

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**LEARNING DESIGN THINKING THROUGH PATTERN GENERATION: A
COMPUTATIONAL FRAMEWORK**

M.Sc. THESIS

Ezgi BAŞTUĞ

Department of Informatics

Architectural Design Computing Programme

SEPTEMBER 2015

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Thesis Advisor: Assoc. Prof. Dr. Mine ÖZKAR

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

**DESEN ÜRETİMİ ÜZERİNDEN TASARIM DÜŞÜNCESİNİ ÖĞRENME:
HESAPLAMALI BİR ÇERÇEVE**

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To my family,

FOREWORD

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ABBREVIATIONS

CAD	: Computer Aided Design
PGS	: Pattern Generation Stage
RRA	: Recall-Retrieve Ability
SSS	: Seeing Shapes Stage
VSA	: Visual Reasoning Ability

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LEARNING DESIGN THINKING THROUGH PATTERN GENERATION: A COMPUTATIONAL FRAMEWORK

SUMMARY

Technology, culture and cross-disciplinary innovations continually reshape design medium, knowledge, models and methodologies. In parallel, the focus of learning how to design has been shifting to learning designers' reasoning procedures that embody perception, imagery and intuition. Pivoting on visual thinking as a fundamental design skill, this thesis illustrates a computational framework to pedagogically support visual reasoning and the ability to recall and retrieve.

The proposed framework functions as a tool to transfer design knowledge in an exemplary construction of a two dimensional geometric pattern. The first exploration is to understand how a pattern construction, in the traditional compass-ruler method of the craftsmen, can be repeated. It primarily involves a deconstructive analysis to see familiar shapes, repetitions, symmetric arrangements and hierarchies of shapes. The designer-investigator intuitively creates the rules along with what is seen while seeing allows for new ways of thinking to emerge and ways of thinking filter what to see. The motivation behind this method of analysis is to find out any underlying operations to learn and the explication of what is essential (which abilities are required) for this transfer. Although explicit representations of tacit design knowledge may not be possible, the aim is to identify which visual thinking skills a designer should hold, learn or improve. The scope of the study is limited to the intersection of skills cited in the design thinking literature and skills that are found to be required in geometric pattern generation. In separate stages of the pattern generation process, divergent abilities such as shape perception, mental imagery, rule synthesis, and drawing, are activated in the designer's mind. Most of these abilities are dependent on each other. Yet, certain abilities are more evident in specific stages. In particular, in polygon generation stage, drawing is the main ability required for representation. However, imagery and perception help transform shapes, see emergent shapes and make the decision for the next move.

The external representation of the exemplar design space contains algorithms for generating a pattern. The exploration in the thesis uses visual rules, part of the shape grammar formalism, for representing this design space, and the related analysis and synthesis. These representations also contain implicit knowledge about mental processes of a designer such as seeing, decision making, synthesizing, imagery and creativity. Without the perspective of visual reasoning, the rule-based system is barely limited to generating design products. With visual reasoning in focus, the thesis identifies the reasoning mechanisms and the complementary skills transferrable for learning or improvement.

DESEN ÜRETİMİ ÜZERİNDEN TASARIM DÜŞÜNCESİNİ ÖĞRENME: HESAPLAMALI BİR ÇERÇEVE

ÖZET

Teknoloji, kültür ve diğer disiplinlerdeki gelişmeler, tasarım ortamını, bilgisini ve araçlarını şekillendirmektedir. Bilgisayar destekli tasarım araçları ve dijital tasarım ortamları yalnız üretimlerin kalitesini artırmaz, aynı zamanda tasarımcının düşünme şeklini de etkilemektedir. Bu değişimler paralel olarak öğrenimde tasarımcının düşünme yöntemlerine odaklanarak tasarım eğitimi de şekillendirecek metodolojilerin geliştirilmesine teşvik etmektedir. Tasarım öğreniminde bir tasarımcının nasıl öğrendiğini anlamak ve açıklamak için, tasarımcının algı, tasvir ve sezgiyi de içerisinde barındıran akıl yürütme süreçleri irdelenmiştir. Bu çalışma kapsamında, bir tasarımcının esas becerisi olarak görsel düşünmeyi merkez alarak pedagojik olarak görsel akıl yürütme, hatırlama ve çıkarım yapma becerilerini destekleyen hesaplamalı bir öğrenme çerçevesi sunulmuştur.

Öğrenme çerçevesi, tasarım bilgisinin aktarılmasını sağlayan bir araç olarak kullanılır. Bunu da iki boyutlu bir geometrik desen örnekleminin üretim sürecinden elde edilen çıkarımların analitik kullanımıyla elde eder. Örneklemdaki geometrik desenler, Anadolu Selçuklu desenlerinin Amasya ve Tokat'taki örneklerinden seçilmiştir. Literatürde geometrik ve görsel altyapıları incelenmiş olan desenlerin nasıl üretildiğine dair çalışmalar bulunmaktadır. Ancak bunlar genellikle aynı deseni ya da geometrik parametrelerini değiştirerek aynı örtük kuralları barındıran desenin çeşitlemelerini sunmanın ötesine geçmemiştir. Bu çalışma kapsamında, seçilen desenler, öncelikli olarak yazarın kendisi tarafından sistematik bir şekilde çözümlenmiş ve protokol çalışması olarak tüm süreç kaydedilmiştir. Bu sürecin kaydı hem görsel çizimlerle her tasarım adımını gösterecek şekilde hem de sözel olarak her hareketin yapılışındaki amaç ya da niyeti anlatmak üzere yapılmıştır. Buradaki amaç, sürecin sadece tasarımcının görselleştirmeleri üzerine değil, daha çok bu görselleştirmeleri neden ve nasıl yaptığı üzerine yani akıl yürütme mekanizmaları üzerine yoğunlaşmaktır. Çünkü sadece tasarım görselleri üzerine yapılan retrospektif çalışmalar, bu süreç içerisinde öğrenilen tasarım bilgisini aktarmakta yetersiz kalmıştır.

Çözümleme sürecinde tasarımcı, pergel ve cetvel yönteminin mantığını kullanarak geleneksel Selçuklu zanaatkarının desen üretim şeklini tekrarlamaya çalışır. Çünkü, bu yöntem içerisinde, desenlerin üretimi için gerekli düşünme yöntemlerini barındırarak yeni şekillerin belirmesine ya da görülmesine olanak tanıyarak yaratıcı üretim sürecini destekler. Çalışma için tasarımcıya desenin fotoğrafı ve iki boyutlu bir dijital çizim ortamı sunulur. Bu yöntemle göre desen, dairelerde oluşan bir altlıktaki kesişim noktaları, çizilecek şekillerin köşe noktalarını oluşturur. Yöntemin bilinciyle araştırmacı, desende oluşturulacak tekrarlayan şekilleri, hiyerarşilerini ve bu şekillerin dizilimini gerçekleştiren simetrisi algılamaya çalışarak başlar. Algıladığı şekillere göre aklında canlandığı imajları çizime dökerek ilerler. Akıl

yürütmesinin sonucu olarak verdiği her karar yani çizdiği her şekil bu desenin oluşmasını sağlayan biçim kurallarını oluşturur. Zihninde ürettiği görsel düşünceler bir sonraki adımı etkilerken, çizim olarak görselleştirdikleri zihinde yeni düşüncelerin oluşmasını sağlamaktadır. Bu bağlamda, bu çözümlerin bir yaparak öğrenme olması, öğrenme sürecinin temelini algı, zihinde tasvir gibi görsel düşünme, hafıza ve çağrışım yapma gibi becerilerin oluşturduğu görülmektedir.

Çözümleme süreci ve üretilen her bir şekil biçim grameri formasyonunda kaydedilerek, her bir desenin tasarım uzamı oluşturulmuştur. Biçim gramerleri, eğitimde tasarım keşifleri için bir analiz-sentez yöntemi olarak kullanılmakta olup, bu çalışma kapsamında çözümleme sürecini sistematikleştirmede yardımcı olmuştur. Bu da süreç ve tasarım uzamının kıyaslanarak, asıl odaklanması gereken konuların vurgulanmasını sağlamıştır. Oluşturulan biçim kurallarının tek başına, bu desenleri üretmek için yeterli olup olmadığı, yeterli değilse aslında öğrenme için ne gibi mekanizmalara ihtiyaç duyduğu sürecin incelenmesinden daha analitik bir şekilde analiz edilmiştir. Kuralların bir araya getirilebilmesi desenin üretilebilmesi için de yukarıda bahsedilmiş olan becerilere gerek olduğu görülmüş ve süreçte hangi aşamalarda hangi becerilerin kullanılması ve geliştirilmesi gerektiğine dair çıkarımlar yapılmıştır.

Çalışma kapsamında sadece bu desenlerin üretimi sırasında ihtiyaç olduğu düşünülen becerilere odaklanılmıştır. Desen üretim aşamaları ayrı ayrı incelenmiş, her bir aşamada belirli becerilerin daha baskın olduğu ancak hepsinin birbirini tetiklediği görülmüştür. Bu becerileri ölçmek ve aslında bu süreçte öğrenilen bilginin bu becerilerin gelişmesi olduğunu desteklemek için ikinci bir protokol çalışması gerçekleştirilmiştir.

Profesyonel ve eğitim anlamında eşit deneyime sahip, iki mimar katılımcı kullanılmış ve ikisinden de aynı tasarım problemini çözmeleri istenmiştir. Bu tasarım görevleri, tasarım uzamında bulunan ve tasarımcının içgüdüsel olarak çözdüğü problemlerdir. Bu problemler tekrar bir desen üretimi şeklinde değil, bu süreçte karşılaşılan ve farklı becerileri tetikleyen ara sorunlardır.

Bu testlerden ilki tasarımcıların algı becerilerini test etmek için gerçekleştirilmiştir. Bir desenin fotoğrafı gösterilmiş ve içerisinde tekrar eden hangi şekli ya da şekilleri gördüklerini sözel olarak ifade etmeleri istenmiştir. Aynı testin ikinci parçası olarak, gördükleri şekilleri çizmeleri istenmiştir. Çizim devreye girdiğinde ikisinin de düşünme şeklinin ve elde ettikleri sonuçların değiştiği gözlemlenmiştir.

