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An Experimental Study On Generation Process Of Geometric Patterns (Paper)

Topic: (Architecture, Design, Geometry)

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Main References:
[1] George Stiny *“Shape: talking about seeing and doing”,* The MIT Press, 2006
[2] Mark Garcia, *“Prologue for a History, Theory and Future of Patterns of Architecture and Spatial Design”,* Archit. Design-79 ,2009
[3] Birgul Colakoglu& Tugrul Yazar& Serkan Uysal “*Educational Experiment on Generative Tool Development in Architecture, PatGen: Islamic Star Pattern Generator”* eCAADe 2008
www.generativeart.com

Abstract:
Artists and designers use geometric patterns to cover surfaces since ancient times. In the 13th century the architectural works show artists have a broad knowledge of creating geometric patterns. Mathematicians conduct researches and achieve creation principles of these patterns barely in the 20th century. In this context, the principles of patterns can be known by its designer but cannot be distinguished easily with a deductive approach. Geometric shapes that are typically repeating in order form a geometric pattern. Patterns are seen as an integrated composition of geometric shapes. Nowadays, computer-based programs help to create various patterns fast and efficiently. Mathematical operations are defined to make transformations on shapes. Executing simple transformations like moving, copying, mirroring and rotating on an initial shape creates 2D geometric patterns.
The first objective of this study is to search the generation process of geometric patterns and find out which parameters are used to create these patterns. This study aims not only to create shapes or geometric pattern alternatives but also to teach generation principles of geometric patterns to design students experimentally by a generative code. In the scope of this study, 2D geometric patterns are studied which are analyzed by a deductive approach.
According to analysis, the following parameters are used in generation process;
Specification of initial shape / Position of initial shapes / Distance between repeated shapes / Number of the repetition of x and y-axis / Determination of the angle transformations
By changing these parameters experimentally in coding interface, the transformation of patterns and variety in pattern geometry are examined. Before changing parameters, the main structure of code modified three times. At the first coding, hexagon shape is created by using simple lines. By copying hexagon ten times on “x” and “y” axis and moving one shape (hexagon) many different patterns are created. Besides, sub shapes are emerged in the pattern, which are not hexagons anymore. At the second coding, changing the edge number of initial shape is transformed hexagon into a pentagon. The angles between pentagons edges are modified, and pentagons become stars with different angles. These star geometries also rotate on the axis to generate different geometric patterns. During the third modification of code, hexagons edge number is set as a variable. Changing the edge number creates a pattern that includes lines, triangles, square, pentagon, hexagon and polygons with more edges than six.
As a result of modified parameters like sizes, positions, edge numbers and angles many unpredictable patterns emerge. This study shows the efficiency of coding on pattern generation. Emerged shapes can be used again as an initial shape, and new patterns can be generated with a high variety.

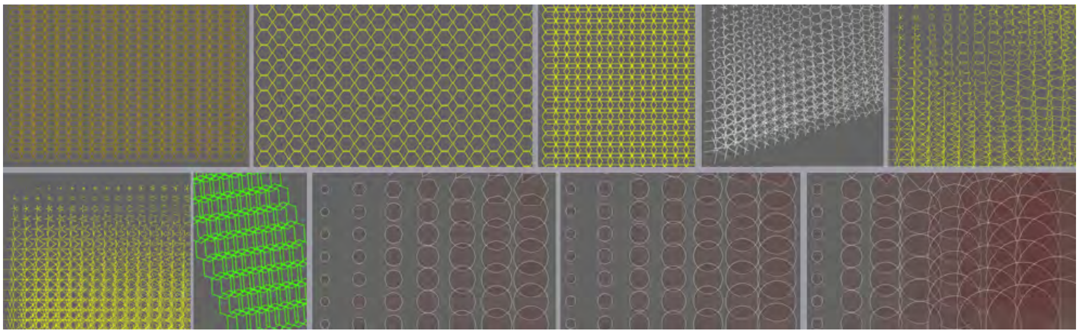

Figure: Geometric pattern alternatives generated with Processing code

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Keywords: Geometric pattern, parametric design, shape, sub shape, coding.

3. An Experimental Study on Generation Process of Geometric Patterns

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Abstract

At first, the importance of emergence on pattern generation process is emphasized. The concept of emergence is also encouraged by studies of Gross and Stiny. The studies of Gross and Stiny shows that different pattern generation approaches cause emergence in particular levels. To analyze varying emergence levels, three pattern generation approaches are investigated. These approaches are classified under the title of set-based, parametric and shape-based. Then, a generative code is developed to construct patterns experimentally. Various patterns are obtained by using set-based and parametric approaches. Because of the difficulty of implementation on computer and sophisticated philosophical background, a pattern is not generated with a shape-based approach. Pattern generated by set-based and parametric methods are criticized in comparison with shape-based approach. While criticizing, it is focused on the type of emergence and use of emergent shapes in design process. As a consequence, this study is experienced not only to create geometric pattern alternatives but also to discuss the creativity levels of pattern generation approaches.

1. Introduction

The aim of this study is not only to create geometric pattern alternatives but also to discuss the creativity levels of pattern generation approaches through emerging shapes in patterns. As a scope, two dimensional periodic and aperiodic geometric patterns are considered. Before generating patterns experimentally, three different pattern generation approaches are explained upon previous studies in the design field. Investigated studies enable to analyze the generation process of geometric patterns and find out which parameters are used to create patterns. A generative code is developed based on analyzed studies. The generative code is run six times with minor modifications on parameters and codes structure. Experimentally generated patterns show the differences between used techniques and give an idea about how shapes emerge in pattern design process.

2. Geometric Patterns In Design Field

The pattern as a contemporary concept means sequence, structure, a series of a repeating unit. In the spatial pattern theory; order, scale, proportion, symmetry, balance, complexity, unity, function, nature and creativity are the related concepts. The variety of relevant concepts emphasise the role of pattern in the design process [1].

Geometric patterns inspired designers and artists since ancient times. Many designer, artist and craftsman from Ancient Rome and Ancient Greece struggle on design and built patterns. Mathematicians conduct researches and achieve design principles of patterns barely in the 20th century. Researchers establish that artist from the 13th century has a broad knowledge of design principles of patterns. In this context, the principles of patterns can be known by its designer but cannot be distinguished easily with a deductive approach [1,2,3,4].

Today, mathematical and computational tools help designers to discover the generation principles of geometric patterns which are only known by its designer. Modern techniques and original methods can differ in generation process. Creating various species of known patterns can be thought as an achievement for these modern techniques [5].

In this study geometric patterns are considered as compositions constructed by shapes. Specified shapes constructing the patterns can be points, lines, planes or more complex elements. A geometric pattern is formed by geometric shapes which are typically repeating in a given order. During this repetations new shapes or subshapes can emerge. Gross [6] also mention that computer based designs can support perception ability of human.

Stiny [7] emphasise the importance of emergence when calculating with shapes. According to Gross [6] there are 3 types of emergence for shape representation.

