Parametric design in the education of architecture students

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ABSTRACT: In this article selected issues are presented that relate to the didactics in the field of computer software allied to the basics of algorithmic and parametric design in the education of architecture students. The findings are based on the experience of the researchers at the Department of Descriptive Geometry and Digital Technologies of the Institute of Building Design in the Faculty of Architecture at Cracow University of Technology, Kraków, Poland. This is part of the evolution of its educational offer. The introduction of new technologies and computer programs in the teaching is described, starting with the decision of which programmes to teach, and staff training, ending with the description of long-term results.

INTRODUCTION

Dynamic progress in information technology forces societies to try to keep up with this rapidly changing domain. The academic staff have to familiarise themselves with new software and upgraded versions of existing software. Scholars at technology universities, in particular, are obliged to follow the changes, as it is up to them to know what is available on the market, and then select programs that best fit the educational profile of a given faculty and specialisation. In order to make the right decisions in choosing computer programs, academics need to be familiar with new software. The process is not only time-consuming, but it also entails financial costs including the purchase of the software, and then a series of training sessions to learn how to use it.

The expense continues as new versions of the software require purchases of updates followed by training. Negotiations with IT companies determine purchase terms and conditions for software programs and the methods of obtaining adequate certification for staff. What follows is the introduction of these new tools into education. A key datum is which software the students must become familiar with, and then how many hours of training are required.

A Polish pioneer in the field of algorithm-parametric design, Maria Helenowska-Peschke, points out the need to update academic syllabi:

> *Modern architecture schools enhanced their educational offer with advanced numerical design techniques based on computer script languages (knowing that without such competencies it is close to impossible for a design team to compete with contemporary vanguard teams) and are engaged in research projects regarding the new methodology. Hence on both sides of the Atlantic the last decade saw an ever growing group of parametric designers* [1] *for whom algorithm-parametric design became the dominant method of realising research projects, experimenting and discovering new possibilities of shaping architectural space* [2].

In this study, the authors share their experience in introducing the Rhinoceros - NURBS (non-uniform rational b-spline) modelling program enhanced with an algorithm-parametric addition: Grasshopper. Considered in this study was how students and teachers mastered the program, as well as activities undertaken by students to learn to design with this tool. Summarised in the conclusions are the results of many years' experience of working with the software.

THE ALGORITHMIC-PARAMETRIC APPROACH TO DESIGNING

The algorithmic-parametric approach to designing involves the use of algorithms in which appropriate parameters are determined in order to obtain a design result. The features that characterise this kind of architecture are *systematic, adaptive variation, continuous differentiation (rather than just wide variety), and dynamic, parametric figuration,*

interior design, and the world of products [3]. Another important advantage is the ability to optimise the design. It leads to a structure with an economical shape, with a minimal number of construction elements, well-planned lighting and acoustics.

Algorithmic-parametric methods are currently used by leading design offices around the world. These include: Arup Associates, Foster and Partners, Grimshaw Architects, Kohn Pedersen Fox, LAB Architecture Studio, Zaha Hadid Architects. Patrik Schumacher (director of Zaha Hadid Architects) opines that there exists a *new style* in architecture, which he calls *parametricism* [3]. It is characterised by the impact of digital methods on architectural solutions.

The use of algorithmic-parametric programs may lead to generative architecture. Its characteristic feature is that the designer participates only in establishing the rules and initial conditions, and the rest is performed by the program that generates the object itself. Architects usually use generative methods only to a limited extent. They control the process of creating an object at every stage. They make numerous modifications, eventually obtaining the most satisfying effect for the creator.

Helenowska-Peschke states:

> *Technical innovations in the way of recording the design idea and in production processes allows an unprecedented level of symbiosis between art and engineering, efficiency of structural solutions and material use and a significant shortening of the path and time of transition from concept to materialisation* [2].

THE GRASSHOPPER PROGRAM AND THE HISTORY OF PARAMETRIC DESIGN

Daniel Davis, both in his doctoral thesis [3] and in a history-oriented article [4] investigated the origin and development of the subjective approach. He defines its beginnings:

> *The time before Grasshopper, before Samuel Geisberg's Parametric Technology Corporation and Ivan Sutherland's Sketchpad, before the invention of the computer, and the birth of Gaudí* [5].

