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ASPECTS OF

# PARAMETRIC ARCHITECTURAL DESIGN

IN THE CONTEXT OF

# GRAPH THEORY

AND

# COORDINATE SYSTEM TRANSFORMATIONS

PHD THESIS BOOKLET

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2019

# Introduction

Parametric design is a design method which uses computers and algorithms to create three dimensional models. The advantage of parametric design is that it is very useful for optimization and form finding, because it is possible to get different versions of a model with changing the input parameters of the algorithm. It is possible to handle a lot of different spatial elements together, and with its mathematical and geometrical commands it is possible to create shapes and forms which would be very hard to handle with traditional architectural tools.

Its disadvantage is that the understanding of algorithms is necessary to be able to use it efficiently. If it is used in cases which cannot take its advantages, it is a more circumstantial and difficult solution.

# About the research

In this thesis work I examined parametric architecture and its applications on numerous ways. During this research I got an overall view about of this branch of architecture and I used this knowledge not only in further research but in design tasks and in education too. Because of this my research is widespread in the field of parametric architectural design.

I researched and classified the parametric design tools and I also assigned its connections to traditional architectural design. I created a plug-in for Grasshopper, the parametric software I primarily use, which contains coordinate system transformation tools partly based on another similar tool, Formex Algebra. I also added more tools based on the specifications of parametric design. With these tools I created numerous domes and tested their static behavior, and analyzed it compared to their graph characteristics.

I teach parametric design for architecture students for five years. During this time, I researched and experimented how to teach this subject on an interesting and comprehensive way.

I also included in this thesis work some designs I made with parametric tools, which are connected to my research. These works represent the advantages and applications of parametric design well.

# Problem statement, purpose, scope and research methods

The main focus of this research is parametric architecture. The aim is to understand the cognitive model [1, 2], the tools and the applications of parametric design, improve the theoretical concepts and add to the practical utilization.

Parametric design is a new, specific field of architecture. It is an interdisciplinary field, geometry, mathematics and programming are also fields of science which are necessary for parametric design. In this research all of these play a part.

The first intent of this research was to understand parametric design better. For this purpose, the parametric design techniques were analyzed and classified. To be able to do this it was necessary to understand the logic, the cognitive model of parametric design. How a shape or a pattern is created depends on the shape or the pattern itself. The different surfaces, even freeform surfaces are well researched in the field of geometry, so the main focus was the creation of the patterns. It was necessary to examine patterns on a more comprehensive way. For this the graph representation of patterns were used. Based on the graph representation of patterns they were classified as regular and irregular patterns, which is the base of the classification system.

The next step was to utilize the possibilities of parametric design and to develop a dome and vault creating tool for parametric design. The basic concept relies on Formex Algebra [3, 4]. This tool creates spherical, cylindrical or polar grids from rectangular or triangular grids with coordinate system transformation. A similar tool was created in a more user friendly environment, with a newly developed calculation method for easier application. The environment is Grasshopper [5], which is a graphical algorithm editor and compared to Formex Algebra it does not require programming skills from users.

The next goal was to create new, similar tools for other curved surfaces. A similar, but more freeform tool was created for rotational grids. Two different versions were developed. The first one is a modified version of the cylindrical tool, where the second direction is vertical, the thickness of the grid is horizontal. The second coordinate direction of the second tool is alongside the generating curve, and the thickness is always perpendicular to the curve.

The next aim was to determine if the "pattern" of a structure can affect its static behavior on a way which can be clearly determined by its graph characteristics. For this research a series of domes were created with the previously introduced dome tool. Single-layer truss-grid domes, single-layer domes with fix joints and double-layer truss-grid domes were created and analyzed. The graph characteristics of the domes were calculated. It showed that graph characteristics are correlated with the static behavior of truss-grid domes. The graph characteristics of single-layer truss-rid domes are in clear correlation with their graph characteristics. In the case of double layer truss-grid domes the correlation is not clear, some exceptions appear, but still can be used to improve the build-up of a designed dome structure.