- Emergence from intersecting shapes: two or more shapes intersect to create new subshape.
- Emergence from alternative configurations: different configurations with same shapes.
- Emergence from figure-ground reversal: a new shape is formed by the edges of other drawn shapes.

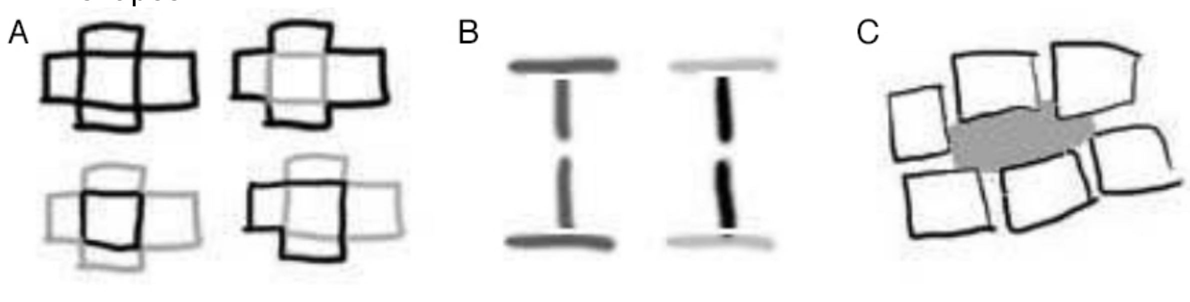

Image 1. Three types of visual emergence: (A) intersecting shapes (B) alternative configurations (C) figure-ground reversal [6]

Both Stiny and Gross [6,7] criticize computer implementations for recognizing closed shapes and specified geometries. However, the parts that are composing the shape cannot be listed because there are always alternative ways to see the shapes.

3. Geometric Pattern Generation Approaches

There are various approaches to generate geometric patterns. In this study, these approaches are classified as set-based construction, parametric construction and shape-based construction. This study make a comparison between these 3 approaches in the context of emerging shapes. First, previous studies are examined to make this comparison. Then, the evaluation will be done through developed generative code.

3.1 Set Based Construction

Set based construction approach grounded on predefined vocabulary elements. A vocabulary is a limited set of shapes and designs can be created with Euclidian transformations on given shapes [8]. In set-based construction approach, geometric patterns are created by combining a finite set of shapes. Distinct shapes can be recognized easily in the composed pattern by human eye. To be more precise about set based approach, 3 pattern generation studies are investigated.

The tile work "Zillij" is an explicit example for set based pattern design. Jowers et al. [9] work with tiles called "Furmah" to compose 2D geometric patterns. In their study, 15 furmah is obtained from original analyzed patterns. In pattern generation process, furmah tiles are modified under Euclidean tranformations, and three patterns are generated by a set based construction approach. Overlapping furmah is forbidden in Zillij works, so it is not possible to state that there is an emergence from the intersection of shapes. The only type of emergence in the Zillij works originate from figure ground reversal [9]. Eventually, the emerging shapes from figure ground reversal are still the member of the set. It can be said that there is no novelty on shapes or subshapes emerged.

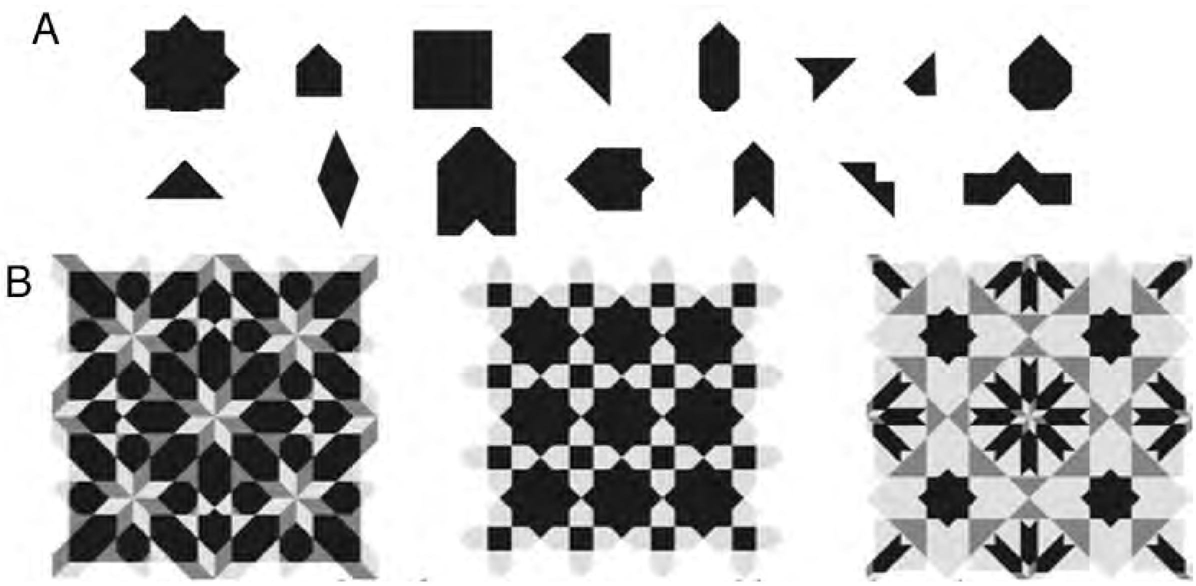

Image 2. (A) Set of Furmah (B) Generated Pattern Furmah Set [9]

Roger Penrose make researchs on aperiodic patterns. Penrose succeed on covering the surface aperiodicly with tile sets which include 6 tiles. Next, Penrose discover 2 other tile sets which use only 2 tiles to cover the surface. Thus, Penrose proved the producibility of aperiodic patterns mathematically. Later, Arık and Sancak developed a new tile set based on Penrose tiles which also include 2 tiles to cover the surface. [10,11]. Even these produced patterns are aperiodic and complex, patterns include only the shapes within a predefined set of shapes.

