manufacturing). The second method was subtractive manufacturing, using CNC milling machines and Laser cutters, which entailed taking account of the constraints, tolerances and specific characteristics of the materials and machines used. When the code was completed, the students 3d printed some of their results, namely the family of forms that emerged from their parametric model, and then they selected one of them as a model for further digital processing and 1:1 fabrication, experimenting with different construction materials.

Iro Skouloudi, who designed the project "Pinecone", studied the mathematical rules that define the geometry and structure of pinecones, using them as input for the parametric model that described its geometry. Through her research she found that the position of the petals on the pinecone coincides with the intersection points of clockwise and anticlockwise spirals, the amount of which corresponds to two successive Fibonacci Sequence numbers. Thus, the number of the petals and the sunlight intrusion is optimized. Moreover, the opening and closing of the petals (their angle to the central axis of the pinecone) depends on humidity. These observations were then transferred to the parametric model of the restructured version of the pinecone (fig. 1).

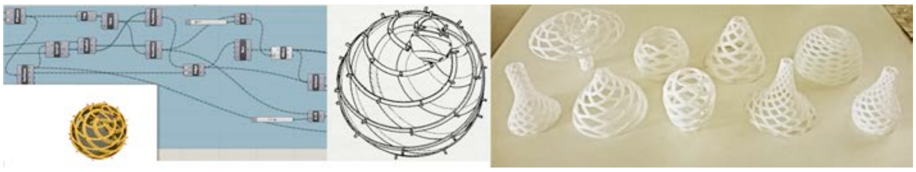

*Figure 1.* Parametric model of the reconfigured pinecone and 3d-printed family of forms.

*Figure 2.* 1:1 scale model.

The model started with a surface defined by intersecting spirals. The intersections of these spirals were the positions of the supports of the petals, which were adjusted to always be vertical to the plane that was tangent to the clockwise spiral at the intersection point. The size of the petals was correlated to the z axis, which was defined by the vertical axes between the intersection points. By controlling and modifying the initial overall form, and the position, orientation, and shape of the petals through the parametric model, the student could flexibly create and print different variations of the outcome (fig. 1). In the next stage, the student modified the parametric model, in order to introduce the manufacturing parameters of two versions of the object as it was implemented in 1:1 scale by plywood (fig. 2).

The next project by Alicia Markianaki, started from an examination of butterfly flaps, in order to determine the shared branching rules of their ribs. The student found that the edge that is attached on the body of the insect is always smaller than the external one, that there is successive bisection of the ribs along the flap, and that the cross-sections of the ribs become larger towards the base of the flap. The student created a parametric model in the form of code, introducing these rules, which could control the general shape, the bisection sequence, and the changing cross-sections of the ribs. The model generated a family of forms, which were 3d-printed in small scale (fig. 3). Subsequently the student explored fabrication methods, using plaster and clay casted in CNC-milled wood mold (fig. 4), to build one the variations on a 1:1 scale.

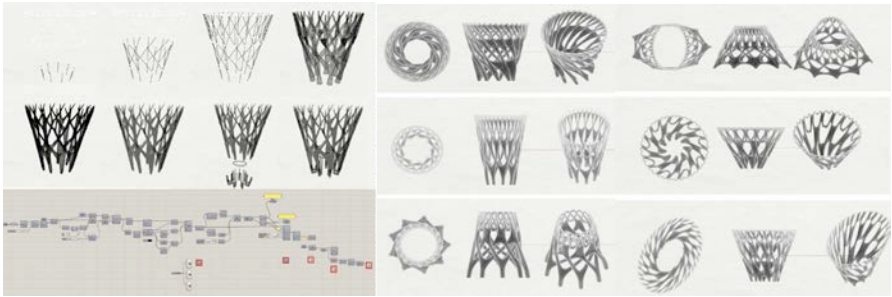

*Figure 3.* Parametric model and family of forms.

*Figure 4.* Wooden mold and clay models

Giorgos Spyridakis's project point of departure were the draperies of speleothems and the processes that generate them, namely successive layers of water and calcite. Using Kangaroo physics engine plugin for Grasshopper, the student could dynamically simulate this process using wind force, and freeze the derived form on a moment he preferred. After the initial 3d printing session of his model, the student studied potential fabrication techniques (contouring the model and building it by stacking wooden boards, cast using rammed earth etc.). He chose to fabricate it using polyester and polyurethane mold (fig. 5).

*Figure 5.* Kangaroo model of surface, 3d printed model and natural formations

In our view, the contribution of the course is that it helped us understand the possibilities of digital tools and parametric models, and enhanced students' skills to manage complex geometries from the stage of the concept to final fabrication.