İkinci test desenin içerisinde tekrar eden ve uzamsal bir dizilimle bütünü oluşturabilen bir modülü kullanarak, bütüne ulaşmalarıdır. Bunu iki katılımcının da alışık olduğu iki boyutlu bir çizim programında, elde çizim yönteminde kullanılamayacak komutları uygulamadan gerçekleştirmeleri istenmiştir. İki katılımcı da gördükleri tekrar eden bir şekli tamamlayarak bütün dizilime ulaşmaya çalışmıştır. Farklı şekillerde de olsa bu ikisinin de görsel düşündüğünü göstermektedir.

Üçüncü test, bir desenin tasarım uzamından alınan bir biçim modülünün hangi şekillerin bir araya gelmesi ile oluşabileceğinin çözülmeye çalışılmasıdır. Bu testte tasarımcıların daha çok zihinde tasvir becerisi test edilmiş ve algının eksikliğinde bu becerinin tek başına gelişemediği sonucuna ulaşılmıştır.

Son test ise, görsel hafızayı sınamaya yöneliktir. Katılımcılara bir şekil gösterilmiş ve içerisinde bu şekli barındıran fazlalık çizgilerin olduğu bir çizim verilip, fazlalıkları silerek gösterilen şekle ulaşılması istenmiştir. Burada önemli olan bu

şekil tasarımcıya verilmemiş sadece belirli bir süre bu şekle hatırlamak amaçlı bakması istenmiştir. Katılımcı çizgilerin silinmesiyle hatırladığı şekilleri oluşturmaya çalışmış ancak bu şekillerin nasıl oluşabileceğinin algısına sahip olmadığı için asıl şekle ulaşmakta başarısız olmuştur.

Çözümleme ve testlerin sonuçları bu becerilerin tasarım yapmak için gerekli olduğunu göstermiştir. Tasarım bilgisine sahip olan kişi ile olmayan kişi arasındaki fark bu becerilerinin yeterince gelişip gelişmemesi ile ilgilidir. Aslında tasarım bilgisinin aktarılması, bu kapsamda gelişen becerilerin aktarılması olarak görülmelidir.

1. INTRODUCTION

The creative use of technology and computation reshape design by providing innovative approaches to design problems as medium, tools and theories. The alterations in design tools and methodologies over the years affect not only the design products but also how designers design and the way their thinking contributes to the development of design knowing, and in consequence, learning. These advances alter the focus of design learning from design situations to “designerly ways of knowing” and “designerly thinking”.

The literature on design thinking concentrates on designers’ reasoning and decision-making mechanisms rather than design situations (Oxman, 2001; Eastman, 2001). A physical representation of a design situation is the explication of a design move as a response to an argument. An explicit representation of design reasoning can evoke visual thinking yet is not adequate in transferring design knowledge. Focusing on how to reason and decide for designing activity supports analytical mechanisms in learning. Despite the ambiguity of design representations, design reasoning can be analyzed in a systematic way. The explicit representation of tacit design knowledge may not be possible due to design problems being ill defined or wicked. However, emphasizing on how designers think or learn revealed that there are certain abilities that are required for a designer to have related to how a designer perceives the world, constructs images in mind.

Designers think visually by constructing perceptual images in mind or generating representations as visual shapes. Embracing visual thinking, an analysis-synthesis medium for design exploration is intended for exploring reasoning mechanisms underlying a visual design process. Pattern generation as a visual system which is composed of repetition, hierarchies and orders of shapes, with a sufficient amount of complexity is selected as a tool for observing reasoning behavior of a designer.

This study presents a computational framework that serves as a tool to transfer design thinking using the construction of two-dimensional geometric patterns. The

framework consists of visual reasoning of shapes, formulating thought processes as shape rule representations. The computational model of design thinking in pattern generation is shaped by the analysis of the author's own design activity along with the conducted protocol studies. The said design activity is representing the process of a traditional craftsman's constructing a Seljuk pattern, which displays features of repetition, symmetry and hierarchy. In order to represent the process, the pattern is deconstructed into its components. As collected data from this process, diaries that shows the progress, early drawings of deconstructing and constructing the pattern with verbal reports document similar patterns and underlying mechanisms in the process in order to find out the essential operations to transfer as knowledge.

1.1 Purpose of Thesis

This thesis focuses on learning design thinking and aims to construct a computational framework that function as a tool to transfer design knowledge using geometric patterns as an analysis tool. Designer-investigator as a visual thinker repeats generation process of a Seljuk pattern produced by a compass-ruler method of a traditional craftsman by a deconstructive analysis, which involves familiar shapes, repetitions, symmetric arrangements, and hierarchies of shapes. The motivation on design thinking is for exploring analytical approach in the act of designing in order to find out underlying operations for learning. During the process, designer experiences internal conversations and mostly mental representations. Each design situation the designer fulfills, new inferences are made. In the context of pattern generation, design situations are figural arguments whereas the inferences are conceptual arguments. At the end of each trial and error, designer creates her own knowledge implicitly.

A framework that could improve designers' visual thinking abilities is proposed by firstly conducting a protocol study of self-exploration on analysis of Seljuk patterns. Having selected five different Seljuk patterns from Amasya and Tokat, the patterns are analyzed, deconstructed and constructed again. During this process, shapes, rules and arguments are generated forming the design space of the five different patterns in order to transfer this knowledge to another designer. Each move and corresponding argument in these stages is recorded as rules or the way designer thinks. The mutual relationship of figural and conceptual arguments exhibits a structure that reveals the

relationship between thinking and seeing. Drawing shapes as figural arguments intuitively creates the shape rules along with what is seen. Seeing lets new ways of thinking to emerge and the ways of thinking filter what to see. The nature of design thinking is directly subject to diverse mechanisms such as those that embody perception, imagery, memory and how they are supported while designing emphasizing on the way designer thinks. These abilities are required and improved in pattern generation process.

For composing a computational framework to transfer design knowledge, design knowing and learning is examined. With the purpose of generating transferrable design knowledge, author analyzes own design activity of pattern generation, which evokes visual thinking directly. Inferences made from this analysis encouraged designer to search for different mechanisms for learning rather than sharing design experience in an insufficient transfer method as mere artistic or technical drawings. Narrowing the scope of these mechanisms for pattern generation process, visual reasoning and recall/retrieve abilities of designers are investigated to create ways to improve these abilities.

Design space of Seljuk patterns are examined to construe which stages of pattern generation process trigger which abilities. Having decided on the tasks testing different abilities, a protocol study on experimenting these abilities is conducted on different subjects. The results are reported in chapter 4.

1.2 Literature Review

Design is a complex skill in which includes a lot of variants. Design schools educate designer candidates about design by physical and conceptual studios. Design knowledge is acquired by finding appropriate solutions to design problems in the content of the process in the studio. This process is ‘learning by doing’ mostly focusing on end product and measuring learning with. Students mind the end product more than their processes (Lawson, 1997). This Beaux Arts approach, which is problem-oriented, deals with design objects and artifacts. Students learn by experience and one to one critics sessions with studio instructor based on graphical or artistic explication of their design. In these sessions, principles of design methodology are not well expressed and the method is incapable of transferring

design knowledge fully (Oxman, 1999). In order to be able to transfer design knowledge, how designers think and the measures of learning should be focused on.

Thought processes in design reasoning and strategies can contribute to design learning, having considered design learning as a mental process. Representation, reasoning and knowledge areas of cognitive science which is not in the scope of this study contributes to design education and suggests a conceptual framework of representation, construction and implementation of knowledge structures for design education for learning. Having considered the fact that designer's conception of solving a problem designates the information required comprehending the problem. Designer cannot formulate the problem until solving it, which makes design problem wicked (Rittel & Webber, 1973). Task of designing should switch from the inclination to generation of design objects to cognitive processes in design (Oxman, 2001).

Designer can be modeled as a processor of related design data, which shows that design process is shaped by the experience and cognitive restraints of a designer and directs the process as a problem of search (Akin, 1991). Designers retrieve information from environmental factors, specifications and constraints. Creating a design goal, which consists of design problems to be solved, follows this initial state. The problem space which substitutes information from the initial state is constantly modified by evoking relevant information from long term memory and updated by new sub-goals and sub-problems (Simon, 1974). This framework suggests a cycle in which there is a flow between design alternatives and evoking mechanisms of a designer, which is similar in principle with Schön's design description. Schön describes design as a "reflective conversation with the materials of a design situation" (Schön, 1992). That is, designers are thinking while they are doing design representations. This suggests that visual reasoning is a distinctive element of designing. Furthermore, Jones (1992) claims that 'designing by drawing' is the whole process. Designer has a conversation with the drawings of design situations. The emphasis on the drawings suggests that as the core medium of the process, the representations have a significant role in design reasoning.

Designers are mostly engaged in representations such as drawings and sketches. There are studies, which show the relationship between external representations and generating solutions in mind (Goldschmidt, 1991; Goel, 1995; Kavakli&Gero, 2001).

Systematic analysis of the need of external representations in creative discovery and mental processes that occur during visualization is conducted by many theorists (Shepard, 1978; Anderson & Helstrup, 1993). After various studies, it is claimed that in the limitation of resources such as lack of memory or the impossibility of operating in mental imagery. For investigation of these limitations and mental processes, a visual model, which evokes these mechanisms, is presented in the scope of this study.

Shapes provokes perception, imagery, analogy and creativity and used for tasks to test these abilities (Reed & Johnsen, 1975; Chambers & Reisberg, 1985; Finke, 1993, 1996). In the scope of this paper, Seljuk patterns that constitutes parameters such as hierarchies, symmetrical arrangement and order of shapes is selected as a tool to provide a design space that requires these design abilities.

Seljuk patterns constitute geometric and mathematical knowledge, which is widely investigated in art history, mathematics and physics. The analysis of mathematical structure underlying these patterns revealed that they are created by using compass and ruler, starting with drawing circles (Hankin, 1925; Critchlow, 1976; Bakırer, 1981). In addition to the generation method, having considered the fact that measurement knowledge of today was not available then, Seljuk patterns are not designed only geometrically but also visually. In the context of education, these patterns are used as tools for teaching math through art and design in museums (Metropolitan Museum of Art, 2004), or in architecture schools, for instance, as parametric design tools in which derivative algorithms are produced to create variations of an existing pattern using shape grammar (Çolakoglu, 2008; Çağdaş, 2006). Moreover, computer programs based on Islamic star patterns are produced (Kaplan, 2000). The use of Seljuk patterns in education is mostly concerned with analysis of those and synthesis of novel variations, which are composed with same topology. Özkar (2011) claims that visual schemas, which contain variations, relations and rules, support establishing and transferring intricacy and versatility of relations in design learning. Examining Seljuk patterns as production of shapes that contains relations listed above, they can be used as a tool in design learning for transferring design thinking that lies behind production of these patterns.

