Parametric design in architectural education

Kacper Radziszewski & Jan Cudzik

Gdańsk University of Technology
Gdańsk, Poland

ABSTRACT: Educators dealing with architectural education must anticipate the changes in the discipline and act to prepare students to face the challenges of the future. Therefore, it is necessary to provide them with state-of-the-art knowledge and relevant skills. To achieve that for new design techniques requires education. One new technique is parametric design, which has become one of the commonly used tools in architectural design practice. An overview is provided in this article of the present teaching programme, concerning parametric design, in the Faculty of Architecture at Gdańsk University of Technology (FA-GUT), Gdańsk, Poland.

INTRODUCTION

Design tools have changed architecture. This change has had a significant impact on architectural education. Teaching new generations of architects involves mastering various digital tools, from digital drawing through 3D modelling to computation. The need for improvement and the design process itself points to parametric design as a new tool.

Architectural education has changed due to the emergence of new technologies. At first, most architecture schools introduced basic computer-aided design tools starting with two-dimensional drawing software, such as Autodesk AutoCAD or Bentley MicroStation. Subsequently, the complexity of computer-aided architectural design has evolved in parallel with the available tools. Though at first 3D modelling was considered an extension of basic digital drawing, it has now become an essential tool students apply. With the growth of computing power, 3D modelling became detailed enough to replace the need for 2D digital drawing. With the growth of data processing, architects found it necessary to learn programming. This opened the field to experiments in parametric design. Branko Kolarevic explains the potential and rationalisation for parametric design:

> *Parametrics can provide for a powerful conception of architectural form by describing a range of possibilities, replacing in the process stable with variable, singularity with multiplicity. Using parametrics designers could create an infinite number of similar objects, geometric manifestations of a previously articulated schema of variable dimensional, relational or operative dependencies. When these variables are assigned specific values, particular instances are created from a potentially infinite range of possibilities* [1].

To meet the requirements of such contemplative architecture an appropriate teaching programme has to be created which involves the introduction of parametric design. The process has to be divided into consecutive levels adjusted to match the advancement of students.

PARAMETRIC DESIGN

Parametric design in recent years has become one of the most important design tools. However, only two decades ago, it was just starting to fill gaps in the design process, as Wassim Jabi wrote:

> *Designers have begun using parametric design software, which allows them to specify relationships among various parameters of their design model. The advantage of such an approach is that a designer can then change only a few parameters and the remainder of the model can react and update accordingly* [2].

The change is architecture started in the early 1990s and has evolved rapidly. In 2003, Kolarevic argued:

> *Digital technologies are changing architectural practices in ways that few were able to anticipate just a decade ago. [...] Digitally-driven design processes, characterized by dynamic, open-ended and unpredictable but consistent transformations of three-dimensional structures, are giving rise to new architectonic possibilities* [3].

His statement was a few years later supported by Greg Lynn and Mark Foster Gage:

> *It is only in recent years that software and rapid prototyping have enabled the designer to move so fluidly between the virtual and the physical. As design and fabrication feed each other, our digital dreams could quickly become real nightmares if not handled carefully and seriously. Design today requires learning a new formal language, honing these new tools and welding them with great focus* [4].

As a result of growing interest in parametric design, the term was explained by many contemporary architects and researchers. Patrick Schumacher, a partner at Zaha Hadid Architects, in his parametricist manifesto argues that:

> *Contemporary avant-garde architecture is addressing the demand for an increased level of articulated complexity by means of retooling its methods on the basis of parametric design systems. The contemporary architectural style that has achieved pervasive hegemony within the contemporary architectural avant-garde can be best understood as a research program based upon the parametric paradigma. We propose to call this style: Parametricism* [5].

Despite having a huge impact on architecture, parametricism did not become a new *avant-garde* style in the sense Schumacher expected it to be. To understand parametric design means to understand the shift in the design process, from subjective vision to a data-driven design. Vitor Gane, in an interview with the academic, Axel Kilian, defined parametric design as:

> *A process of choosing appropriate parameters for a design problem setting up the model definition that then can be used to explore the solution space* [6].