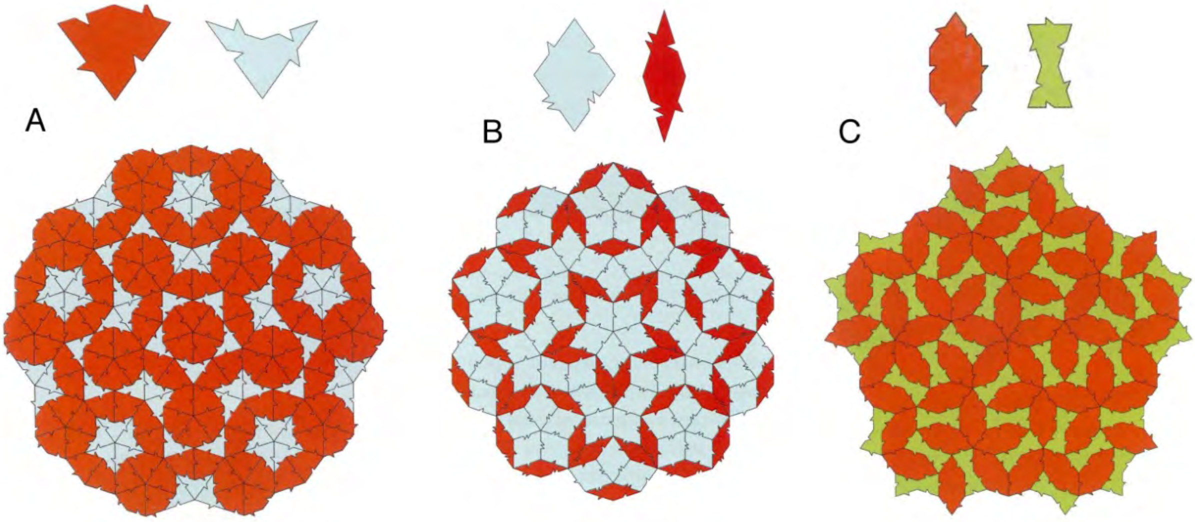

Image 3. (A & B) Penrose Pattern [10] (C) Bow and Tie [11]

Another method called Girih Tiles are used to create aperiodic geometric patterns. The set of Girih Tiles includes decagon, pentagon, hexagon, bowtie and rhombus shapes. Lu and Steinhardt [12] suggest that Girih Tiles enables to create complex aperiodic patterns from the 15th century.

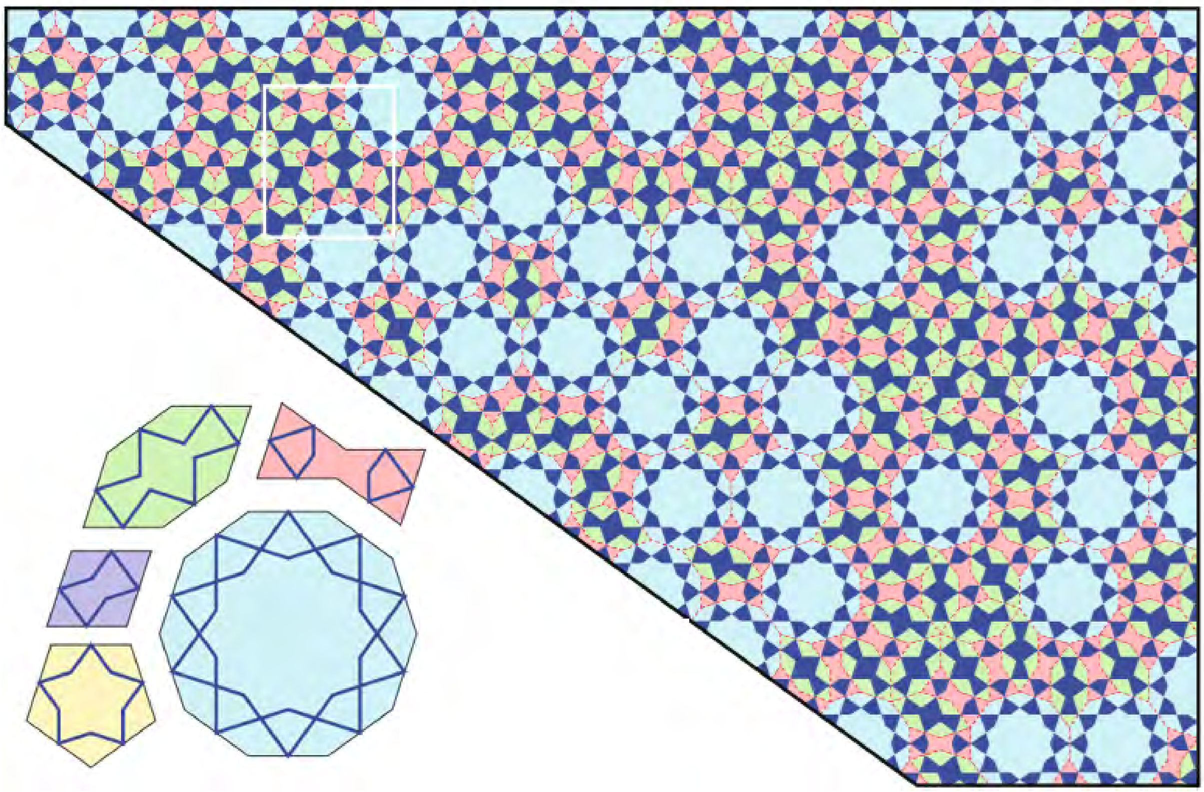

Image 4. Girih Tiles and Reproduced Facade Darb-ı Imam Shrine [12]

Penrose Tilings and Girih Tiles are both covering surfaces without leaving any gap between tiles. The tiles also do not intersect or combine. Even if the patterns are aperiodic and complex, the parts of sets which composing the pattern can be easily seen.

As stated before, points, lines and planes are basic elements that create geometric shapes. Furthermore, shapes may include many subshapes. As it can be seen from investigated examples, set based approaches do not rely on shape-subshape relations. Set based approach uses a set of predefined elements to create patterns.

3.2 Parameter Based Construction

Parametric design term indicates the use of parameters to define a design. Mathematical meaning of parameter refers to a range of values. Parametric design is based on the relationship between shapes controlled by variables [13,14,15].

According to Dino, parametric modelling approaches provide an opportunity for generating alternative design solutions. Changing parameters induce to real-time changes in the shape. With these features, parametric systems focus on manipulation of the parameter values for the purpose of change the design. The parametric design techniques help to make dynamic modelling and modifications. Parametric operations require certain values to make these modifications. Using certain values for generation is limiting to explore wider design possibilities [16,17].

A parametric model can be defined to a computer by using a programming language. Today, many computer aided design applications are developed to provide parametric functions [15].

Parametric models are also used for creating geometric patterns. Before structuring the parametric model, the underlying mathematical principles of geometric patterns can be analyzed with a deductive approach. With defining these principles to the computer, geometric pattern alternatives can be constructed. The following two studies analyze the generation processes of geometric patterns. Both studies discover different parameters and produce design alternatives.

In Bökü's [18] study, the mathematical creation principles of patterns are associated with shape grammar method, which used in the architectural field. The language of Anatolian Seljuk Geometric Patterns are analysed with shape grammar method. Later, the usability of shape grammars is discussed as a pattern generation method. With analysis of existing patterns grammar rules are derived. By using same shape grammar rules and making parametric changes various patterns are produced. Image 7 shows the effect of modified initial shape on the whole pattern.