The final goal of this research was to create a syllabus for architectural students with which they are able to acquire parametric design easily and effectively. To aim this goal, the earlier results were used especially from the first part of the research. The knowledge of the cognitive model of parametric design and the parametric design tools is the first step to define an efficient teaching method. The necessary knowledge has to be also defined and examined which part of this knowledge is already thought for architectural students and which has to be covered by this subject. With the consideration of all of these factors a syllabus was defined which makes possible to implement parametric design to the curriculum of architectural students.

# Thesis 1

## Classification System of Parametric Patterns

***I have created a theoretical based classification system for parametric patterns and structures.***

I have studied the existing groupings and classifications and created a clear, more comprehensive system. The former classifications were usually based on the execution of parametric design techniques. I have created a theoretical based classification system which gives a clear overview of parametric design techniques. This classification system can help architects and designers to understand and apply parametric design in a more efficient and concise way.

Related publications: (1), (2), (3), (4), (5), (6)

## Subthesis 1 about previous classifications

***I have researched and compared the existing classification systems and identified their imperfections.***

The problems were primarily based on the fact, that these works mostly concentrated on the practical solutions. Because of this they were not totally consequent and comprehensive.

Related publications: (1), (2), (3), (4), (5)

## Subthesis 2 about parametric workflow

***I have created a model to describe the workflow of parametric design.***

It was necessary to be able to create an adequate classification system. Thanks to this the classification system matches the parametric workflow.

Related publications: (3), (4), (5)

## Subthesis 3 about graph characteristics and regular and irregular patterns

***I have classified the patterns based on their graph representation. I have created an exact solution to differentiate regular and irregular patterns based on their graph characteristics, and I have extended this solution to spatial structures too.***

Related publications: (3), (4), (5)

# Thesis 2

## Formex Algebra Adaptation

***I have proved it is possible to implement Formex algebra into modern software. I have created a tool in Grasshopper based on the mathematical solutions used in Formex algebra. I have created a new calculation method which can transform grid structures given in Descartes Coordinate System into domes, vaults or polar structures using ellipsoidal, cylindrical or polar coordinates.***

Formex algebra is a very efficient tool to create dome and vault grid structures because it uses coordinate system transformation, at the same time it requires programming skills which is not very common among architects. In modern parametric software it can reach a wider user community.

I have implemented the coordinate system transformation method which can create dome structures from triangular grids. I have created a solution which is more user friendly than the original one. The user can define the properties of the structure with input parameters. They do not have to take a lot of mathematical calculations to reach the desired outcome like in Formex algebra.

Related publications: (6), (7), (8)

## Subthesis 1 about ellipsoidal coordinates

***I have improved the Formex algebra formulation by using ellipsoidal coordinates not spherical coordinates to create dome structure.***

It makes possible to create domes with different height and radius. This solution allows for a more versatile shape definition.

Related publications: (7), (8), (9)

## Subthesis 2 about modified structures

***I have created various modified grid structures based on the ellipsoidal dome structure. In these modified structures one or two angular coordinates are replaced with planar coordinates.***

Because of these structures are created based on ellipsoidal coordinates, these modified structures fit into the same system, their not modified edges can be connected with ellipsoidal structures, their modified edges can be connected with other modified structures. The vault and polar grid tool also contains this kind of modification.

Related publications: (7), (8), (9)

## Subthesis 3 about the Cupola tool

> ***I have created a new Formex algebra form that was not covered by the original approach. This is one of the modified dome structures, I named it 'Cupola' tool.***

Related publications: (7), (8), (9)

## Subthesis 4 about triangular grids

> ***I have implemented the triangular grid based solution into the polar grid and the vault tool, which was not covered by the original Formex Algebra.***

For this I have created a solution, which calculates the skew coordinates of a triangular grid structure. With a coordinate system transformation, the triangular grid is transformed to fit into a rectangle. This grid can be transformed with the same calculations to dome vault or polar grid structures just like a rectangular grid. With this solution I have created a universal solution to transform triangular grids just like rectangular grids.