According to Minsky (1980), learning is “some representation of something is constructed, stored and later retrieved” (p. 1). Research in design cognition and

psychology alters the perspective of a researcher from design situations to underlying mechanism in design thinking and drawing such as visual reasoning and recall/retrieve abilities of a designer. A computational framework to improve these abilities for transferring design thinking is proposed.

The analysis of design studies are performed by different research methods to understand how designers manage design process and handled by which systematic techniques. The strategies used for exploring designer behavior and collect relevant data are protocol analysis, content analysis, process isolation and situated studies. Protocol analysis is mostly used to infer information processing mechanisms underlying human problem solving behavior (Pedgley, 2007). In the scope of the study, two different think-aloud protocol studies conducted for exploring reasoning mechanisms of a designer (author) and testing these mechanisms in other subjects to find out the relation to learning.

1.3 Hypothesis

This thesis proposes a computational framework that function as a tool for transferring design knowledge by focusing on design thinking. In order to understand how design knowledge is transferred, it explores how it is learned. Since learning is a mental process and design is a visual thinking activity, it conducts a deconstructive analysis of pattern generation as a computational tool.

The study, focusing on transfer of design knowledge, searches for clues of vital mechanisms for learning rather than mere external design representations. Explication of design idea contains implicit knowledge of reasoning mechanisms yet is not accessible through the eyes other designers, failing on transferring tacit knowledge. The method of design learning exploration consists of two distinct protocol studies, which are a self-exploratory of author in pattern generation process to collect information on what is essential for learning and a think-aloud protocol on other subjects to test these mechanisms.

Concentrating on designer's abilities required to fulfill a design task rather than design product, gives the motivation to form a framework for transferring design knowledge by training design abilities needed for this knowledge.

2. COMPONENTS OF LEARNING DESIGN THINKING

Education embodies transfer of knowledge and skills from one to another. There are various theories on whether transfer of knowledge is possible or can be performed fully. In some, it is stated that people do not use context while learning but records patterns to use in other problem solvings (Brown et al., 1989). Some claims that transformation of knowledge is not possible since learner adapts what he/she learns to what they already know (Larson-Freeman, 2013). Surface structure gets in the way of people's ability to see the deep structure of the problem and transfer the knowledge they have learned to come up with a solution to a new problem.

In Gestalt theory, psychologists agree that humans learn by making sense of the relationship between what they see and what they already know instead of obtaining knowledge from what's in front of us. Since designers hold a unique perspective of the world, humans have the ability to generate their own learning experiences and interpret information divergently. Hence, learning is regarded as an internal mental process including insight, information processing, memory and perception.

Design, which is connected, to sciences, technology and arts is mostly learned by doing in conceptual and physical studios. A designer experiences unique internal mental processes where she also learns resulting in new design products. An educator should be focusing on developing methods that improves cognitive mechanisms during designing for learning design.

These cognitive mechanisms are the abilities of a person to design. Ability is used as a term rather than skill due to the notion that ability is possession of means to do something whereas skill is the ability to do something well, expertise as stated in dictionary. The abilities discussed in the scope of this paper are also cognitive mechanisms required for learning, and are not limited to design. Where painting is considered as a skill, perception and imagery are the abilities required to paint.

In the context of design learning, design ability as features to be able to design, external representations as products and stimuli and contribution of shapes in design

education are investigated with the conjecture of support for the computational framework for design learning.

2.1 Design Ability

Cross (1992) defines design ability as what a designer needs to be able to handle a design task. There are six features of design ability which are “managing goals and constraints, coping with ill-defined problems, problem structuring, generating solution concepts, thinking by drawing, intuitive reasoning” (Cross, 1995). In his summary of design activity, Cross (1990) suggests a designer should be able to “produce novel, unexpected solutions, tolerate uncertainty, working with incomplete information, apply imagination and constructive forethought to practical problems, use drawings and other modelling media as means of problem solving” (p. 130). Exploring abilities a designer should hold, he continues to identify as “comprising resolving ill-defined problems, adopting solution-focussed cognitive strategies, employing abductive or appositional thinking and using non-verbal modelling media” (p. 127). This point of view focuses on problem solving behavior and tackling with complications that emphasizes that designing is not a well-defined act.

Designing requires various abilities and skills since it includes conceptual design phase that needs to be introduced to clients or co-workers working with divergent design tools and mediums. In her dissertation, Yukhina (2007) summarizes Löwgren and Stoltman’s approach to relations of design mediums and requirements with corresponding abilities as follows:

Modeling a new form requires creative and analytical abilities; decision-making calls for critical skill; working with a client requires rationality and communicative skill; designing structural properties requires insight and understanding of technology; designing functional properties requires insight and knowledge of exploitation/usage; designing ethics-related properties requires insight and knowledge of values and ideals; designing aesthetical properties requires the ability to generate a form as well as the knowledge of composition. Design intelligence requires an advanced ability to think logically but also to be characterized by a developed synthetic thinking. (p. 7).

This approach shows that there are fundamental abilities such as thinking logically

and synthetic thinking for holding the skills listed above. Cognitive abilities of a designer lay behind design acts.

Mental imagery is also a significant aspect in design ability. Paivio (1971) found that the ability to mentally conceptualize the information referents has an impact on learning ability. It is the ability to externalize or shape what is being visualized by the mind's eye. Therefore, a designer needs to be able to operate on a design medium such as physical models and sketches in order to achieve satisfactory design solutions (Schön, 1983, 1992; Bennet, 1996). A designer can perceive or create associations and construct relationships that need to be communicated. Bernstein (1998) states that designer relates "the object to its purpose, the object to the user, and, most importantly, he has to relate the object to the user to the environment in which that object is being used." (p. 204). For a designer to correspond the relations such as purpose, user and environment, she needs to be able to recall from experience, put different factors into a whole and retrieve relevant information.

To sum up, a designer needs to be able to think logically, perceive visuals to work with visual media, create mental images to think visually, recall from memory, retrieve relevant information and synthesize to integrate information.

2.2 Learning Styles

Focusing on design ability, different learning styles are developed in design learning. Each style educates different skills and improves various thinking mechanisms. Four different styles explained below are holistic, analytic, verbal and imagery style. As being liable to be more cooperative, logic of analytic individuals are confident of well-reasoned sequences and vertical reasoning. They tackle systematically the decision-making process, research with a structured procedure, and manage solving problems more safely performing gradually. However, holist designers are inclined to reason with an urge acting progressively and think creatively. In holistic thinking, instant, wide-open methods are favored in decision-making, reckoning on unsystematic approaches while exploring design space and maintaining a more comfortable attitude on problem solving (Zeleny, 1975; Lynch, 1986). On the other hand, Verbal-Visual style diagnoses if an individual tends to represent information while verbal reasoning, or visualizing in mind (Riding & Cheema, 1991). Table 2.2 shows the characteristics of analytics, holists, imagers/visualizers and verbalizers.

Table 2.2 : Learning styles summarized by Riding & Douglas (1993)

Analytics	Holists	Imagers/Visualizers	Verbalizers
Structured exploration	Impulsive synthesis	Mentally visualize data to conceive ideas	Represent information verbally
Study rules sequentially	Prefer concepts to facts	Prefer visual data	Prefer verbal/written data and communication
Step by step approach to problem solving	General overview of the problem and concrete experience	Need visual stimulation	
No risk error as they learn or resolve problems	Random, rapid, open-ended approaches	Strong imagination	Inner dialogue to remember and understand
Fear making errors	Risk and experimentation as a part of their learning		

Learning styles are classified according to how learners receive and process information. Based on Experiential Learning Theory of Kolb, Demirbaş and Demirhan (2003) explain four different types of learners as accommodating learners who are good at learning by doing and experiencing, diverging learners who are best at learning by experiencing and reflecting, assimilating learners who are good at learning by thinking and reflecting, converging learners who are opposite of diverging learners.

2.3 External Representations in Design Process

Drawings such as sketches and diagrams are used as memory aids for externalizing the visuals constructed in mind while designing. As an external representation, they provide information input for visual reasoning. Purcell & Gero (2006) states: “Drawing during the design process could be performing the same function, which is of maximizing the conditions necessary for the reinterpretation of an image and the emergence of new ways of ‘seeing’ it.”

The external representations as drawings in this case are associated with imagery, which designers use to generate or see new forms to be externalized as drawings, or they use drawings to generate visuals in mind.

According to Purcell & Gero (2006), mental imagery is not essential to creativity but the insights that are revealed by the interpretation of images. Creativity is associated with the different means of seeing images, which arises in mind.

Eastman explains that learning to write, we recognize and write alphabet that requires hand-eye coordination. In order to learn reading, we identify the alphabet and then whole words and put them together. After a while, the process is internalized and automatically performed without effort. In addition, mathematical operations can be made in mind when math symbols are learned and internalized. That is, if we learn an external representation, internalize it, it becomes automatic. Moreover, a new skill can be developed on an internalized representation skill. It is obvious that an external representation evokes visual reasoning mechanisms of a designer. Below, Eastman (2001) draws attention to the relation of mentally reasoning in representations and reading representations by questioning whether they are complementary capabilities or one leads the way:

A more general question regarding mental representations is “at what point of learning any external representation does it become available for internal representation and support mental reasoning?” With repeated practice, “reading” an external representation becomes easier and eventually becomes transparent, allowing automatic interpretation. In roughly parallel fashion, practice allows us to gain the ability to mentally use the representation and to carry out simple mental operations. Do these two capabilities— automatic reading of a representation and the ability to mentally reason in the representation—come into being at the same time as complementary capabilities, or does one precede the other? It would be valuable to determine this relation, if it exists. If they took place together, then testing could use one capability as a surrogate for the other. (p. 173).

External representations are constructed during the reasoning task and serve as externalizations to the mental reasoning processes also providing input for creating mental images. Mental representations are constructed during reasoning on an external representation and they serve as temporary abstractions in extent, level of

detail, or quality from the external. Mental reasoning on these abstractions can lead to modifying the external representations (Goldschmidt, 1994; Purcell & Gero, 1998; Vertijnen, 1998).

Chambers & Reisberg (1985) state that the reason to significance of drawing may correlate with its expansion of situations to reinterpret and avoid problems related to specific reversals in imagery.