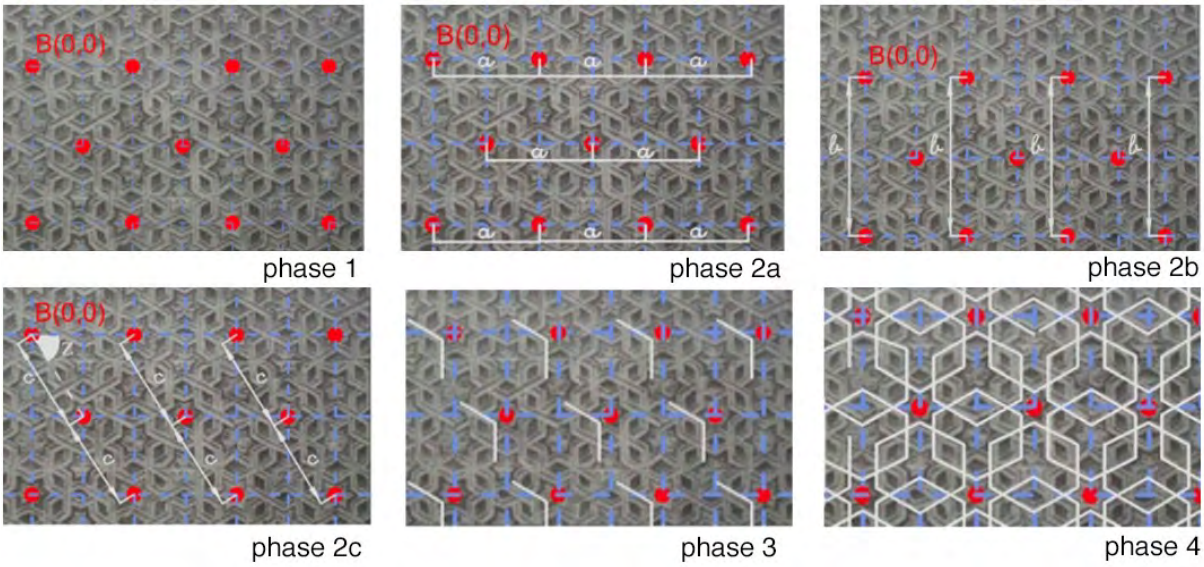

Image 5.Phases of Pattern Creation Process [18]

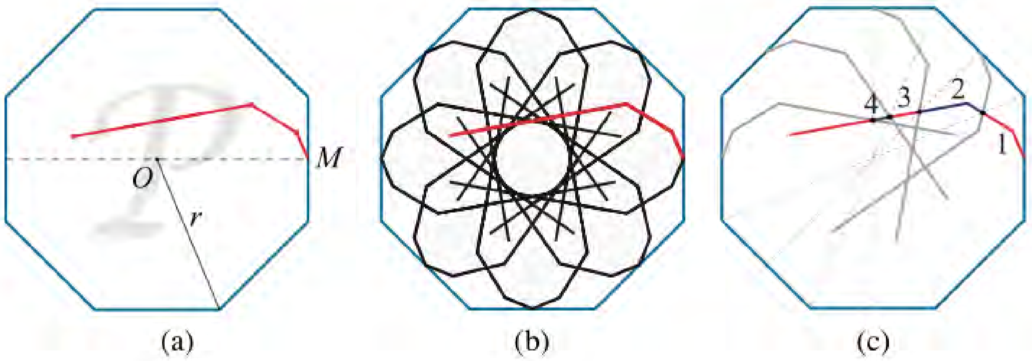

Image 6. Rotating Initial Shape Line on a center point “O” [5]

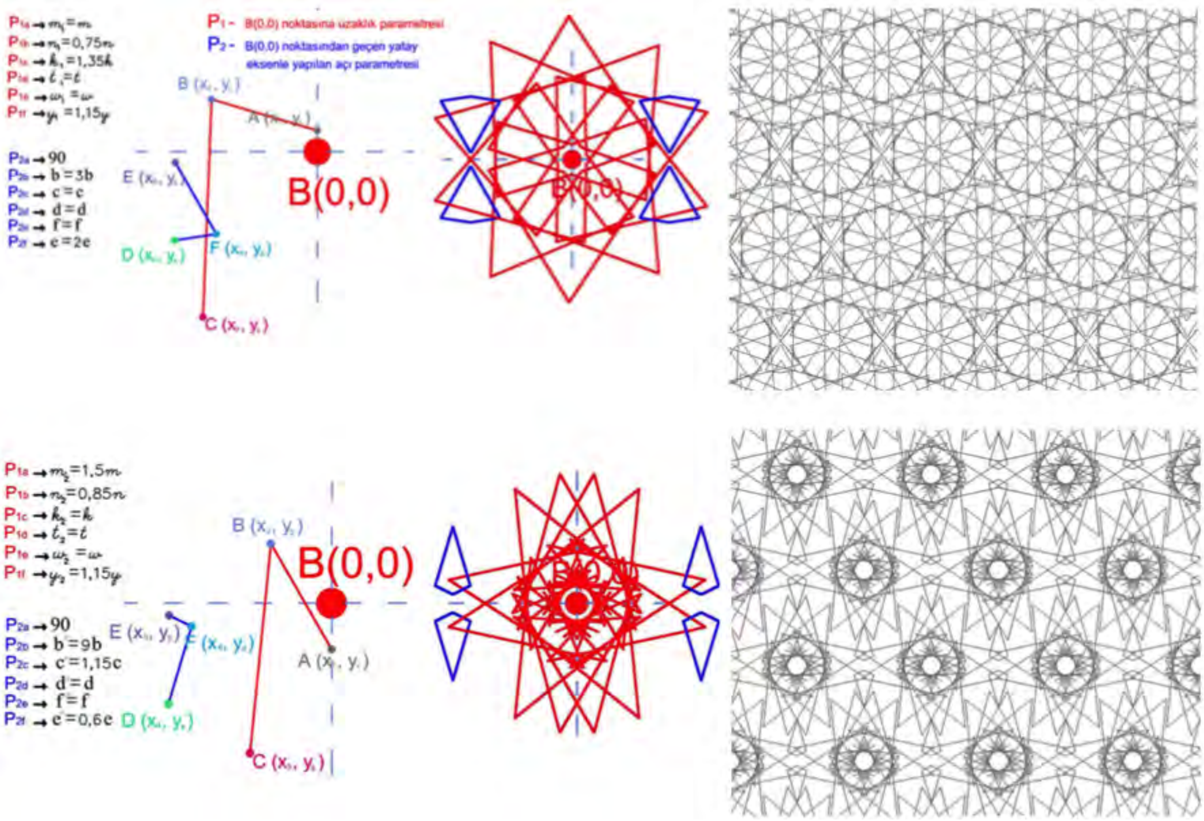

Image 7. Pattern Alternatives using the same shape grammar rules on a modified initial shape [18]

As Çolakoğlu et al. [19] stated, designers can choose how to structure the pattern parametrically. Changing the parametric structure of the same pattern can create different variations of the original pattern. The created patterns show the unpredictable results of parametric changes.

The parameters used in Pat-Gen can be listed as; the number of modules on x and y-axis; module size, the radius of the inner star, radius of infection, the angle of infection, line with and line depth. The parameters are derived from the analysis of original rosette geometries [19].