Related publications: (7), (8), (9)

## Thesis 3

### Rotational Grid Tool

***I have created a new calculation method in Grasshopper which can transform any grids given in Descartes coordinate system to rotational grids. The rotational surface can be given with its generating curve.***

Related publications: (10), (11)

### Subthesis 1 about different mathematical calculations

***I have created two tools with different mathematical calculations. The calculation of the height and thickness of these structures are different.***

The first one deeply lies on the basis of the cylindrical coordinates, the second one follows the properties of the generating curve more. The two tools calculate the height and the thickness of the structures differently, they can be used for different purposes.

Related publications: (10), (11)

## Subthesis 2 about triangular grid version

***I have created a version of both tools which transforms triangular grids to rotational grids.***

Related publications: (10), (11)

# Thesis 4

## Graph Characteristics of Dome Structures

***I have proved that the statical behavior of single layer truss-grid domes can be predicted by the calculation of specific graph characteristics of the dome.***

I have proved that the application of fix joints, which can transfer both axial and shear forces, torsional and bending moments changes this behavior and the statical behavior of these dome structures is not clearly in correlation with their studied graph characteristics.

I have proved that studied graph characteristics cannot be used in the same form to predict the statical behavior of double layer truss-grid domes because the studied graph characteristics cannot represent the properties of spatial structures clearly.

Related publications: (12), (13)

# Thesis 5

## Teaching parametric design

> ***I have proved that the education of parametric design can be imported to the curriculum of architect students despite the fact that it requires special skills which are not common among architects.***

I have identified the skills which have to be improved for architectural students to be able to acquire parametric design and I have built in exercises to the curriculum which improve these skills.

I have proved that it is necessary to teach the cognitive model – Parametric Design Thinking – and the actual application of parametric software together to earn success with teaching parametric design for architecture students. I have implemented this method into the curriculum.

Related publications: (14), (15), (16), (17)

# Publications

(1) Paper in conference proceedings (in Hungarian)
Classification of Parametric Design Techniques Based on Architectural Point of View, in Hungarian, Réka Sárközi, IV. Conference Proceedings Interdiszciplináris Doktorandusz Konferencia 2015, pp. 449-464. ISBN:978-963-642-830-3

(2) Paper in conference proceedings
Classification of Parametric Design Techniques, Réka Sárközi, Péter Iványi, Attila Béla Széll, Proceedings of the Fifteenth International Conference on Civil, Structural and Environmental Engineering Computing, 2015, Paper 227, pp. 1-15. ISBN:978-1-905088-63-8

(3) Conference abstract
Classification of Parametric Design Techniques, Réka Sárközi, Péter Iványi, Attila Béla Széll, 11th Miklós Iványi International PhD&DLA Symposium, 2015, Conference abstract, pp. 106., ISBN:978-963-642-876-1

(4) Paper in conference proceedings
Classification of Parametric Design Techniques, Types of Surface Patterns, Réka Sárközi, Péter Iványi, Attila Béla Széll, CAADence 2016 International Workshop and Conference, Conference proceedings, pp. 253-258., DOI: 10.3311/CAADence.1661

(5) Paper in scientific journal

Classification of Parametric Design Techniques, Types of Surface Patterns, Réka Sárközi, Péter Iványi, Attila Béla Széll, Pollack Periodica: An International Journal for Engineering and Information Sciences 12(2) pp. 173-180. (2017)

(6) Paper in conference proceedings

Historical Preludes of Parametric Design Techniques, Réka Sárközi, Péter Iványi, Attila Béla Széll, Places and Technologies 2019: The 6. th International Academic Conference on Places and Technologies, pp. 524-528.