James Dana used the term *parameter* for the first time in 1837 [6]. In modern mathematics *parametric equations are a set of equations that express a set of quantities as explicit functions of a number of independent variables, known as parameters* [7].

In the computer age John Frazer says:

> *…the first documented computer programs were written by Ada Lovelace in 1843 for Charles Babbage's proposed analytical engine and were based on his algorithms* [8].

The first computer system for parametric design was Ivan Sutherland's Sketchpad.

> *He harnessed the computational power of the TX-2 computer to create Sketchpad, the first interactive computer-aided design program. Using a light pen, a designer could draw lines and arcs, which could then be related to one another with what Sutherland called atomic constraints. Sutherland never used the word parametric in his writing, but the atomic constraints have all the essential properties of a parametric equation* [5].

The term *parametric* in architecture was first used in the 1940s by Luigi Moretti. He defines parametric architecture as the study of architecture systems with the goal of *defining the relationships between the dimensions dependent upon the various parameters* [5]. In 1960 in the *Parametric Architecture* exhibition in Milan, Moretti presented several versions of the sports stadium designed in a parametric way. He explained in this example how the object's form can be derived by considering 19 parameters (e.g. angle of visibility, economics of the cost of a reinforced concrete structure). Another Moretti project – the Watergate Complex - was created in the years 1960-65, and is considered the first architectural implementation with significant computer use.

The first computer program for architects that achieved commercial success was AutoCAD (introduced to the market in 1982). With its use it was possible to draw using the keyboard, not a pen. In AutoCAD 2010 (2009), parametric functions were introduced, which were defined as a *ground-breaking new capability*. These are geometric bonds to which functions can be assigned. In addition, AutoCAD allows for text-based scripting in the AutoLISP programming language.

In 1985, Samuel Geisberg founded Parametric Technology Corporation, which in 1988 introduced the parametric program Pro/ENGINEER that achieved commercial success. Revit was another product from this company. According to the intention of the creators, it was to be the first parametric building modeller for architects and building design professionals. In this program, parametric functions are hidden under the interface.

The real revolution began with the emergence of visual scripting, where:

Architects got their first visual-scripting language when Robert Aish, then working for Bentley Systems, started secret beta testing of Generative Components with selected architecture firms in 2003. Robert McNeel & Associates, after trying unsuccessfully to licence Generative Components, assigned developer David Rutten to make their own version. Released in 2007 as Explicit History, Rutten later dubbed his visual scripting interface Grasshopper. Both Grasshopper and Generative Components are based around graphs (a mathematical name for a type of flowchart) that map the flow of relations from parameters, through user-defined functions, concluding normally with the generation of geometry. Change to parameters or the model's relationships causes the changes to propagate through the explicit functions to automatically redraw the geometry [5].

Parametric design programs operate on the basis of geometrical bonds or user-created algorithms. The assumption of Revit is bindings, while the Dynamo add-on (the equivalent of Grasshopper for Rhinoceros) enables creating algorithms and downloading parameters from Revit or assigning parameters independently. The potential of algorithmic and parametric approach in designing was also noticed by Graphisoft, who published Grasshopper-ArchiCAD Live Connection enabling direct connection of ArchiCAD with Grasshopper under Rhinoceros. SolidWorks now also has a module for the visual creation of algorithms.

RHINOCEROS AND GRASSHOPPER IN THE TEACHING OF ARCHITECTURE STUDENTS

The history of introducing Rhinoceros and Grasshopper to the education of architecture students at Cracow University of Technology is unusual. It starts with the architecture students of Cracow University of Technology staying at the University of Tennessee in Knoxville. After returning to Poland, the student scientific club IMAGO (a student circle in the Department of Descriptive Geometry and Digital Technologies whose supervisor is Dr inż. arch. Farid Nassery), initiated student workshops entitled *Informational infrastructures*. This was led by Prof. arch. Gregory Spaw from the University of Tennessee in Knoxville. The final result of the students' work was a spatial representation: *What does the river hear?* (Figure 1).