This definition was extended by Kolarevic, who noticed:

> *To develop such parametrically complete representations of architectural elements, one needs to evaluate, understand and interpret the inherent behaviour of these elements; this process may actually be quite subjective, which is a rather typical occurrence in the architectural design* [3].

Most of the definitions of parametric design agree upon the impact of parameters and the hierarchy chosen by the creator. This dependency is based on a proper understanding and evaluation of both design topics and the limitations of available tools. Contemporary architects agree that algorithmic architecture should be supervised and controlled by an experienced architect.

APPLICATION OF PARAMETRIC TOOLS TO ARCHITECTURE

Parametric tools are used in architecture for several reasons during the design process. beginning with 3D modelling, through simulations, automation, optimisation, digital fabrication, and finally, to digital assembly. Because of the complexity of architectural projects and the strict documentation requirements, at present there are no architectural projects designed solely using a set of algorithms. However, computer programming allows designers to make use of the available tools and programs or to write their own dedicated algorithms to aid the design process, which includes:

- Advanced modelling.
- Automation.
- Simulations.
- Digital fabrication.

Advanced Modelling

Advanced modelling with algorithmic tools enables digital three-dimensional modelling of various shapes and complexity. Parametric design is often associated with freeform building facades and plans due to the works of world-famous architects such as Zaha Hadid Architects, Frank Gehry or Foster+Partners. It is important to note that algorithmic design techniques do not limit the scope of possible architectural designs to the field of freeform structures.

Automation

An aim of programming is the automation of time-consuming and repetitive tasks. The introduction of computer-aided design (CAD) in architectural design, enabled efficient drawing and modelling; however, the process itself mainly is based on a large set of simple commands with a low level of automation. Computer-aided design tools enable the application of automation in many programming languages, e.g. AutoLISP, Python and C#. As a result of architects' lack of programming knowledge, programmed methods rarely find application in everyday design. Visual programming with an easy-to-understand interface simplifies the algorithm writing process and has led to their growth in popularity among architects.

Simulations

Design projects written in the form of an algorithm enable the immediate adjustment of building parameters. Architectural projects require verification of structural design, visual, thermal comfort and energy consumption. The combination of the simulation's accuracy and algorithmic design enables a project design to be rapidly adjusted. Architects increasingly introduce optimisation into their designs to select a project design based on simulations from among thousands of possible variations.

Digital Fabrication

Along with the growing complexity in architectural design, production of building components requires the application of computer-aided manufacturing (CAM). This can be defined as the effective utilisation of computers in manufacturing. Apart from standard façade elements, automation, which does not require programming and is possible to prepare with CAD software, CAM techniques allow the realisation of a complex three-dimensional structure. Programming methods allow the application of direct digital manufacturing, which enables avoidance of building production documentation which, with irregular geometries, would require a vast number of plans.

FACULTY OF ARCHITECTURE AT GDAŃSK UNIVERSITY OF TECHNOLOGY

The present teaching programme divides the education of parametric design into a series of classes. The level of exercises and required knowledge grows as students advance and involves design projects. It consists of:

- descriptive geometry and parametric design;
- advanced CAD;
- elective seminars;
- workshops.

Descriptive Geometry and Parametric Design

With the availability of computational tools for architecture, hand drafting of geometry has become unnecessary. Most of the descriptive geometry applications are within CAD software. This shift in design practice to using software applications requires an update of the teaching of spatial and drafting skills, which are a part of the scope of descriptive geometry teaching. Algorithmic design enables the generation of complex geometries, such as freeform surfaces, NURBS (non-uniform rational basis spline) geometries, minimal surfaces, mesh geometries and point clouds. With a growing set of possible geometrical applications within architectural practice, it is essential to be acquainted with geometrical mathematical fundamentals and their spatial properties.

The descriptive geometry programme takes place during the first two semesters of undergraduate studies at the FA-GUT. During the last three laboratories totalling nine hours, students are introduced to the principles of parametric design and visual programming through introductory exercises regarding selected surface properties. Preceded by a lecture, the first three-hour laboratory is designed to present students with the basics of programming, software interfaces and modelling of a geodesic dome. The dome geometry is designed with Grasshopper 3D software supported by the Weaverbird mesh modelling library.

