PARAMETRIC PATTERNS IN ARCHITECTURE – EXPERIENCES, CHALLENGES AND OPPORTUNITIES

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Abstract: As well as in art, patterns are used in architecture as elements of language presenting certain rules. In this paper the term pattern is used to describe regularity in shape. That considers repetition of visual units ordered by some rules.
In architecture pattern interpretation as algorithmic variability of the parameters provides more advantages than mere visual appearance. The main benefit of parametric design is that the material and structural properties and fabrication tools can be considered during the design process. In this paper the challenges and opportunities of parametric patterns in architecture are discussed. Applications based on authors' experience and different approaches to interference of algorithmic interpretation of visual properties with structural and fabrication properties are shown.
Keywords: Parametric design, Architecture, Digital fabrication, Complexity

INTRODUCTION

Pattern means repetition, and as a visual approach it uses echoing the single element to construct a sense of rhythm, balance, contrast or movement. Patterns are used by artists as a technique of composition, often as the structure that organizes the parts of a composition. As well as in art, patterns are used in architecture as elements of language presenting certain rules. In architecture there is wide variety of meaning attributed with the term 'pattern'. In this paper the term pattern is used to describe regularity in shape in which the repetition of visual units is ordered by some rules. In architecture patterns vary from simple translational or rotational symmetry to complex ordered patterns that have large information content, which is organized and coherent[1].

1 N. Salingaros. "Architecture, Patterns, and Mathematics", *Nexus Network Journal* 1(Torino), 1999, 75–85

Fig. 1

Patterns by their logic, organization rules and application are firmly linked to technology. Mutual mathematical background as underlying structure in patterns and technology organizes surfaces or structures in a consistent, regular manner. Advanced tools allow integration of the technology into the design process in a contrast with basic tools which are only used after the design process. Such technological advance shifts the paradigm of the design process towards the human-machine symbiosis which has certain advantages[2]. Advanced tools allow high complexity to be incorporated in the design process, making the base for the expansion of pattern design in architecture in a new way.

One of the ways of generating patterns with the support of the technology is use of a parametric design tools. Basic parametric tools became available in the last few decades in software used by architects, and more recently the tools used for parametric design are much improved and offer the possibilities to create more complex relationships between the parameters. In this paper, the challenges and opportunities of parametric design tools used for pattern generation in architecture are analyzed. The aim of the paper is to explain and present the possibilities and constraints of parametric tools applied to architectural pattern design.

PARAMETRIC PATTERNS IN ARCHITECTURE

Parametric design is based on algorithmic thinking and definition of rules, rather than definition of the design result. By selecting the parameters and setting the rules, designer creates the design intent which indirectly leads to the design result. In that way it is possible to examine the whole range of possible solutions and variability of the design. The process eliminates repetitive tasks and minimizes the effort needed to create and test design variants. With less energy put into manual work, more space is open for a creative work. The simplification of the manual tasks in design process can also serve as a base for achieving more complexity in the design[3]. In parametric environment the complexity of the patterns can be

2 A. Youngs, "Embracing Interdependencies: Machines, Humans and Non-humans" in: *Robots and Art. Cognitive Science and Technology*, eds. D. Herath, C. Kroos, Stelarc, Singapore 2016, 89–111.

3 I. Dino. "Creative Design Exploration by Parametric Generative Systems in Architecture", *METU Journal of Faculty of Architecture* 29, no 1 (Ankara), 2012, 207–224.

Fig. 2

achieved in two main design aspects: a) definition of the shape and appearance of the pattern units and b) taking into account external influences such as material, structural properties and fabrication tools[4].

By introducing parametric tools into the design process, complex variations of shape and appearance of pattern units are possible and easily controllable by the designer. The complexity is applicable to two dimensional as well as to three dimensional shapes or any attribute of the pattern unit such as color, tone, texture, etc. Complex patterns (man-made or observed form nature) can be generated by transferring the simple rules which define the pattern[5]. Simulation of random distribution, irregularities and organic structures can be introduced as variable and controllable parameters directly into the design process. Such variety of parameters and relationship rules changes the way of thinking about and applying patterns in architecture. The application can be seen in many recent designs such as Zahra Hadid's designs or Marc Fornes' pavilions.