Figure 1: An artistic installation visualising different levels of sound intensity for two types of acoustic pollution in the Vistula riverbed in Cracow (2014) (photographs by Farid Nassery).

This was the visualisation of different levels of sound intensity for two types of acoustic pollution in the Vistula riverbed in Cracow. Workshops were preceded by a series of training programmes on computer software. One was Rhinoceros with Grasshopper - an algorithmic-parametric plugin. This was their first contact with this way of designing. It aroused so much interest that within one year a decision was made to include the software in the teaching. Regular training of all teaching staff and the purchase of a multi-station program licence began.

a)   b)
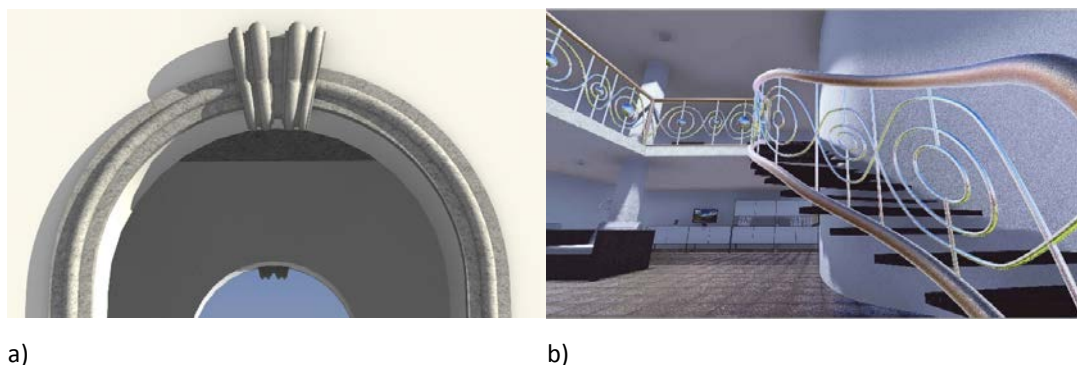
Figure 2: Students' work from the course TKwP (CTiD) and CAD1: a) courtyard with portal and hip roof (2016); b) stairs with a balustrade (2017).

In the 2015/2016 academic year, there were four hours in the second semester of the first-degree studies as part of the subject, Computer Techniques in Design (CTiD). At that time, the outline of the courtyard with the portal and hip roof was produced (Figure 2a). In the following year, Computer technology in design covered six academic hours and the work consisted of creating a parametric staircase with an individual balustrade pattern (Figure 2b). The team also conducted classes in Computer Techniques for students from the Erasmus exchange programme. As part of the course in the academic year 2017/2018, a parametrically engineered building with elevation was produced. A lamp and connectors were then 3D printed and combined into a spatial structure using standard drinking straws. A Cracow courtyard was also modelled with architectural details having parametric structures of roofing's, balustrades and spiral stairs.