As an external representation, drawings are both representational medium and communicative tools produced during design process. Discussions above explain imagery aspects of external representations. However, drawings evoke perception resulting in different ways of seeing it as a part of design thinking. Examining early drawings of distinguished architects such as Leonardo da Vinci reveals mental processes such as memory and imagery in decision-making processes (Herbert, 1993).

Since this study focuses on visual thinking, how a designer creates shapes to form a drawing and more significantly how a designer perceives shapes and interprets them is a fundamental stimulus.

2.4 Shapes in Design Thinking

As geometric representations, shapes are points, lines, planes or volumes regarding their dimension and have a position, orientation and a size in the coordinate system. New shapes can be formed by two or three-dimensional transformations such as rotation and reflection. As visual elements, shapes are ambiguous and constitute numerous sub shapes. As Stiny (2008) illustrated, one can see a triangle, bits of hexagons or letter A in different orientation with intersection of three lines (Figure 2.1).



Figure 2.1 : Seeing various sub shapes (Stiny, 2008)

One can see different shapes as part of wholes or can generate new shapes from existing shape with emergence of novel shapes. This may occur with recursion of a

rule applied to an initial shape. A rule is constructed with a design idea. However, recursion of this rule creates shapes that are not predefined but are produced by interaction of original shapes (Figure 2.2). Seeing emergent shapes is a common ability for designers, yet variations in the perceived shapes result in creating novel form alternatives. This variation is the result of different visual reasoning mechanisms. Minsky (1986) claims that the perception of the world is mostly depends on what we see and think inside our brain with a slight affect of what comes from our eyes in a certain duration.

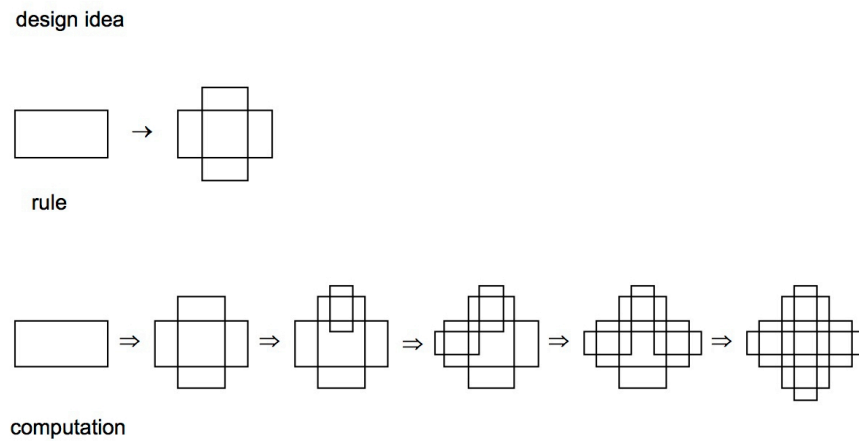


Figure 2.2 : Recursion of rules

This formalism of shape grammar is used for analysis-transformation-synthesis of shapes. Figure 2.3 shows the analysis of Chinese ice-ray designs revealing the rules that can form the whole with recursion. Designers learn about ways of designing by analyzing finished designs of others. For example, the grammar of architect Alvaro Siza has been constructed with analysis and used to create novel designs as synthesis (Duarte, 2005).

Starting with an initial shape and a rule that exhibit a spatial relation together for design intention fulfills synthesis of shape grammars. Using this spatial relation one can generate various design alternatives. In some occasions, the spatial relations learned from analysis of existing shapes are transformed to generate novel forms.

Islamic geometric patterns have been widely investigated by these analysis methods to comprehend how the artisans generate these shapes. In Bakırer's method, using compass and ruler, drawing a circle as an initial shape, a circular template, which constitutes the spatial relations of shapes, is constructed.

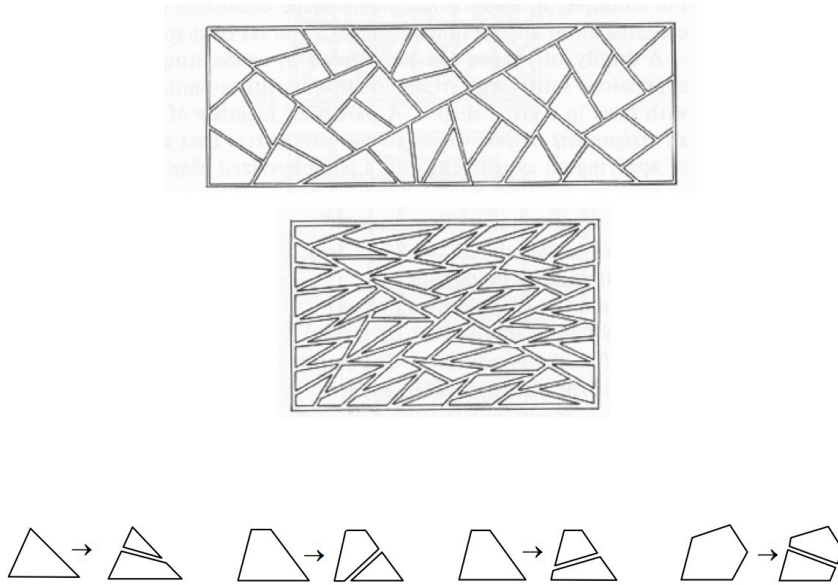


Figure 2.3 : Chinese ice-ray shape grammar (Stiny, 1977)

Using the contact points of the circles, various shapes are generated. As illustrated in Figure 2.4, various shapes can be generated regarding the arrangement of the motif. In addition, there are various ways to construct a divergent spatial arrangement.

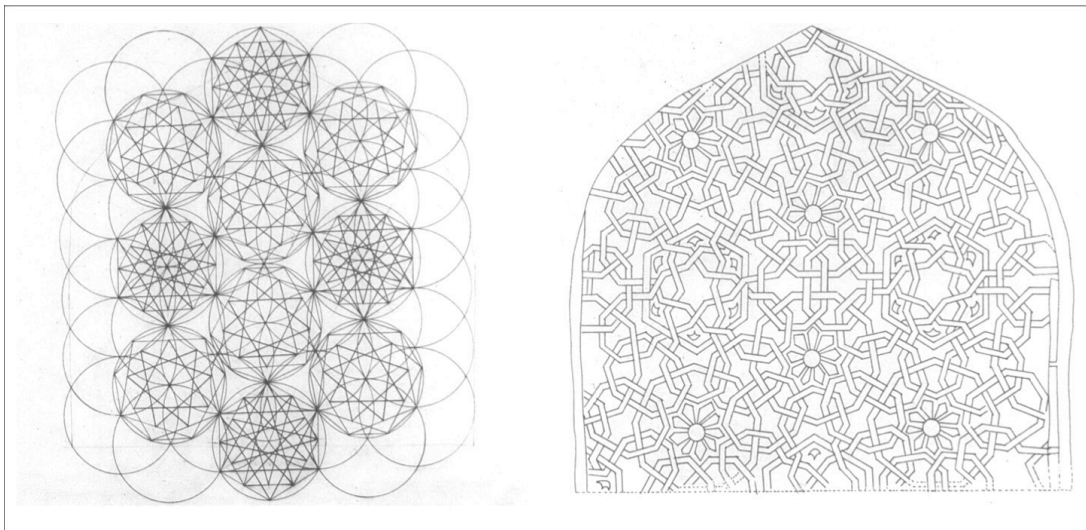


Figure 2.4 : An exemplary analysis of a Seljuk pattern from Aksaray (Bakırer, 1992).

The arrangement of the motifs holds various potentials in the orientation and tessellation of the circles as well as the variations in the scale of the circles. Hence, numerous shapes may be generated even using the same shape rule. As seen in Figure 2.5, with compass ruler method, varying sized circle grids can be formed in addition to possibility of various line configurations with grid guidelines and numerous intersection points (Özkar&Lefford, 2006).

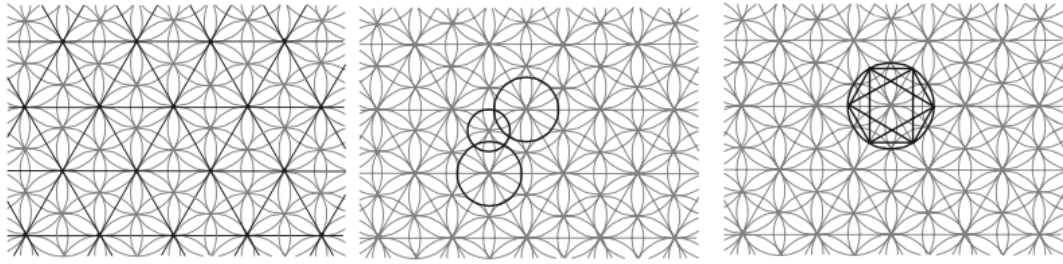


Figure 2.5 : Compass and ruler construction of circular grid (Özkar&Lefford, 2006)

In the scope of this study, investigation of pattern generation process is fulfilled by using compass ruler method not only repeating a Seljuk artisans work but also due to the fact that it holds more potential in polygon generation and emergence of new shapes.

2.5 Seljuk Patterns in Design Education

A traditional design education curriculum is composed of three parts as art, sciences and technology or instructions as practice and theory. New methodologies for teaching in this curriculum are being established due to the paradigm shift in design thinking as design cognition and design computing. Regarding science and technology as perception and action, Findeli (2001) believes that intuition and visual intelligence associated with perception and action can be developed by students in basic design education that will continue till last year of design education in parallel with design studio. In current basic design studios, students are educated for the understanding of basic design elements, developing drawing skills, constructing relations with different shapes and objects.

Mitchell (1990) describes design as “computation of shape information that is needed to guide fabrication or construction of an artifact.” (p. 1) As designers, we calculate, think and reason and trained visually for solving design problems. With digitization, visual calculations are moved to a new medium for exploration. Even though digital tools are aids for generating more solutions spending less time and broadens the limits of analog exploration, computation does not have to involve computers. Such a design constitutes an algorithm that includes initial shapes, a repertoire of shape rules for transformation and various combinations of the operators (rules) in which the computation occur (Mitchell, 1990). This reduction helps recognition of design elements more consciously establishing more space for emergence and creative

discovery. Terzidis (2004) also describes design computation as an inductive algorithm that “can be regarded as extensions to human thinking and therefore may allow one to leap into areas of unpredictable, unimaginable and often inconceivable potential.” (p. 6).