In architecture, variability of the parameters provides more advantages than mere visual appearance[6, 7, 8]. The main benefit of parametric design is that the material and structural properties as well as the advantages and limitations of fabrication tools can be considered during the design process. There are many examples where complexity in architectural design is achieved by applying structural and material simulations in parametric environment. In recent applied researches such simulations are used to determine and/or improve repetitive pattern and its variability in order to achieve best structural performance. In the case of Armadilo pavilion in Venice biennale by Block research group very thin complex shell structure is made out of irregular cubical stone blocks without the use of glue

4 C. Poli, *Design for Manufacturing*, Woburn, 2001.

5 B. Holland, "Computational Organicism: Examining Evolutionary Design Strategies in Architecture", *Nexus Network Journal* 12, no. 3 (New York), 2010, 485–495.

6 D. J. Gerber, E.S. Lin, "Designing in complexity: Simulation, integration, and multidisciplinary design optimization for architecture", *Simulation* 90, no. 8, (Newbury Park), 2014, 1–24.

7 F. Moussavi, "Parametric software is no substitute for parametric thinking", *The Architectural Review*, (London), 2011.

8 M. Meredith, "Never enough." In: *From control to design: Parametric/algorithmic architecture*, ed. T. Sakamoto, A. Ferre. Barcelona 2008.

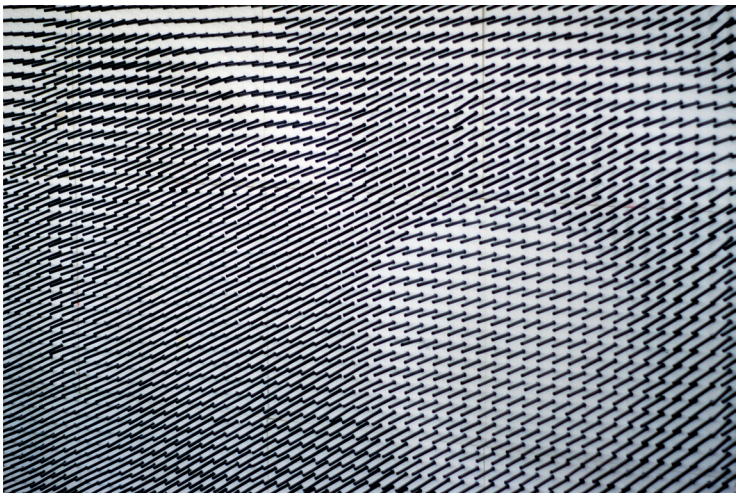

Fig. 3

or ties. Lace wall by Cita, is large highly complex stiff structure made completely out of materials with low stiffness by repetitive variation of a single unit.

Models made in parametric environment can also be easily adjusted to the properties of latest digital fabrication tools, such as CNC machines, industrial robot arm or the 3D printers. High precision of such tools makes complex patterns possible in architectural practice. Tools can be used to make complex shapes which can be arranged into the irregular pattern as it is designed in 3D printed facade reconstruction for Munich's Deutsches Museum or to achieve higher complexity of patterns made by simple elements such as bricks patterns in designs of Gramazio and Kohler who use industrial robot for brick lying.

APPLICATION OF PARAMETRIC DESIGN

Previously described approaches of parametric design used to include structural properties and/or characteristics of the fabrication tools are applied by the authors of the paper and will be shortly presented in this chapter. In each of the presented designs algorithm which interference desired visual characteristics with structural and/or fabrication properties is made. Flexispot pavilion (Figure 1) is made in 2017 and it represents a structure which has a high stiffness although it is made out the materials of low stiffness. In that way the properties of the material are the main driver for the design and the appearance. Algorithm for complex simulations performance is used in order to shape the structure in a way that is aesthetically pleasing as well as to achieve the expected structural behavior[9] .

Igloo pavilion (Figure 2) is made in 2016 out of the styrofoam blocks cut into the more than two hundred different conical hexagonal pieces that fit the shell structure. The design of the pieces is guided by the algorithm relaying on the tessellation principles and the constraints of the industrial robots used for hot wire cutting of pieces[10].

9 M. Vučić, B. Tepavčević, V. Stojaković, M. Jovanović, D. Mitov and I. Bajšanski, "Topology design of form-active gridshell structures." in: *eCAADe RIS 2018 – Sustainable Computational Workflows.* ed. O. Kontovourkis, Nicosia, 2018, 109–110.

10 M. Jovanovic, M. Vučić, D. Mitov, B. Tepavčević, V. Stojaković, and I. Bajšanski. "Case Specific Robotic Fabrication of Foam Shell Structures." in: *eCAADe.* Eds. A. Fioravanti et. al., Rome, 2017, 135–142.