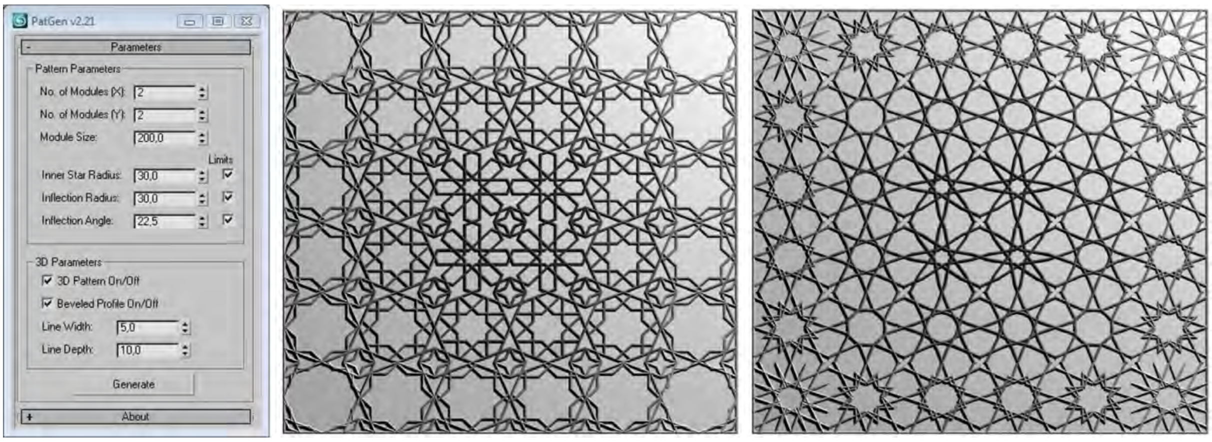

Image 8. Parameter control panel and created patterns by Pat-Gen [19]

The readily visible emerged shapes are observed from intersecting shapes. The other important point is the continuously changing shapes, which construct the patterns.

3.3 Shape Based Construction

Shape based construction approach is mainly trying to explicate the philosophy on visual calculating with a shape more than their mathematical or geometric features.

In the design process, designers make calculations intentionally or unintentionally. To understand the relation between “calculation” and “design” designers should become distant from the term calculation in a classical sense. Classical calculation deals with discrete elements called symbols, which are building up the vocabulary of design. However, shapes are not like symbols. With visual calculation, every seen shape can join design process. The interaction between shape, eye and brain helps the creativity [7].

According to Stiny [7], with the help of ambiguity, seeing shapes in different ways and making visual calculations is a vast source of creativity.

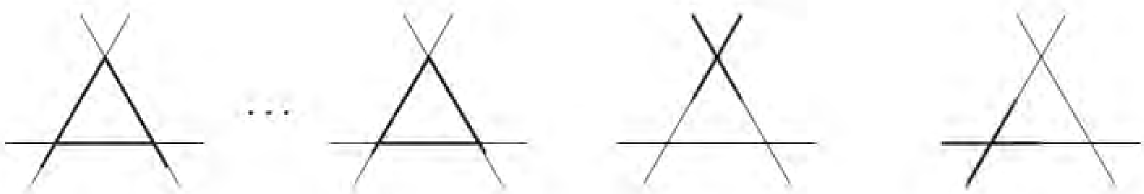

Image 9. Seeing different embedded subshapes [7]

The image 9 shows that the parts that are composing the shape cannot be listed as certain. Because of rules applying to embedding parts, there are alternative ways to see for the designer. Rule application on parts of shapes can generate new shapes that are not predefined. The recognized subparts produced by “seeing” activity. If the shapes are discussed as a class member, achieving emergent shapes become impossible [7,20].

The visual calculation on shapes is not based on a vocabulary. The examined works in this study is mostly focused on rules and predefined shapes. Set-based and parametric approaches contradict with Stiny’s ambiguity concept.

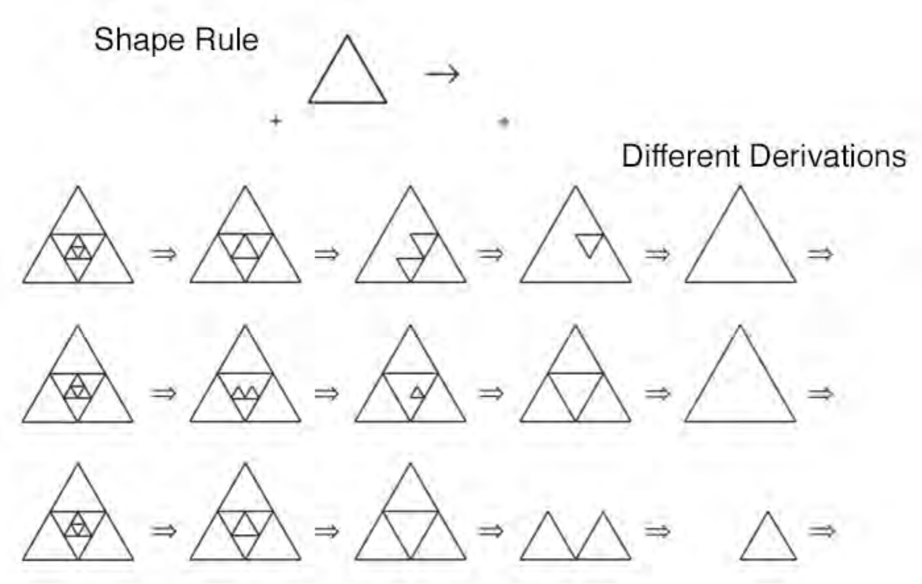

Image 10.Different derivations with same shape rule application [7]

Not like symbols shapes change freely in the creative process. People can think differently from each other or seeing different things. Calculating with shapes does not mean combining the predefined parts. Keep away from calculating is not possible when there are recognized parts to use. Subshapes appear when rules are applied to calculate with shapes [7].

For all these reasons, calculating with shapes and parts of shapes is a challenging problem for computer applications. Many shape grammar interpreters has limits for emergent subshape recognition

Keles et al. [21] emphasise these limitations and intent to discuss shapes within the part and whole relations. As Stiny stated [7], shapes may include many parts, and visual calculations continue while working with these shapes. In this context, it can be said that shapes have a continuous nature. Modelling this continuity in a computer based shape grammar interpreter is a fundamental problem. The parametric shape recognition techniques are useful for well-defined engineering problems [21].