## 3. Parametric Models in the context of Digital Design

The last 20-25 years, computer-aided design and manufacturing has allowed designers to draw, manage, and construct geometrically complex buildings and structures, which often led to a "neo-expressionist" or "post-organic" architectural vocabulary based on curvilinear forms. This "topological tendency" in architecture (Di Christina, 2001), can be traced in the practices and discourse of architects like Peter Eisenman, Frank Gehry, Greg Lynn, Foreign Office Architects (FOA), UNStudio, Sanford Kwinter, Stan Allen, and Peter Saunders, and in numerous publications of Architectural Design (AD) magazine. Rivka Oxman attempted to categorize the outcome of many years of digital design practice into a number of design models, drawing on Donald Schon's design theory and his concept of "reflection in action", to examine the relation between the designer and the object of design in each design model (Oxman, 2006). Digital design processes use a dynamic environment of topological deformations, morphogenetic force fields, and generative form-finding processes. Such design practices seem to point to a shift from the concept of form and its representation, to the concept of formation, i.e. the mechanism, the performative process of form generation (aka emergence). This shift, from a representational to a performative approach to digital design, seems to be an emergent characteristic phenomenon of digital design, and defines the concept of formation as a flow of events and open potentials, in which the form is only a moment of effectuating the virtual, in Deleuzean terms, the diagrammatic machine that generates the form.

## 4. Conclusion

Design using parametric models, as studied in the course we discussed, presents significant differences in relation to other digital design models, as discussed by Oxman. First, it manifests the systematic representation, not of form, but of the code that describes it. Second, by contrast to algorithmic design models that automate form-finding, such as the evolutionary design models that use genetic algorithms, and the grammatical transformative models, that use mathematical expressions for the generation of shapes through transformational rules, the parametric model gives designers the capacity to constantly interact with the model (adjusting parameters or even the topological relations that define it through the visual code). Third, designers are able to parametrically control the initial design intentions to generate discreet variations of the model (family of forms), "searching" within a wide range (albeit finite) of virtual results.

Finally, digital techniques bring forth a new framework for design thinking. Contemporary experimental and built parametric design projects, such as those by Foster & Partners, Zaha Hadid Architects, NOX, NBBJ, and Ball Nogues Studio, demonstrate an attempt to reconfigure foundational concepts of modernist architecture and design, by replacing cultural patterns of the "first machine age", characterized by normative processes of standardization and repetition, with alternative ways of thinking embedded in the so-called "digital culture" (Gere, 2008), characterized by the discreet, the flexible and the differentiated, rooted in Deleuzean philosophy, and the sciences of complexity.

## Acknowledgements

We would like to thank the students of the postgraduate course "Space, Design and Built Environment" of the School of Architecture Technical University of Crete, Iro Skouloudi, Alisia Markianaki, and Giorgos Spyridakis for giving permission to publish their work in this paper.

## References

AISH, R. AND WOODBURY, R., 2005. Multi-level Interaction in Parametric Design. In: A. Butz et al., eds. *Smart Graphics: 5th International Symposium* (LNCS vol. 3638). Frauenwörth Cloister, Germany: Springer-Verlag, 151-162.

BUCCI, F. AND MULAZZANI, M., 2000. *Luigi Moretti: Works and Writings*. New York: Princeton Architectural Press

BURRY, M., 2011. *AD Primer: Scripting Cultures: Architectural Design and Programming*. Chichester, UK: Wiley.

CARPO, M., 1993. Ten Years of Folding. In: G. LYNN, ed. *AD: Folding in Architecture.* Chichester, UK: Wiley, 14-19.

DAVIS, D., 2013. Modelled on Software Engineering: Flexible Parametric Models in the Practice of Architecture (Unpublished doctoral thesis). RMIT University.

DI CHRISTINA, G., 2001. The Topological Tendency in Architecture. In: G. DI CHRISTINA, ed. *AD: Architecture and Science*. Chichester, UK: Wiley-Academy, 7-11.

FIORAKIS, K., 2016. Frei Otto: From Form-Finding to Morphogenesis (Unpublished thesis-research project). School of Architecture, Technical University of Crete.

GERBER, D. J., 2007. Parametric Practices: Models for Design Exploration in Architecture (Unpublished doctoral dissertation). Harvard University.

GERE, C., 2008. *Digital Culture*. 2nd ed. London: Reaktion Books.

HUDSON, R., 2010. Strategies for Parametric Design in Architecture: An application of practice led research (Unpublished doctoral thesis). University of Bath, UK.

JABI, W., 2013. *Parametric Design for Architecture*. London: Laurence King Publishing.

OXMAN, R., 2006. Theory and Design in the first Digital Age. *Design Studies*, 27 (3), 229-265.

PETEINARELIS, A., 2015. Frei Otto's contribution - legacy to parametric design and material computation (Unpublished postgraduate essay). School of Architecture, Technical University of Crete.

SAKAMOTO, T. AND FERRÉ, A., 2008. *From Control to Design: Parametric/Algorithmic Architecture*. Barcelona / New York: Actar-D.

SCHUMACHER, P., 2008. Parametricism as Style - Parametricist Manifesto. Retrieved from Patrik Schumacher.com website: http://www.patrikschumacher.com/Texts/Parametricism%20as%20Style.htm.

SCHUMACHER, P., 2010. The Parametricist Epoch: Let the Style Wars Begin. *AJ - The Architects' Journal*, 231 (16).

WOODBURY, R., 2010. *Elements of Parametric Design*. London: Routledge.

YESSIOS, C., 2003. Is There More to Come? In: B. KOLAREVIC, ed. *Architecture in the Digital Age: Design and Manufacturing*. New York: Spon Press, 259–68.