Fig. 4

Fabrixel (Figure 3) is 3D wall art installation made in 2016. The visual interpretation of the raster image is made with the black sticks put in front of the white background where the inclination of the stick resembles the tonal value of the pixel. Industrial robot is used for hole drilling for the stick. The algorithm used considered the desired overall visual appearance as well as the amount of the used material and the properties of the robot as a tool for fabrication[11].

The tessellated shell pavilion (Figure 4) is made in 2016 as a 1:5 scale model. In this design the tessellation combines triangular and hexagonal pattern applied to the complex shape. It is partly perforated and the size of the perforation varies gradually. The structure is made to be self-supported which adds to the lighter and thinner shell. The algorithm used to design this structure considers the shape optimization, friction—fit approach to assembly as well as visual properties of the tessellation and perforation[12].

The Barabarka bench (Figure 5) is made in 2016 and although it has complex shape it is made out of planar material. The algorithm made for this bench considers shape, two colored design and optimization of the material used. The material comes in panels of a certain size, so the sections of the bench are cut with puzzle like seams to optimize the total amount of material consumed[13].

DISCUSSION AND CONCLUSION

When the designer is more familiar with parametric design tools, it becamos more likely to create wider variety of designs, use more optimization and advanced fabrication tools. The opportunity of thinking

11 M. Jovanović, J. Tasevski, B. Tepavčević, M. Raković, D. Mitov, and B. Borovac. "Fabrication of Digital Anamorphic Sculptures with Industrial Robot." in: *25. IEEE International Conference on Robotics in Aple-Adria-Danube Region RAAD.* Eds. A. Rodić, T. Borangiu, Belgrade, 2016, 568–576.

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13 D. Mitov, "Cost-efficiant Approaches in Fabrication of Street Furniture Based on Sectioning Design Strategies" in: *4th eCADDe IR Workshop Between Computational Models and Performative Capacities.* Ed. B. Tepavčević, V. Stojaković, Novi Sad, 2016. 87–92.

Fig. 5

about the concept and design patterns via rules and relationships between different aspects of architectural designs makes new designs possible. For many designers main challenge in application of parametric design are the limitations of software tools and requirement for scripting knowledge. However, with the recent development of the parametric environment adjusted for designers and large variety of extensions which can be incorporated in the design process, the limitations can be overcome. When embedding is involved there are no limits on creativity using rules[14] and the capacity of digital, computational architectures to generate new designs is still highly dependent on the designer's abilities[15].

ILLUSTRATIONS

1: Flexispot pavilion, 2017, Digital Design Center (photo: Digital Design Center)
Флексиспот павиљон, 2017, Центар за дигитални дизајн (фото: Центар за дигитални дизајн)
2: Igloo pavilion, 2016, Digital Design Center (photo: Digital Design Center)
Игло павиљон, 2016, Центар за дигитални дизајн (фото: Центар за дигитални дизајн)
3. Fabrixel, 2016, Digital Design Center (photo: Digital Design Center)
Фабриксел, 2016, Центар за дигитални дизајн (фото: Центар за дигитални дизајн)
4: The tessellated shell pavilion, Digital Design Center, 2016 (photo: Stefan Ivkovic)
Изломљени павиљон у облику шкољке, Центар за дигитални дизајн, 2016. (фото: Стефан Ивковић)
5: The Barabarka bench, 2016, Digital Design Center (photo: Digital Design Center)
Клупа Барабарка, 2016. Центар за дигитални дизајн (фото: Центар за дигитални дизајн)

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ПАРАМЕТАРСКИ ПАТЕРНИ У АРХИТЕКТУРИ – ИСКУСТВА, ИЗАЗОВИ И МОГУЋНОСТИ

Резиме: Као и у уметности, патерни се у архитектури користе као елементи који представљају одређена правила. У овом раду појам патерн се користи за описивање правилности облика, односно представља понављање визуелних јединица одређено неким правилима.
У архитектуре интерпретација патерна кроз алгоритамску варијабилност параметара пружа више предности него анализа визуелног изгледа. Главна предност параметарског дизајна је у томе што се током процеса дизајнирања могу узети у обзир особине материјала и конструкције и алата за израду.
У овом раду разматрају се изазови и могућности параметарских патерна у архитектури. Приказана је примена базирана на искуству аутора и различитим приступима повезваљу алгоритамске интерпретације визуелних својстава са структурним својствима и фабрикацијом.
Кључне речи: параметарски дизајн, архитектура, дигитална производња, сложеност