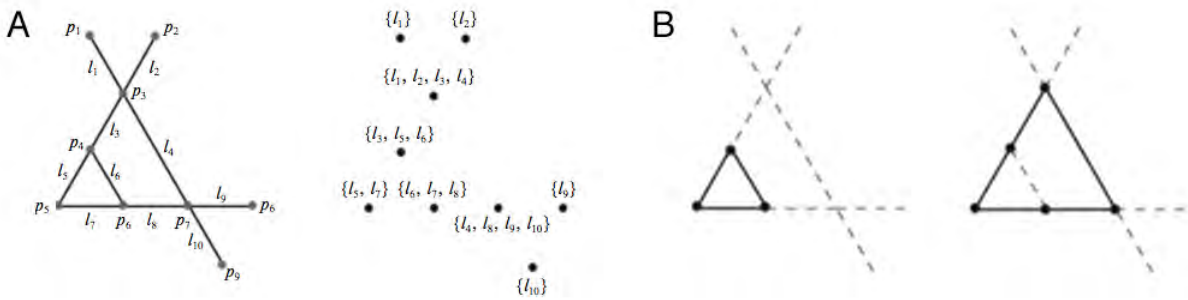

Image 11. (A)Critical point for shape representation (B) Recognizing subshapes [21]

Keles et al. in their studies developed a special recognition system based on critical points in shapes. These critical points help the computer to recognize part relations on different algebras. In the study, a new data structure called “over complete graph” is developed. This data structure does not rely on maximal elements. No limiting the shapes with maximal elements helps the computer to recognize more subshapes. An algorithm performs the searching process for parts. Presented new technique show how part whole relation support shape recognition for the computer [21].

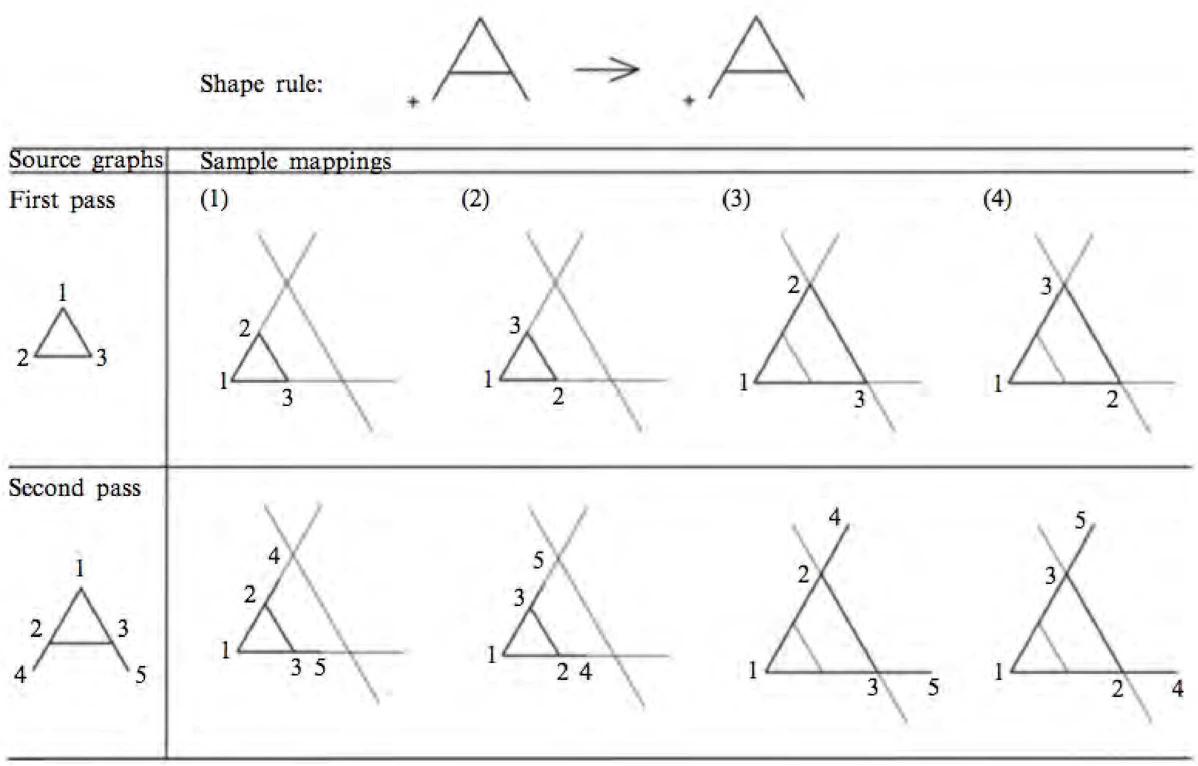

Image 12. Recognizing embedded subshapes within a rule [21]

As it is seen from the earlier shape computation studies, effort is spent on philosophy of shape calculation and technical issues. Since, shape based approach is sophisticated subject to discuss, it is not indented to model a limited implementation in the computer. In this study shape based approach is placed on a different side to criticise set based and parametric approaches.

4. Experimental Study

To make an experimental study about pattern generation process, a code is prepared associated with all parameters derived from former studies. All patterns are generated by modifying the same code structure also the parameters in a successive process.

4.1 Parameters In The Pattern Generation Process

According to analysis of previous studies on pattern generation, the following parameters are integrated into generation process;

- **Specification of initial shape:** The initial shape is the most characteristic element in the generation process of geometric pattern. Based on analyzed patterns, modifying only the initial shape without changing any other parameters occur major changes on patterns.
- **The position of initial shapes:** Position of the initial shape is defining the point where the pattern will begin to grow. Starting position may overlap with the center of the shape or a predefined label point.
- **The distance between repeated shapes:** Distance between repeated shapes is defining the frequency of repetition horizontally, vertically or angularly.

- **The number of the repetition**: Number of repeated shapes on x and y-axis. The number of repetition also determine the size of the pattern.
- **Specification of the angle for Euclidean transformations:** Operations like offset, copy, array are performed with a defined angle.
- **Angle and length of initial shapes:** The initial shape line constructs the shapes also the patterns. Defining the length and angle of initial shape are necessary for constructing regular polygons.
- **Edge number:** Polygons constructed by initial shape may have different edge numbers.

4.2 Modifying the Generative Code

By changing listed parameters experimentally in coding interface, the transformation of and variety of patterns are examined. Before every run of code, parameters are changed. The main structure of code modified once before the sixth run.

At the first run of code, hexagon shape is created by using initial shape line. By copying hexagon 15 times on x and 8 times on y axis with equal distances, geometric pattern is created. Hexagons are filled with light grey. Rhombuses as an emergent shape become visible from the relation between hexagon and its background.