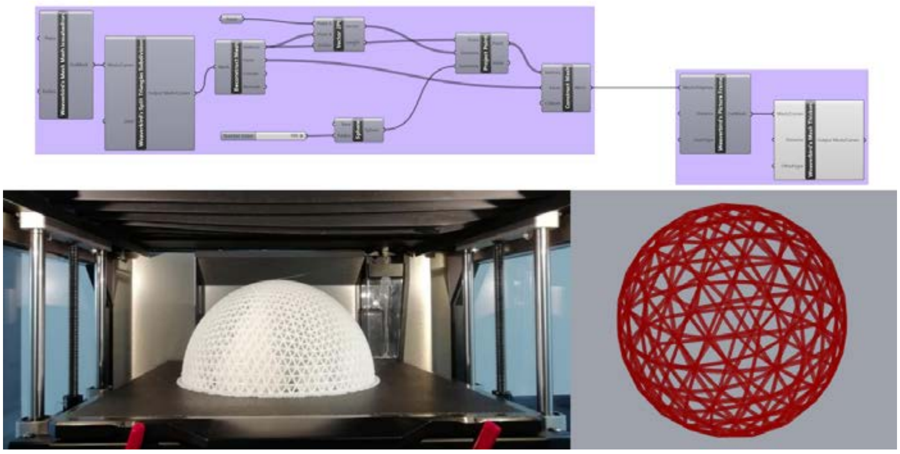

Figure 1: An exercise from a descriptive geometry class.

The laboratory outcome in the form of a three-dimensional geodesic dome is based on a regular icosahedron [7], a convex polyhedron [8] with 20 faces, 30 edges and 12 vertices. The second and third laboratories introduce students to developable surfaces [9], the spatial properties of which can be applied to architectural forms [10]. In four exercises students are instructed to program the geometries of a helicoid, hyperbolic paraboloid, hyperboloid and conoid [11]. These geometric mesh representations were digitally fabricated with 3D print technology (see Figure 1 above).

Advanced CAD

Recent architectural practice has revealed that the application of parametric design contributes to both the design and construction stages by automating the processes. It is important to familiarise future architects with the tools, which will have a direct influence on the design process and therefore its quality. Students have enough knowledge of architectural design to understand the full purpose and application of programming methods in their field.

During the 15-hour course Advanced Computer Aided Design, lessons cover the parametric representation of three contemporary architecture objects and there is a set of exercises regarding abstract geometrical concepts. Classes introduce the basics of non-uniform rational b-spline curves and surfaces [12], which are applied to write the algorithms for the following buildings: 2009 Serpentine Pavilion by SANAA, 30 St Mary Axe by Foster+Partners and Beijing National Stadium by Herzog and de Meuron (see Figure 2).

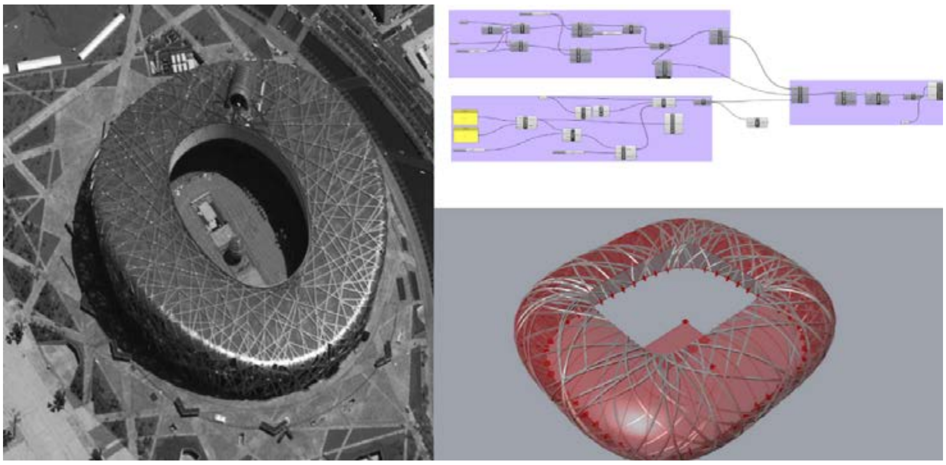

Figure 2: An exercise from the Advanced CAD course.