Islamic patterns are used to teach symmetry (Celani, 2004), geometry, create tessellations of shapes and their variations (Kaplan, 2002). Containing geometry knowledge, spatial relations, symmetry, hierarchy and order of abstracts shapes, these patterns are suitable for a basic design exercise that constitutes visual computation, reflective relations of perception and action. Tools such as PatGen: Islamic Pattern Generator developed by Serkan Uysal are used to teach computational thinking to designers and introduce them systematic thinking and formal logic of programming (Tuğrul et al., 2008).

In Medieval Islamic Period, geometers used ‘cut and paste method’ to teach artisans the geometry knowledge since artisans were not interested in proving possibility of geometric knowledge but generating an inspirational ornament dividing and assembling figures (Özdural, 2000). Considering Özdural’s statement above, these patterns seem to be visually produced rather than mathematically. A set of Seljuk patterns are analyzed in this research not only for understanding and deriving architectural geometry for generating various design alternatives yet for revealing the reflections through exploration on visual thinking processes of a designer. In this study, analysis of patterns means revealing the design process of construction. The process includes the tool, method and reasoning. The explication of the process is an implicit algorithm that constitutes design knowledge produced in the generation of the pattern. Aiming to transfer design knowledge, an analytical approach which focuses on relation between shape computation and visual reasoning abilities are embraced rather than dealing with design products.

3. PROTOCOL STUDY OF PATTERN GENERATION

A protocol study is conducted by designer-investigator deconstructing a Seljuk pattern in order to find clues on how to mimic traditional craftsmen's generation process using compass-ruler method. Two dimensional drawings and verbal arguments related to these drawing are recorded. The intention and decision making mechanism are searched for in the drawings and verbal records. Applying the same think aloud protocol on five different ornaments, study is analyzed to discover the recurrence of similar behaviors that can reveal reasoning of designer. With retrospective approach in analysis process, observation of task reveals five distinct stages of seeing and generating a pattern. Separate stages are examined in a way to realize required distinct skill sets for fulfilling the task.

3.1 Selection of Patterns

Five Seljuk patterns; three from Tokat Mahperi Hatun Caravansary, two from Amasya, Gök Madrasah and Halifet Gazi Tomb are chosen and shown in Figure 3.1 respectively. The reason for choosing the Tokat patterns from the same building is based on the assumption that the same craftsman worked on one building. Pattern I and II are from the upper panels of left and right niche of caravansary where pattern III is from the crown gate. Pattern IV is from one of the blind niches of Gök Madrasah. Curbstone pattern of Halifet Gazi Tomb is selected as the fifth pattern.

The intention behind selection of these patterns lay on comparative analysis of the outcomes depending on their differentiations in symmetrical variations, embedded shapes (whether it is a star pattern or not) and colors.

Through creative discovery, each linear representation constitutes embedded implicit structures that are fundamental for representations such as patterns, local configurations or functional order and relations (Oxman, 1995). The next stage of the study is a visual analysis by deconstructing the pattern generation process. Since the aim is to comprehend the visual reasoning mechanisms with the computation of relations, rules, embedded shapes of the pattern, material parameters that affect the

process are not included in the analysis. These patterns are assumed as two dimensional, vector drawings.

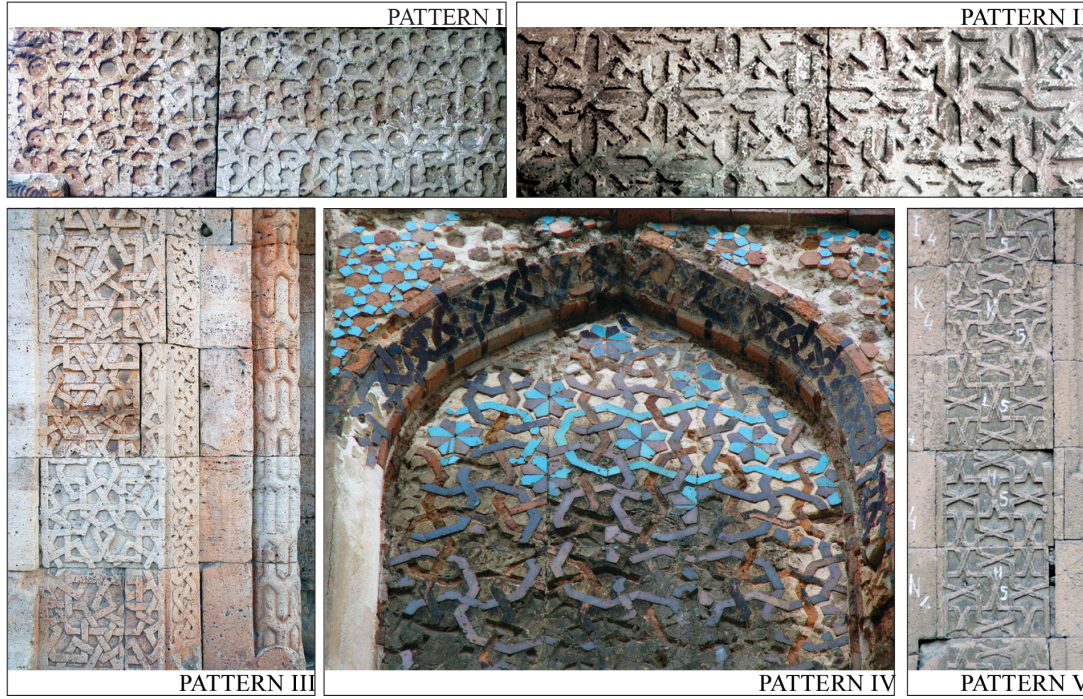


Figure 3.1 : Selected Seljuk patterns

3.2 Analysis by Deconstruction of Pattern Generation Process

The patterns are generally considered as finished works or tiling. However, they constitute visual thinking and production knowledge when pattern generation process is analyzed. The analysis of these patterns is not for generating mere geometric rules or symmetric tessellations yet to comprehend the production knowledge that reflects visually produced designs with the logic of computation.

The analysis is realized by representation of pattern by regenerating it. Pattern generation process is analyzed by deconstructing perceived shapes detecting repetitions, symmetric arrangements, order and hierarchies of shapes. The method used for recreation of the patterns is quite similar to Bakırer's (1995) since its arrangement has more potential than tessellation methods to discover embedded structures underlying pattern and provides new ways for emergence and creativity.

The designer-investigator author is given a photograph of the pattern to work on and a two dimensional CAD program for drawing and representation. However, CAD program is only used for representation of designer's mental processes trying to

repeat the craftsman's production process. Commands that cannot be repeated in a compass-ruler method are not allowed. The actions of the author are recorded both in shapes and verbal arguments. Shapes are recorded in a way that consequent shapes represent moves of the designer regarding the arguments based on previous drawings where verbal arguments illustrate the intention behind the moves. Moreover, video records are used for investigating implicit intentions unspoken while deciding on the design move.

3.2.1 Generation stages of patterns

Designer-investigator resolves five Seljuk patterns described above using the same method. It is noticed that there is a repeating pattern in designer's deconstruction process. Starting by detection of embedded distinct shapes and sub shapes, which are known by the designer and repeat all over the pattern, designer finds out the fact that there is a covert template (grid) underlying the pattern. This discovery encourages the designer to identify the covert template and draw the initial shape (circle) in this arrangement. Regarding the method, investigator starts to draw polygons using the intersection points of shapes as edge points in order to generate shapes that can trace the distinct shapes detected in the first glance. After creating lines that trace the pattern, redundant segments are omitted. The last step is to give the thickness of the lines, which is evident on the stone. Until this stage, pattern is abstracted into two-dimensional linear drawing, which has no thickness and color with the presumption that thickness is as an offset of the lines in the same direction and does not affect the overall arrangement. However, it is seen that direction of offset changes, transforming the pattern altering the ratio of shapes embedded in.

3.2.1.1 Seeing shapes

Numerous shapes are embedded in all of the five Seljuk patterns. With a spatial approach, perception is filtered into receiving larger repeating geometries. Divergent geometries can be perceived as parts of the pattern that can form the whole. When there is such a conflict, designer attempts to construct the whole from chosen part in mind using Euclidian transformation. However, drawing in mind does not provide a representation for eyes to see again. Transformation system can be remembered, as a path yet remembering the whole part as a result of transformations may not be possible due to the complexity of the patterns that embodies various sub shapes. In

this situation mentally constructed model is drawn in CAD program using the original photograph as a base to fit shapes.

Having decided the shape or shapes, the eye follows a path detecting the place of these shapes. On some occasions, designer uses her finger to follow the same path to help the mind. These paths create an axis for the spatial arrangement of shapes revealing the underlying grid in the pattern.

Perception of shapes in pattern I from Mahperi Hatun Caravansary

It is observed that the pattern consists of a leaf shape and its four different variations in orientation. Each intersection of leaf shapes generates an X like shape, which repeats in the entire pattern as placed on the corners of a square grid. X like shapes which hold the same orientation follows a diagonal path. Both diagonal and square grids are studied and the outcomes are explained in polygon generation section.

Perception of shapes in pattern II from Mahperi Hatun Caravansary

An eight-pointed star is perceived at first glance observing the pattern. A five-pointed star is detected on the four symmetrical points of the main star. The set of an eight-pointed star with four five pointed star on the symmetrical edges forms a square grid at the contact points. It is foreseen that the tessellation of the square set can build the pattern.

Perception of shapes in pattern III from Mahperi Hatun Caravansary

Designer- investigator starts by detecting repeating shapes, which are a six-pointed star and a hexagon with the star in the center. Designer recognizes the two stars on the edge of the curbstone after detecting the hexagon and tracing it with the presumption that there should be a star in the center of the hexagon. With the verification of this outcome, the triangular grid becomes apparent.

Perception of shapes in pattern IV from Gök Madrasah

In the case of pattern IV, a repeating eight-pointed star is perceived. Firstly, the blue colored polyline that surrounds two eight pointed star is seen and regarded as a repeating module. However, the distances between the stars are varying. Based on the symmetry, which is observed in the placement of blue polyline mentioned above and the mirrored incomplete version of the polyline, instead of seeing the repeating module as one star, a set of four stars is studied. There are two different sets including same four stars with different alignment, which is later realized as the

perpendicular rotation of another. Perception stage is quite significant for pattern IV for the generation of the pattern is not in the regular order but perception is nested with polygon generation and setting up the grid.

Perception of shapes in pattern V from Halifet Gazi Tomb

An X like shape, which is tessellated vertically and horizontally, is detected. Following the middle points of the repeating module with the same orientation, a diagonal grid with an angle of 90 degree is perceived. On the other hand, a square grid behind the pattern can also be observed when the middle points of both vertically and horizontally tessellated shapes are followed. However, diagonal grid is preferred since it involves the square one.