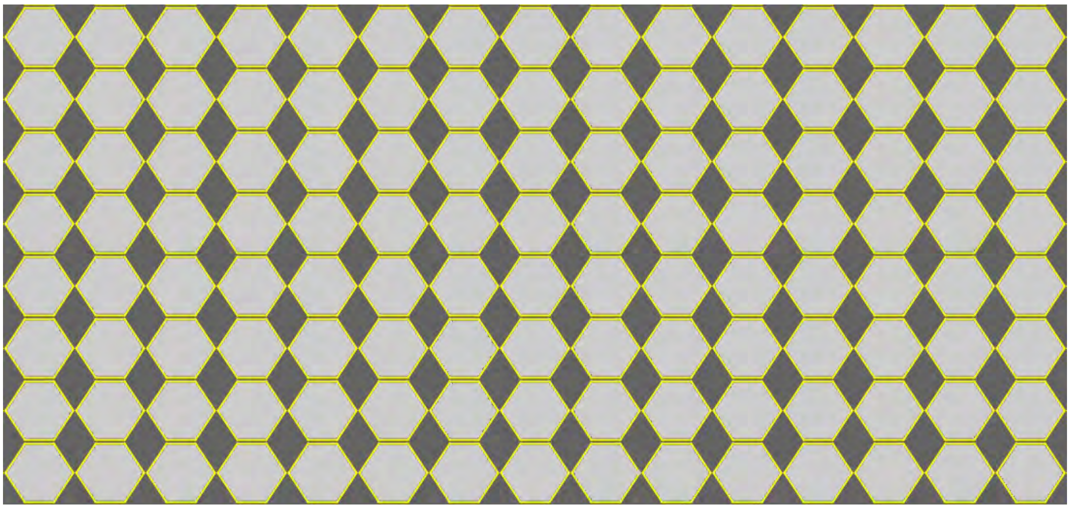

Image 13.Periodic pattern constructed with only hexagon shapes

At second run, the distance between repeating shapes (hexagon) is changed, and various patterns are created. Although, hexagon is the only element that composing the pattern, sub shapes have emerged from overlapping parts in the pattern which are not hexagons anymore. Even there are some other shapes that emerge from intersection of hexagons. These emerging shapes are not recognized or used in the design process. The created patterns do not respond to the idea of using emerging subshapes in design process.

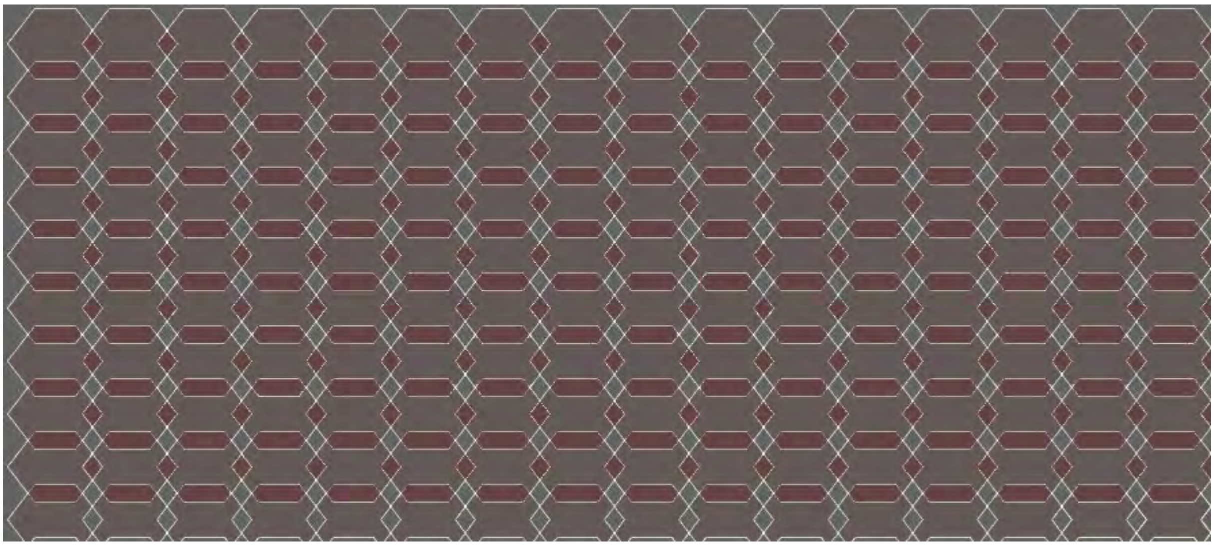

Image 14. Periodic pattern constructed with intersecting hexagon shapes

At third run of code; the angle of transformation is changed depending on mouse coordinates. Rotating hexagons also intersect at different angles and a variety of subshapes are emerged.

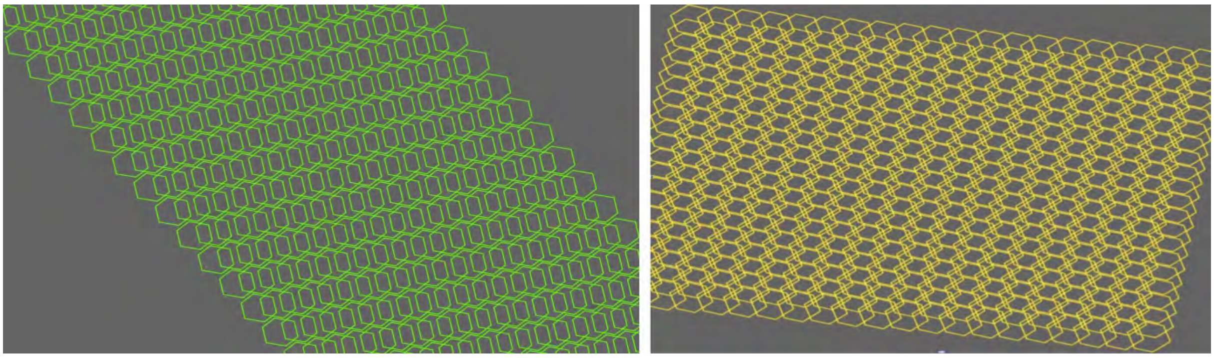

Image 15. Pattern constructed with rotated hexagon shapes

At fourth run, the length and the position of lines that compose the hexagon shape are modified. For this reason, initial shape line does not construct a proper hexagon or any predefined shape. The repetition of this not defined shape creates different patterns within the same structure of other patterns. Unexpected subshapes emerged from intersection of these distorted shapes.