Apart from programming the façade surfaces of the buildings, students are shown a set of methods enabling façade design, i.e. panelisation and Voronoi diagrams [13]. The short duration of the course means exercises are limited to basic three-dimensional modelling, which complements daylight, energy, construction simulations and the basics of design optimisation.

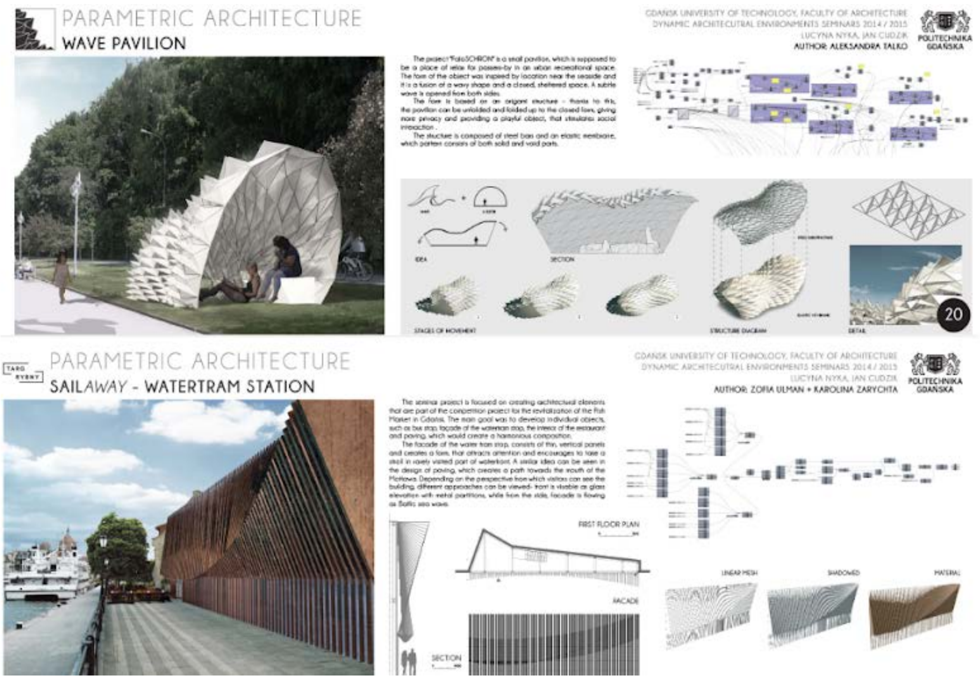

Figure 3: Students' work prepared for exhibition from the Parametric Design elective seminar.

Elective Seminars

Elective seminars give students freedom in the selection of design topics and methods based on their interests. Therefore, students can experiment, and this often involves tools and theories not part of the regular teaching programme [14]. Seminars at the undergraduate level are aimed at teaching new tools and show possible fields for further exploration. At Master's level, the seminars are problem-oriented and show the entire design process from a theoretical and practical perspective.

The experimental aspect of elective seminars can trigger the application of new technologies and tools. The classes are often connected with national or international competitions or exhibitions (see Figure 3 above). The representative examples are from descriptive geometry elective seminars. Based on the students' knowledge of parametric design obtained during the second semester of the Descriptive Geometry course, students were given the opportunity to take part in a 15-hour elective seminar focused on the design and fabrication of the geodesic dome.

The concept of application of geodesic dome geometry into architecture was popularised by an American architect and inventor, Richard Buckminster Fuller, the author of The Montreal Biosphere, designed for the 1967 World Fair. Based on the geometrical knowledge and geodesic dome simplicity and construction properties, students were confronted with the task of applying digital fabrication and building their own semi-scale installation.

During the exercises, participants prepared a set of geometries and possible fabrication methods, calculating the production time, size of the object and labour complexity. Based on the comparison of the projects and discussion, computer numerical control fabrication of plywood sheets was selected as the most reliable method, which resulted in a 250 cm radius geodesic dome structure (see Figure 4).