3.2.1.2 Setting up grid

In the literature of Islamic Patterns, generation process starts with a circle. Circles are drawn using compass-ruler method, which is defining a center point from the starting line and a radius on the CAD program. Once a contact point is introduced, all other shapes are created from these intersection points. For circle grid, the intersection points are the center points to draw new ones (Figure 3.2).

According to Bakırer, all Seljuk patterns can be created using this circular template. Due to the limited design space in the research, the statement cannot be verified yet can be supported since the template functions for all five patterns.

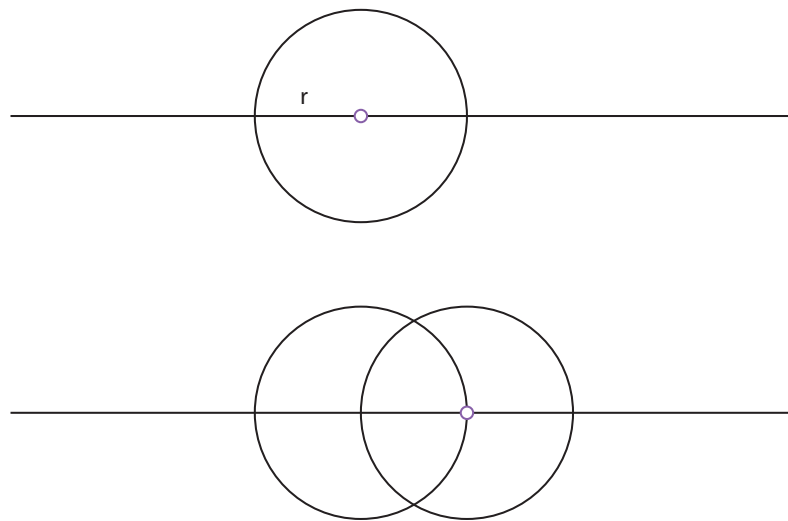


Figure 3.2 : Initial shape of pattern generation

Setting up the grid of pattern I from Mahperi Hatun Caravansary

Using the rule illustrated in Figure 3.2, all tangent circles required for generation of pattern I could be drawn by using the contact point on the circles as the center of next circle. However, in this case, the grid that is the tiling of circumscribed square around circular template is exercised. This method, using square tiling is also used by Broug (2008) and practiced in this example for comparative analysis despite the fact that it is conflicting with the argument that the grids are composed by using the compass ruler way.

In this tiling, each repeating module is contoured by the square cells and multiplied to form the pattern. Generations of polygons are achievable with diagonal secondary grid behind and circles shown in the Figure 3.5.

Setting up the grid of pattern II from Mahperi Hatun Caravansary

Compass-ruler method and also the square tiling method are studied on pattern II. Although there is no common repeating shape in pattern II, and I, both share the same templates. In addition to the square tiling explained in pattern I, the 90-degree diagonal grid is drawn as an extension and the circles, which use the corners of the grid as a center, are chosen for pattern generation stage. In fact, the diagonal grid behind is drawn using the circle template that is arranged to generate the required angle since the generation method is mimicking the compass-ruler (Figure 3.7).

Setting up the grid of pattern III from Mahperi Hatun Caravansary

Various circles in this arrangement are created that follows the underlying grid, which is used as the extension axis. The clue of which circles to be chosen to use or should be more evident for the generation process is given in extension axis perceived in seeing shapes stage (Figure 3.10).

Setting up the grid of pattern IV from Amasya Gök Madrasah

The arrangement of the underlying grid of pattern IV is exceptional among other four patterns. Each pattern seems to be composed of a diagonal (diamond) grid and circle template. However, pattern IV constitutes a nonlinear diamond grid, which is formed by tessellation of a diamond and its 90-degree rotation. The arrangement of diamond generates a third quadrilateral between two topologically same diamond shapes. The nature of the grid results in an unusual circular template, which is not constructed by using the rule in Figure 3.3.

Unlike setting up the grid stage of other patterns, first, the repeating shape is constructed and regarding the local relations between lines the ratio of dimensions in diamond shape is calculated. It is seen that the lines that constructs the eight pointed stars generates the set of four star by each star in the set shares two overlapping lines with consecutive stars. With the arrangement of the stars accordingly, the angle and the ratio of the diamond is revealed. After nonlinear grid is drawn, circles are drawn using contact points (Figure 3.12).

Setting up the grid of pattern V from Halifet Gazi Tomb

Pattern V is generated by using the template with diagonal grid from pattern II yet it is also achievable by operating on the structure from pattern I. As using the rule in the second drawing in Figure 3.3, all circles are drawn tangent to the center of previous circle. Thicker lined circles exhibit the primary tessellation where gray colored circles are essential for generating contact points for polygon drawing (Figure 3.15).

3.2.1.3 Polygon generation stage (PGS)

The method to pursue for generation of polygons is to use contact points of circular grid. Designer starts by drawing polygons that can trace the extensions of the perceived shape in the first stage of the process. The circular grid is placed on photograph of pattern to be able to confirm whether the shapes match or not. Transparency of the photograph is adjusted considering the complexity during shape production.

This stage mostly starts by drawing a triangle as it is a common geometry and requires fewer vertexes to connect by lines. It is simply a mission of connecting vertices with lines to create the shape seen in the pattern or to create more vertices to connect. In the initial moves, shapes are drawn to create vertices for new forms. The decision of which shape to draw comes from detection of contact points on the pattern. The vertices, which create lines passing through these contact points in the pattern, have priority. Detection of contact points creates “x” shapes, which is similar to Hankin’s method. If there are vertices on the collinear extensions of x points, they are connected with lines; if not, new shapes are drawn to create these vertices. A similar pattern in designer’s reasoning is discovered in PGS, which is drawing shapes from contact points, detecting contact points of new form and generation of new

shapes to create new vertices that corresponds to original pattern. On different occasions, the intention behind forming new shapes differs although it results in same design moves. Focusing on intention, a comparison is made and come up with a result that if designer detects a familiar shape like a star, triangle or a pentagon, acts more intuitively assuming she knows how to create that shape.

Pattern generation stages of I from Mahperi Hatun Caravansary

After detecting star shape in the middle of each square tiling, new squares are drawn using contact points of circles and diagonal grid. The aim is to create smaller rectangles that can form an 8 pointed star by superposing the two different oriented ones with the same dimensions. Required polygons for drawing repeating shape inside circles are generated at this stage by applying the square generation rule multiple times. However, the shapes between the circles are not embedded in the polygons. As a second rule/step, new lines are drawn using the contact points from one circle to another that connect the repeating shapes. As the third rule, the lines generated from the contact points are required to extend to trace the original pattern. Particular intersections are evaluated whether they provide the intended vectors.

The square tiling is practical to generate the same pattern. However, it breaks the unity in the design process, and systematic approach followed in the analysis (Figure 3.5, Figure 3.6).

Pattern generation stages of pattern II from Mahperi Hatun Caravansary

Polygons that are generated for pattern II are drawn by using both square and diagonal grid. Polygon generation process of pattern II begins with drawing a square from the intersection points of the diagonal extension axis and the circles. The same rule is repeated using the contact points that provide the edges for drawing a new square. Applying the rule multiple times, new contact points from exterior towards the center of the circle are generated as repeated in the context of each circle. In order to draw the shapes similar to number sign (#) for generating the perceived figures, the rule of drawing a line from contact points is used. The extension of lines rule is followed to reach the intended lines for tracing the pattern while using the square tiling. However, only the first two rules, which are drawing square and line, are adequate when diagonal grid is utilized as a base for generating polygons (Figure 3.7, Figure 3.8, Figure 3.9). The method to trace the pattern is to settle the photograph of the pattern and check if the lines fit the image by adjusting opacity.

Pattern generation stages of pattern III from Mahperi Hatun Caravansary

In one example on the crown gate of Mahperi Hatun Caravansary, designer detects a star with a certain ratio to the circle and attempts to narrow down the space for ratio of the star creating shapes from the inner vertices of the shapes created in the circle without giving attention to “x” points. Having begun with drawing two mirrored triangles, a six-pointed star is achieved. Using the contact points generated by the triangles, a hexagon is drawn. An outer hexagon that is traced from the previously drawn triangles is detected. After repeating the triangle rule using the vertices of the detected hexagon, lines that forms the middle star are drawn using the contact points produced by the intersection of triangles and the smaller hexagon inside the circle (Figure 3.10, Figure 3.11).

Pattern generation stages of pattern IV from Gök Madrasah

Since the underlying structure behind the grid is not linear but the repeating module is the same, each circle is also divided into same contact points to be able to generate the repeating shape. The shape is an 8-pointed star, which can be drawn by using a regular grid rule as shown Figure 3.3. After repeating the star shape in each circle, new lines in order to generate the middle star, are drawn using the inner vertices of the stars. Applying the square rule employing the intersections of the star and the extension, middle eight-pointed star is generated (Figure 3.12, Figure 3.13, Figure 3.14).

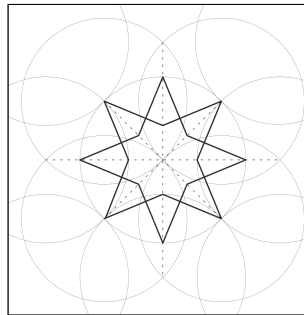


Figure 3.3 : Construction of an 8 pointed star

Pattern generation stages of gate pattern V from Halifet Gazi Tomb

The stage begins with drawing an octagon that embodies a part of the pattern directly and continues with generating rectangles from the contact points in order to create new polygons that instore the parts of repeating pattern or draw lines that trace the shape. Squares are drawn multiple times from contact points followed by drawing segment form intersections (Figure 3.15, Figure 3.16).

Despite the fact that there are distinct stages in the process, similar mental processes occur. Moreover, significance of polygon generation process comes from the conceptual arguments designer makes through perception of shapes and figural arguments as a response. Designer uses imagery to arrange new form combinations and represents visuals of these forms to see if the intention is achieved. Although it is a simple task to handle in mind, designer urges to represent it to see. Designer thinks visually and reasons on visuals that can be seen through the eye since perception is a substantial concept which starts this analysis process and is active on filtering what is received from the external world. Significance of seeing arises in reasoning of a designer, more than a record for memory. Both perception and reasoning functions complementary in supporting shape emergence.