In the 2016/2017 academic year students' mathematical skills were exercised. One of the topics covered from analytical geometry was that of flat curves. Using graphic programs, students constructed curves to make a 3D object, which was presented on a poster. For many years, AutoCAD was used (Figure 3a). But in the 2016/2017 academic year, algorithmic-parametric programs were used for the first time. Although the choice of the program was left to the students, almost all used Rhinoceros and Grasshopper (Figure 3b).
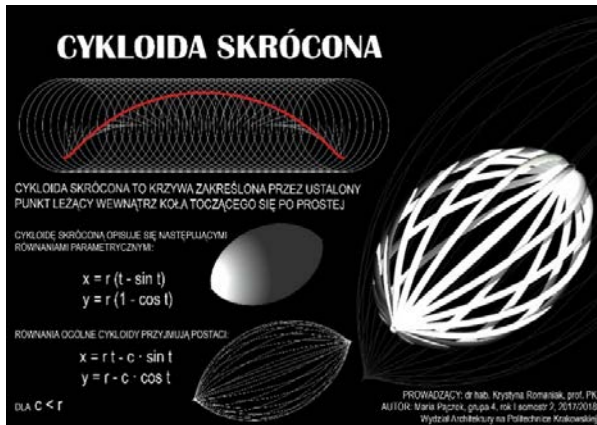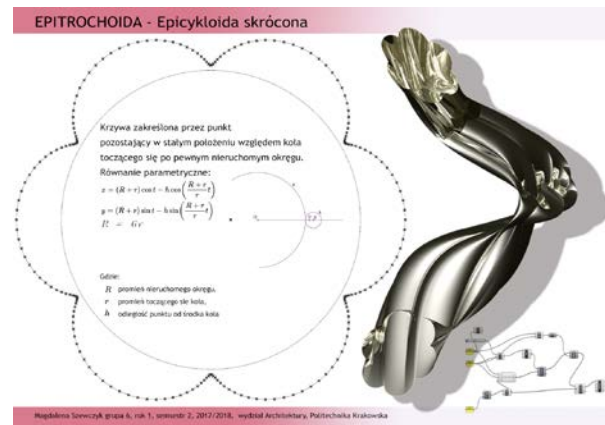
a)   b)

Figure 3: Student work carried out as part of the Mathematics course: a) cycloid constructed with AutoCAD; b) hypocycloid delineated using Rhinoceros + Grasshopper (2018).

A decision was also made to familiarise students in the last year of studies with this design tool. Four workshops were organised as part of the project, *Designed for Professional Success - Competences Commissioned for Architects* co-financed from the European Social Fund, contract number UDA-POWR.03.01.00-00-K258/15. The workshops took place in: Andrychów (20-25/10/2016); Tarnów (4-9/04/2017); Andrychów (6-11/11/2017), and Oświęcim (4-9/12/2017). The supervisor of the workshops was K. Romaniak, and the persons leading the workshops were S. Filipowski and M. Nessel from the Department of Descriptive Geometry and Digital Technologies. These were five-day away meetings, the main purpose of which was to improve the competence of graduates.

The workshops included graduating years 2016/2017 and 2017/2018. They were very popular with students who formed groups of more than 20 people. The subject of the workshop was *Algorithmic-parametric design using Rhinoceros 5 + Grasshopper software on selected design themes and locations*. After studying the project requirements, the students explored the two programs for a few days. The workshops were enriched by lectures conducted by representatives of business. Despite the short time, students mastered the programs (see Figure 4).

Figure 4: Posters presenting student work from the workshops (2018).

The workshop ended with the presentation of works to representatives of local government and business. The projects aroused great interest from local authorities.

Parametric-algorithmic design was highly popular among students of two scientific groups. One of the works, a parametric design of a pavilion, was made by students of the IMAGO scientific club. Using the Rhinoceros and Grasshopper programs, the spatial form of the object was defined. The structure information included in these programs was used to determine the trajectory of the manipulator effector movement that was used to create the actual pavilion model. Using the hot-wire tool, individual elements of the whole structure were cut from polystyrene. It consists of 132 elements connected together in the form of a 3D puzzle. The end result of the work was two models: one with dimensions 12 m long, 7 m wide and 3 m high (see Figure 5), and a simplified one made using 3D printing. Implementation of such a large project was possible thanks to the involvement of many people and institutions.

a)   b)

Figure 5 a) and b): Pavilion designed parametrically and made by the IMAGO scientific club: in the production hall with a robotic arm. (Photograph by P. Gibas); on the campus of Cracow University of Technology (photograph by M. Nessel) (2018).

Above all was the determination of students striving to achieve the intended goal. Due to the interdisciplinary character of the work, it is worth emphasising the involvement of employees of the Faculty of Mechanical Engineering, who provided premises and supported students in their struggle with the manipulator. Mention should also be made of numerous companies which, free of charge, as part of sponsorship, gave the students appropriate materials.

The algorithmic and parametric design is also the subject of the study and development of the Wyobraźnia (another scientific club at the Department of Descriptive Geometry and Digital Technologies, supervised by Dr inż. arch. B. Vogt and Inż. arch. S. Filipowski), that designed and optimised the urban planning for the *Project Earth 2 competition: Cities of Tomorrow* (2018) using Grasshopper.