Figure 4: Geodesic dome created during an elective seminar.

Workshops

In recent years, regular workshops on parametric design were held at the FA-GUT. One of the first workshops evaluated generation of freeform structure based on optimisation goals. The form created with same-size cardboard boxes was a manifestation of digital architecture, and the high potential of non-standard documentation. After creating a small-scale cardboard form, a large-scale object was built from hexagonal wooden panels. The workshop was focused on digital fabrication optimisation and spatial analysis of form that involved building statics. The form represents the beauty of complex geometry (see Figure 5) and became a basis for ongoing spatial experiments.

Figure 5: Pavilion created during summer workshops.

CONCLUSIONS

Contemporary architecture is undergoing rapid changes based on the constant development of design tools and other technologies. To face this, it is necessary to master up-to-date design tools and understand how to use them efficiently. This is one of the tasks today for architectural education. To teach parametric design, many stages are involved, from a basic introduction to design and finally digital fabrication. Only this full experience can adequately show students the potential behind algorithmic design tools.

However, it is important to remember that all automated processes must be supervised and controlled by an architect with appropriate knowledge and skills. Therefore, it is important to teach not only particular tools, but how to connect them and use them properly. To do that, the teaching should involve both theoretical and practical classes. Teaching is shifting more to a project-based model, where students work on a design project. Through this process, students should learn new skills and acquire knowledge of design. This change is already taking place at some universities (e.g. Universität für Angewandte Kunst Wien, The Bartlett University College London and the University of Stuttgart).

The digitisation of architects’ workshop should not completely replace traditional design methods, such as handcraft modelling or drawing, which are still essential for the proper development of early-stage design models. There is also a risk of over-automatisation of the process that could lead to a drop in creativity and critical thinking. The work of an architect has been, and always will be, interdisciplinary, therefore studying should involve as many design aspects as possible.

REFERENCES

1. Kolarevic, B., *Architecture in the Digital Age. Design and Manufacturing.* London and New York: Routledge, 17-18 (2003).
2. Jabi, W., *Parametric Design for Architecture*. London: Laurence King Publishing, 9-11 (2013).
3. Kolarevic, B., *Architecture in the Digital Age. Design and Manufacturing*. London and New York: Routledge, (2003).
4. Lynn, G., *Gage, M.F., Composites, Surfaces, and Software: High Performance Architecture*. New Haven, Yale School of Architecture, 104 (2010).
5. Schumacher, P., *Parametricism as Style - Parametricist Manifesto*. London, 1-3 (2008).
6. Gane, V., Parametric Design - a Paradigm Shift? Master Thesis - MIT, 37 (2004).
7. Weisstein, E.W., Icosahedron, From MathWorld - a Wolfram Web Resource (2019), 1 July 2019. www.mathworld.wolfram.com/Icosahedron.html
8. Lakatos, I., *Proofs and Refutations: The Logic of Mathematical Discovery*. Cambridge: Cambridge University Press, 16 (2015).
9. Hartmann, E., *Geometry and Algorithms for Computer Aided Design*. Darmstadt: Department of Mathematics Darmstadt University of Technology, 113 (2003).
10. Pottmann, H. and Simon, F., Ruled surfaces for rationalization and design in architecture. *Proc. 30th Annual Conf. of the Assoc. for Computer Aided Design in Architecture*. New York, United States of America, 103-109 (2010).
11. Weisstein, E.W., Ruled Surfaces, from MathWorld - a Wolfram Web Resource (2019), 1 July 2019. www.mathworld.wolfram.com/topics/RuledSurfaces.html
12. Piegl, L. and Tiller, W., Curve and surface constructions using rational B-splines. *Computer-Aided Design*, 19, **9**, 485-498 (1987).
13. Aurenhammer, F. and Klein, R., *Handbook of Computational Geometry*. Amsterdam: North-Holland, 201-290 (2000).
14. Romaniak, K. and Filipowski, S., Parametric design in the education of architecture students. *World J. of Engng. and Technol. Educ.*, 16, **4**, 386-391 (2018).