3.2.1.4 Omission of segments

Having completed drawing all necessary segments for the pattern, redundant segments are recognized. Two distinct methods are followed for omitting redundant parts. First one is simply trimming and deleting unnecessary lines; probably it is not the way a craftsman followed (Figure 3.11). Second one is tracing the required lines on the drawing and using them (Figure 3.6). The first method is easier to use in less complex samples yet it lacks the information second method embodies. The approach is focused on segments of shapes in first method whereas it is focused on shapes in the second. The choice of method is profound for being able to reach the exact ratio in giving thickness of the drawing. Since, thickness has a direction and a continuous line (shape) will have the same thickness, seeing parts of the pattern as shapes or segments results in a different pattern.

3.2.1.5 Thickness

In some sample studies, all the shapes have the same thickness whereas in one the ratio of raised stone and hollow parts differ in the same shape in various spatial arrangements. Since most of these patterns are on a curbstone or a stone panel and do not expand to the whole façade, it is not known if change in direction of thickness is an intended act or not regarding the original pattern. However, thickness is considered as a substantial stage since it is a parameter that affects the integrity of the pattern and the method to be chosen in omission of segments stage. Having completed the analysis, tracing the figures method appears to fit best for each pattern.

3.3 Shape Rules

The aim of the protocol study is to record the process of designer-investigator author repeating the pattern generation method in order to discover what is it that designer learns or improves by focusing on reasoning and decision making mechanisms, means that affects these mechanisms in the search for a design knowledge that is transferrable into other designers. Such a purpose requires a systematic representation of the process. Shape grammar formalism is used for representing analysis-synthesis progress of the exploration process in order to create a design space of regenerated Seljuk patterns.

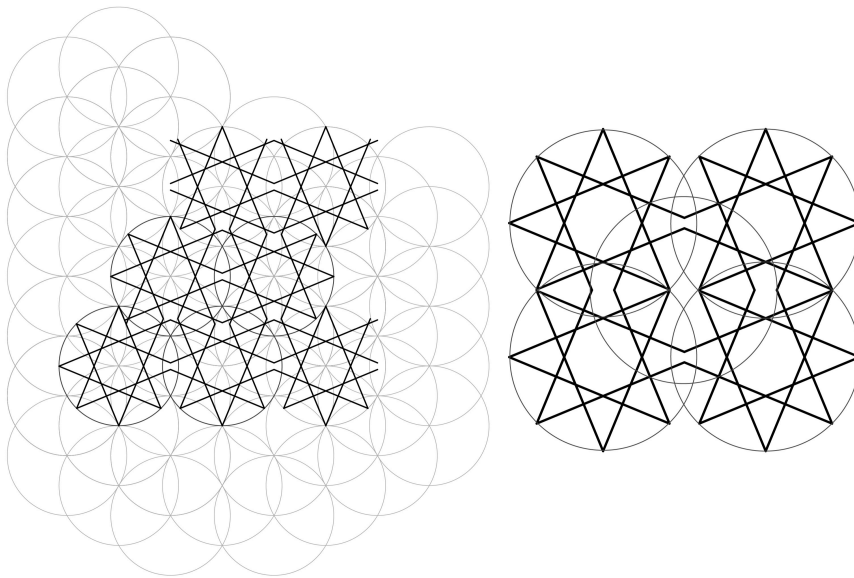


Figure 3.4 : Same shape rules applied on different grids (pattern IV)

Each figural argument or move of designer is represented as $x \rightarrow t(x)$ formalism varying depending on the design situation. Since shapes are drawn from contact points of circle grid, most of the shapes are drawn inside the circle. A repeating circle with extension lines of underlying grid is chosen as a module to define the shape rules applied in each move. Examples of shape rules from the analyzed patterns are shown in Figures 3.5-10, 3.13, 3.15-16. Consecutive application of rule 1 and rule 2 for three times forms the basis for rule 3 and 4. The significance of circular grid is also evident because of the fact that the arrangement of the circular grid changes the pattern created. In the figure, the result of different grid use with the application of

same rules. In addition to this, on occasions of tangent circles, which forms the underlying grid, the interstitial pattern is constructed by extension of shapes, which do not have a contact point (Lee, 1987). That's why generating patterns from a circular grid constitutes more potential in emergence of new shapes rather than tessellation methods. Moreover, in Figure 3.16, a similar inference is made. Without the grid, the arrangement of the circles, the rules are not adequate for structuring the pattern. The order of the circles and the intersections generate novel lines to trace the pattern.

The order of application of the rules is to form the intended pattern. Various combinations of these rules may be used for generating new patterns (figure 3.15). It is obvious that given the order of rules and shape rules, a designer can generate the same pattern. However, can a designer form the same pattern given only the shape rules and are there other factors required to fulfill this design activity?

A practice of shape grammar is demonstrated where it is not only meant to be read or used to create shapes but is also meant to investigate the intrinsic intension in making the rules (how to design the rules) with the purpose of enhancing what and how a designer see. For a designer to choose right rules at the right time, he/she needs to comprehend the intention of forming that rule or shape. The search of how that shape emerges from given rules is achievable with integration of perception that is seeing relevant shape, imagery as constructing mental representations as transforming seen shapes to reach desired shape and visual memory to recall and synthesize perception and imagery in drawing.

For comprehension of implicit knowledge in design space of these five patterns, visual thinking abilities mentioned above are searched in the design space.