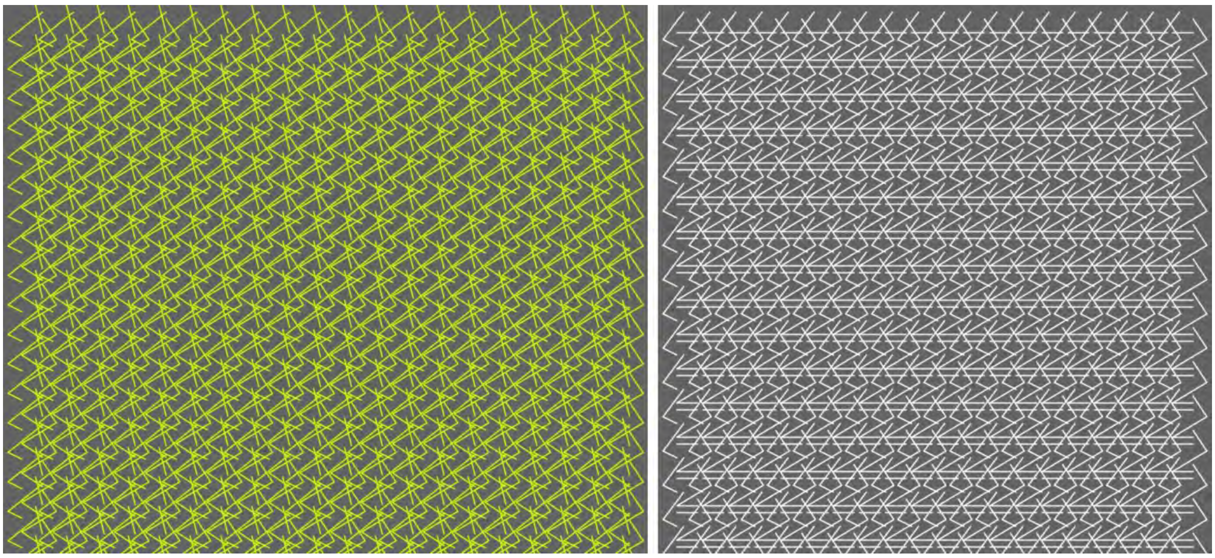

Image 16. Pattern produced from distorted initial shape within same structure

Before the fifth run, changing the edge number of initial shape is transformed hexagon into a pentagon. The angles between pentagons edges are modified, and pentagons become stars with different angles. These star geometries also rotate on the axis to generate different geometric patterns. A large number of stars is composing the pattern. Still, it is possible to say that the number of stars is finite.

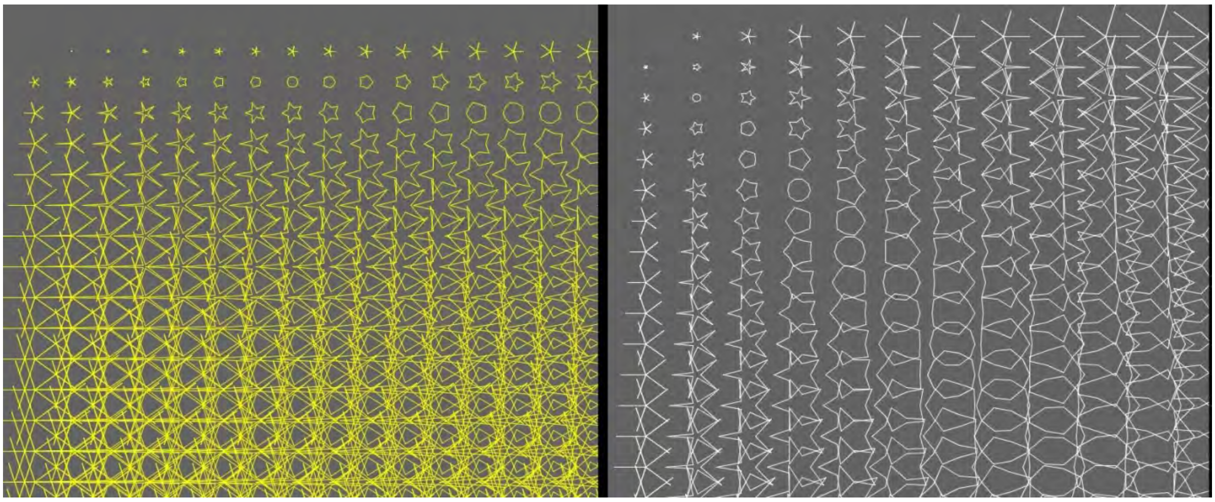

Image 17. Pattern produced with star geometries

At the sixth run of code, structure of code is modified with setting edge number as a variable. Changing the edge number creates a pattern that includes lines, triangles, square, pentagon, hexagon and polygons with more edges than six. A single initial shape is constructing all shapes that are composing the whole pattern. In these patterns, subshapes have emerged from intersection of shapes and gaps between shapes.

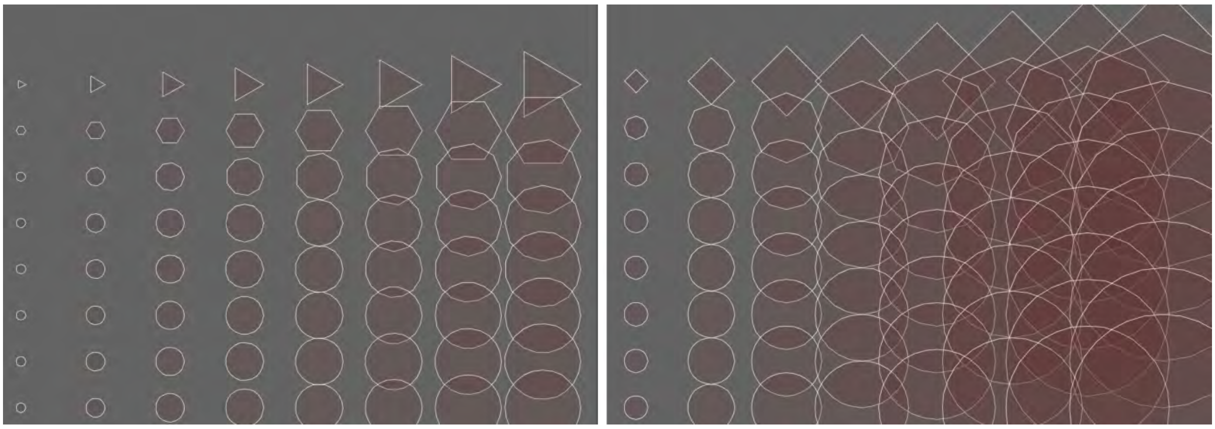

Image 18. Pattern produced with various polygons

5. Conclusion and Discussion

In this study, a generative code is developed and modified by six steps. The same code is used for every generated pattern to provide a common ground to analyses of created patterns. Experimented pattern generation process contains no rules but a sequence of operations. These operations are applied to a given initial shape. The operations of every step of generation process can be modified independently. For creating new patterns codes structure and parameters are changed in every step. Pattern generation techniques can be discussed through the generated patterns.

Parametric tools consist of generative components to produce design alternatives. It has experimented that a parametric model can produce set based design. Patterns generated by set based approach can be seen as a complex structure. On the other hand, these patterns are composed of certain elements which are not supporting the idea of emergence. Parametric design approaches create numerous alternatives and defend the opinion that used generative components are expanding the limits of designs. At this point, Stiny [22] mentions that since the essence of the initial shape that construct the pattern is not changed, the outcomes of parametrically created patterns are not novel designs. The investigated studies about parametric approach are also modifying the initial shape to extend the pattern alternatives. Still the parametric approaches do not recognize or use emerging shapes in the design process.

Shape-based design is based on activities see and do where ambiguity is the key concept. Stiny point out parametric design approach is unable to perform seeing activity. Shapes emerge when they seen by the designer. Designers can look geometric patterns and see many shapes in various ways. With these features shapes are continuous by their nature, people see and make visual calculations.

With these ideas, designers can look pattern production processes with a critical point of view. Computer implementations about pattern generation need to focus on issues about recognizing and using emergent shapes in the design process. Thus, designs can become more sophisticated, customized and far from being alternatives of existing design.

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