(7) Conference abstract

Formex Algebra Adaptation into Parametric Design Tools, Réka Sárközi, Péter Iványi, Attila Béla Széll, 13th Miklós Iványi International PhD&DLA Symposium, 2017, Conference abstract, pp. 114., ISBN:978-963-642-780-1

(8) Paper in conference proceedings

Formex Algebra Adaptation into Parametric Design Tools: Dome Structures, Réka Sárközi, Péter Iványi, Attila Béla Széll, Conference Proceedings, Innsbruck Austria Jan 25-26, 2018, 20 (1) Part XV, pp. 1693-1697.

(9) Paper in scientific journal

Formex Algebra Adaptation into Parametric Design Tools: Dome Structures, Réka Sárközi, Péter Iványi, Attila Béla Széll, World Academy of Science, Engineering and Technology International Journal of Architectural and

Environmental Engineering Vol:12, No:1, 2018, pp. 62-66
DAI: urn: dai:10.1999/1307-6892/10008543

(10) Conference abstract

Parametric Vault Design Tools Based on Formex Algebra, Réka Sárközi, Péter Iványi, Attila Béla Széll, Tenth International Conference on Engineering Computational Technology, 2018, Conference abstract

(11) Paper accepted by scientific journal

Formex Algebra Adaptation into Parametric Design Tools and Rotational Grids, Réka Sárközi, Péter Iványi, Attila Béla Széll, Pollack Periodica: An International Journal for Engineering and Information Sciences

(12) Paper in conference proceedings

Correlation Between the Static Behaviour of Dome Structures and their Graph Characteristics, Réka Sárközi, Péter Iványi, Attila Béla Széll, Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering, 18th Conference on Applied Mathematics APLIMAT 2019 Proceedings, pp. 1035-1040.

(13) Conference abstract

Graph Characteristics of Dome Structures, Réka Sárközi, Péter Iványi, Attila Béla Széll, Conference Proceedings V. INTERNATIONAL ARCHITECTURAL DESIGN CONFERENCE ARCHDESIGN '19, 2019

(14) Conference abstract

Case study: Using parametric tools in architectural practice, Réka Sárközi, Péter Iványi, Attila Béla Széll, 12th

Miklós Iványi International PhD&DLA Symposium, 2016, Conference abstract, pp. 105., ISBN:978-963-429-094-0

(15) Conference abstract

Vasarely Inspired Pavilions - How Architecture Students Can Use Op-art, Attila Béla Széll, Réka Sárközi, 12th Miklós Iványi International PhD&DLA Symposium, 2016, Conference abstract, pp. 114., ISBN:978-963-429-094-0

(16) Paper in conference proceedings

Methods of Teaching Parametric Design for Architectural Students, Réka Sárközi, Péter Iványi, Attila Béla Széll, Conference Proceedings V. INTERNATIONAL ARCHITECTURAL DESIGN CONFERENCE ARCHDESIGN '18, pp. 25-29. (2018)

(17) Lecture Notes

Parametric Design: Graphical Algorithm Editing for Architects in Grasshopper® in Hungarian, Réka Sárközi, 2019, ISBN: 978-963-429-387-3

# Main sources


[1] Oxman R, *"Thinking difference: Theories and models of parametric design thinking."* In Design Studies 52, 2017, pp. 4-39.

[2] Bhooshan, S. "*Parametric design thinking: A case-study of practice-embedded architectural research."* In Design Studies 52, 2017, pp. 115-143.

[3] Nooshin H., Disney P. L. *"Formex configuration processing I."* In International Journal of Space Structures, Vol. 15, No 1, 2000, pp. 1–52.

[4] Nooshin H., Disney P. L. *"Formex configuration processing II."* In International Journal of Space Structures, Vol. 16, No 1, 2001, pp. 1–56.

[5] *Grasshopper – algorithmic modelling for Rhino*. https://www.grasshopper3d.com/ (last visited 5 May 2019).