The didactics for this topic include the basics of NURBS (non-uniform rational basis spline) modelling, basics of Grasshopper operation and visual scripting. There is also advanced data support allowing the simplification of the algorithm and increasing the design possibilities. The design trends using this new approach are also presented. Undoubtedly, the didactic advantage of the algorithmic parametric design is the need to set clear goals and then to synthetically achieve them using the algorithm. This teaches a proper approach to solving design and engineering problems.

The individuals teaching computer techniques specialised in CAD, BIM (building information modelling) and algorithmic-parametrics. Rhinoceros and Grasshopper have been used for both design and scientific research (some employees have architect's rights and use their skills and knowledge of programs in project work). Employees emphasise one fundamental value of this technique - the ability to test different concepts and to choose the solution best suited to the assumptions.

CONCLUSIONS

The choice of software by academic tutors significantly increases the sales of that software. Students who get to know software during their studies become potential customers after they finish their education. An architect usually upgrades to a commercial version of already familiar software. The introduction of ArchiCAD into the Faculty of Architecture of Cracow University of Technology is a good example. In 2004, ArchiCAD was selected after market research on what was available in graphic design software. The choice was supported by a highly attractive co-operation offer by the Graphisoft Company. This offer consisted of obtaining free licences for students and academic computer laboratories, as well as training and certification.

At that time, AutoCAD was the dominant software used by architects. ArchiCAD in the architects' industry was at that time little known. Currently, after many years of teaching, it has become a significant program used by architects in

southern Poland. Will Rhinoceros and Grasshopper be equally effective? In the opinion of students, every major architectural studio will be using this tool in the near future. Will this happen? Time will tell.

The direct conclusions resulting from the introduction of Rhinoceros and Grasshopper are as follows:

- First-year students are moderately interested in knowing the programs. Not many take part in scientific groups to study the matter in detail.

- The huge interest expressed by final-year students might be the result of the knowledge they have at the end of their education and the awareness of new trends in architecture, such as generative architecture. To fully participate in creating forms in compliance with that style, it is necessary to know how to use appropriate tools, i.e. the software. The students are also aware that the ability to use the software equips them with additional competencies, putting them in a better position when competing in the labour market.

- Activities of students' scientific societies follow modern trends in architecture, promoting interdisciplinary co-operation [9]. To design a parametric project and to complete a model of a real pavilion required the co-operation of robotics specialists. The project required co-operation with the Faculty of Mechanical Engineering. S. Krenich provided scientific guidance in the field of robotics. Students were assisted not only in terms of scientific support but a large laboratory site was also provided. There they could use a huge manipulator cutting out individual elements of the structure. The manipulator was courtesy of ASTOR.

- During the project some students acquired knowledge of programming languages. Those additional competencies resulted in their being employed in the IT industry. Therefore, the knowledge and skills they acquired significantly influenced their careers.

- The experience gained by academics using software in their research projects is consistent with opinions of architects worldwide who perceive it to be a highly useful design tool with greater design possibilities than other graphic programs. However, the architects as creators want to be able to modify and correct a structure at any stage of its creation. The final result should agree with the architect's original vision and not merely be an output of a computer algorithm.

- A big chance opens up for scholars: they are able to use software in their scientific research and projects. The first innovative publications have already emerged and many more will follow.

Considering the relatively short time of four years since the academic staff of the Faculty first became familiar with Rhinoceros and Grasshopper, an educational success has been achieved. Without doubt, these programs are invaluable in making students better architects, allowing them to follow the newest trend, which is generative architecture. Enhancing the education process and competencies with knowledge of algorithm-parametric programs is proving highly positive. It can only be recommended for other educational units to introduce IT tools into education, research projects and experimental activities.

At the end is a quote from Schumacher:

…computationally advanced design techniques like scripting (in Mel-script or Rhino-script) and parametric modelling (with tools like GC or DP) are becoming a pervasive reality. Today it is impossible to compete within the contemporary avant-garde scene without mastering these techniques [3].

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