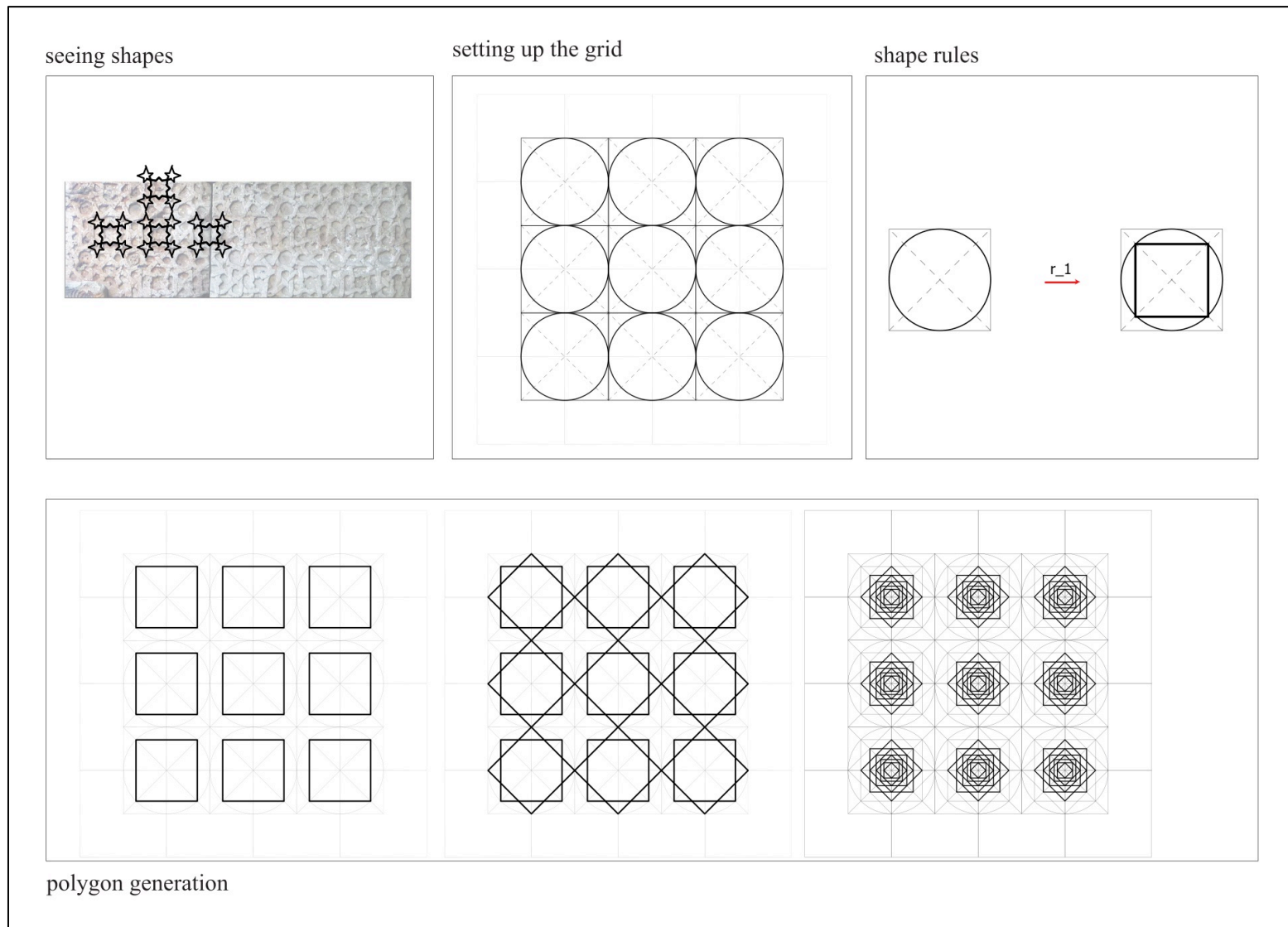


Figure 3.5 : Pattern generation stages of pattern I

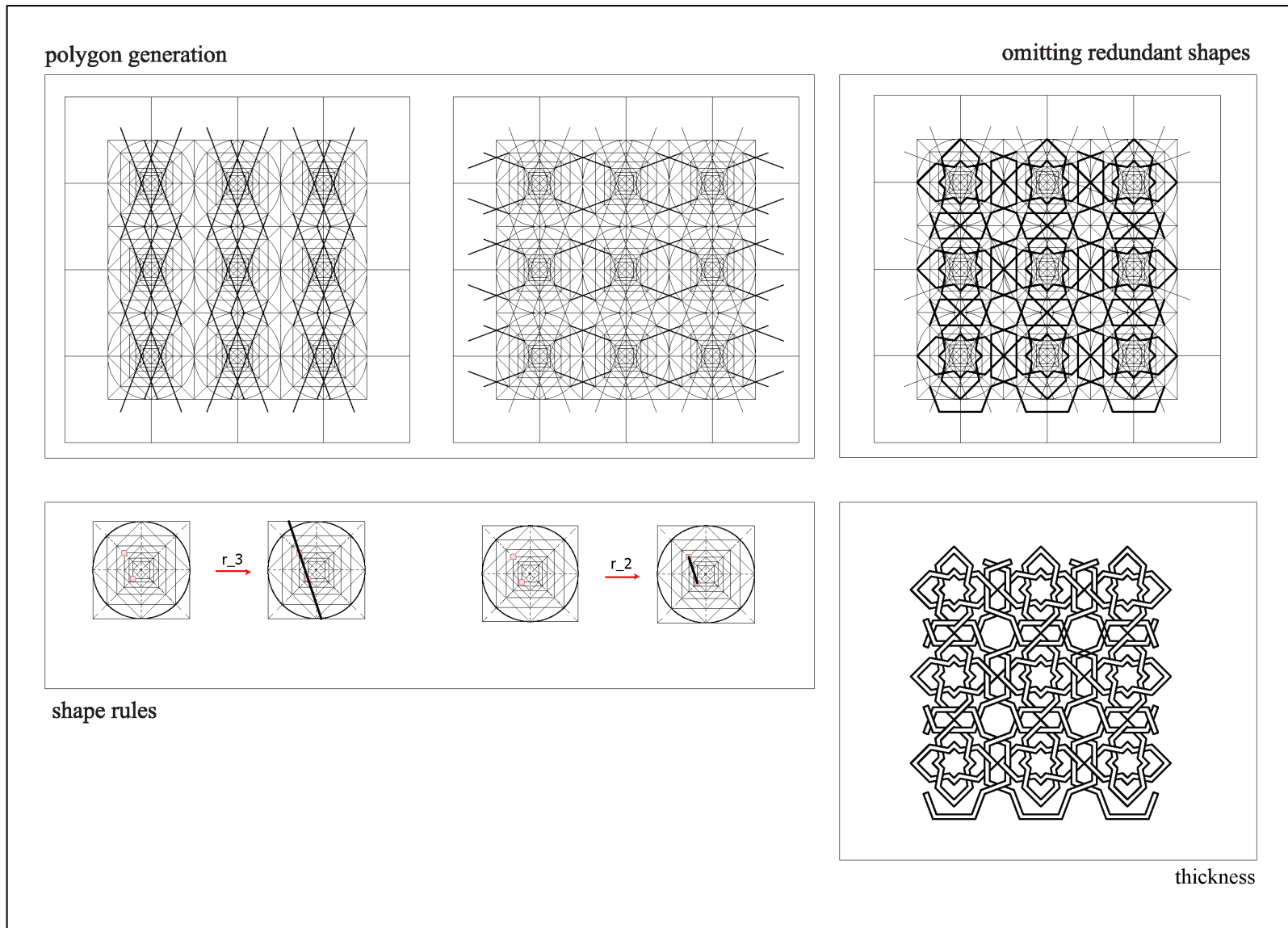


Figure 3.6 : Pattern generation stages of pattern I

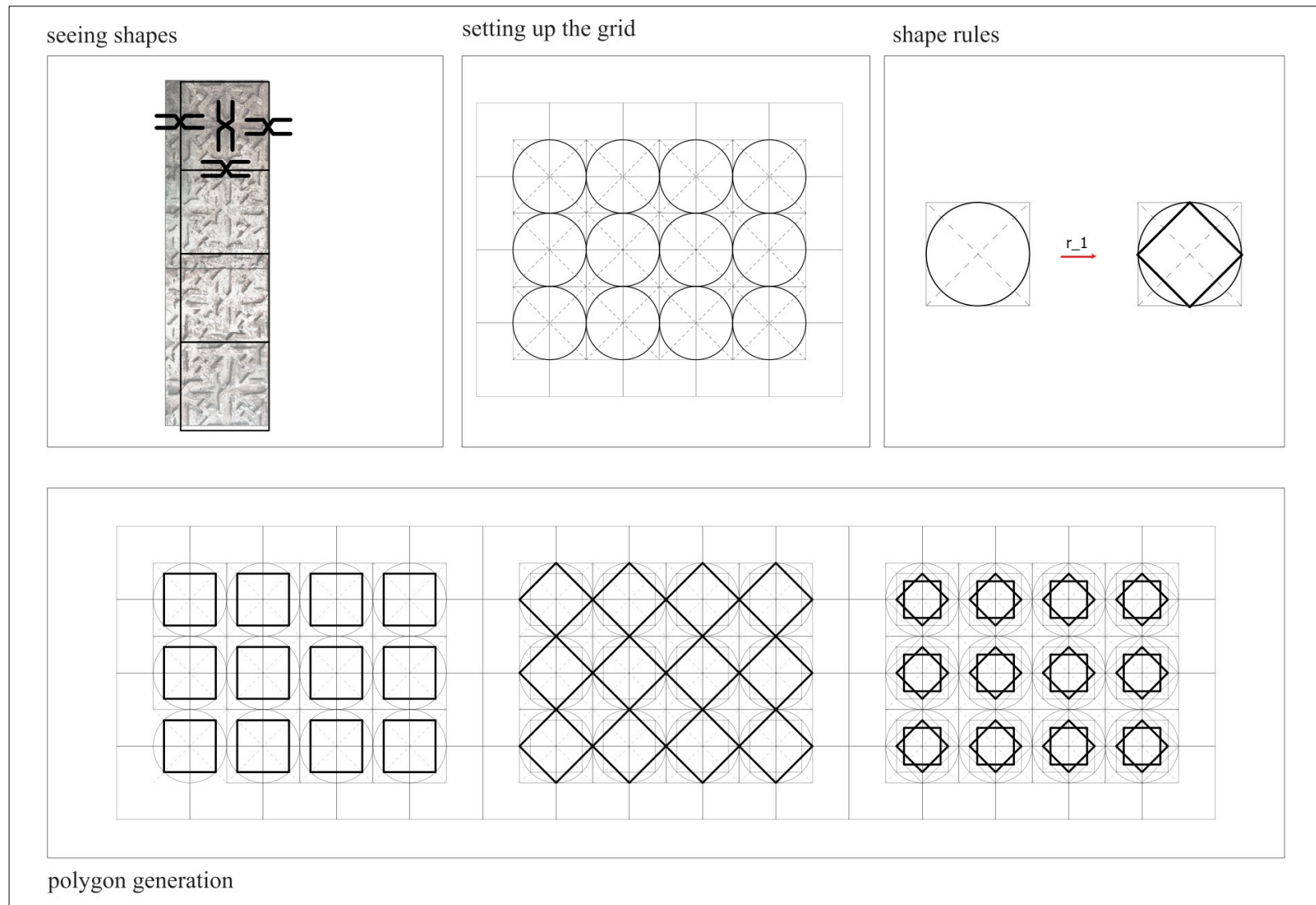


Figure 3.7 : Generation stages of pattern II

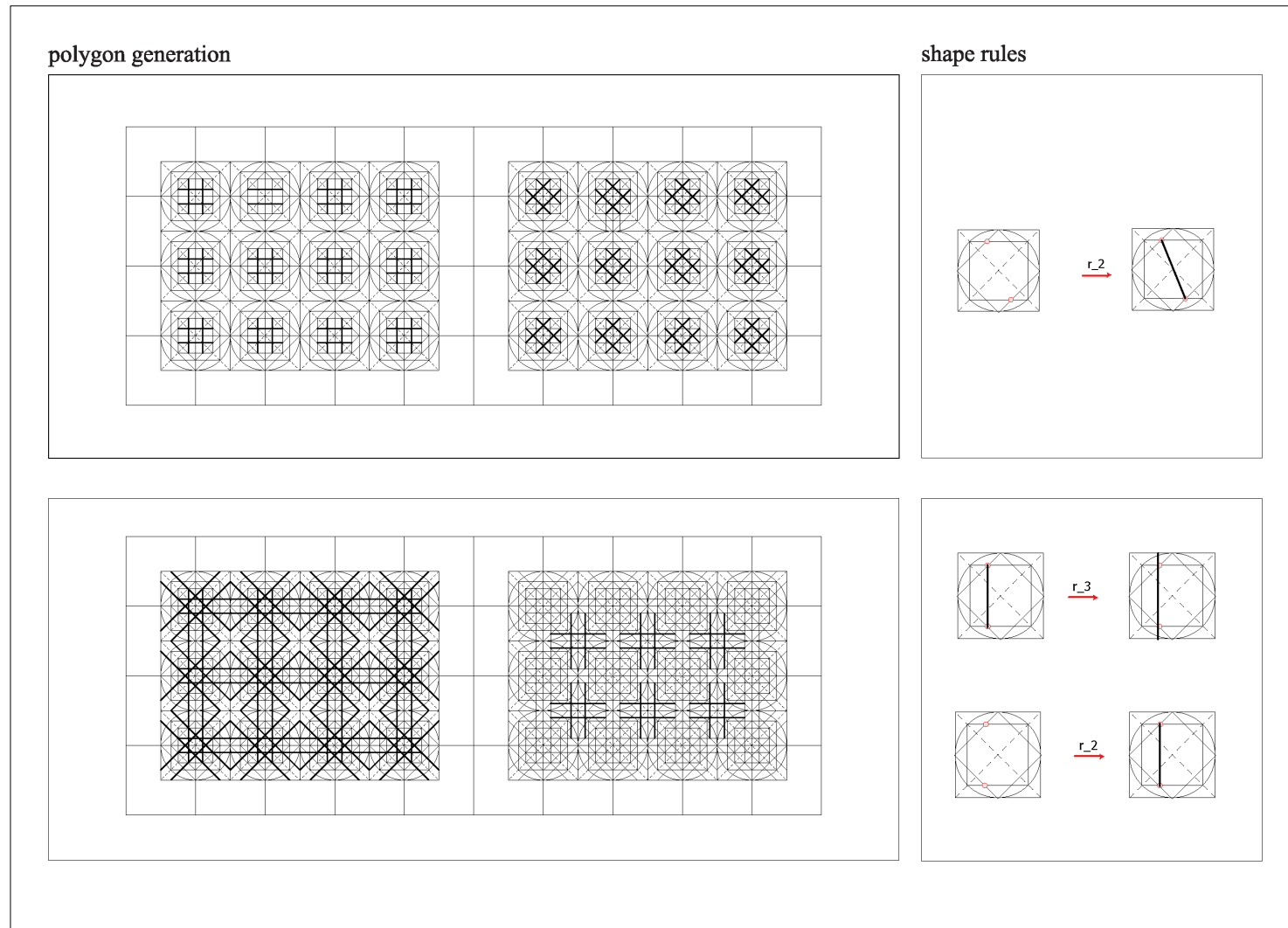


Figure 3.8 : Polygon generation and shape rules of pattern II

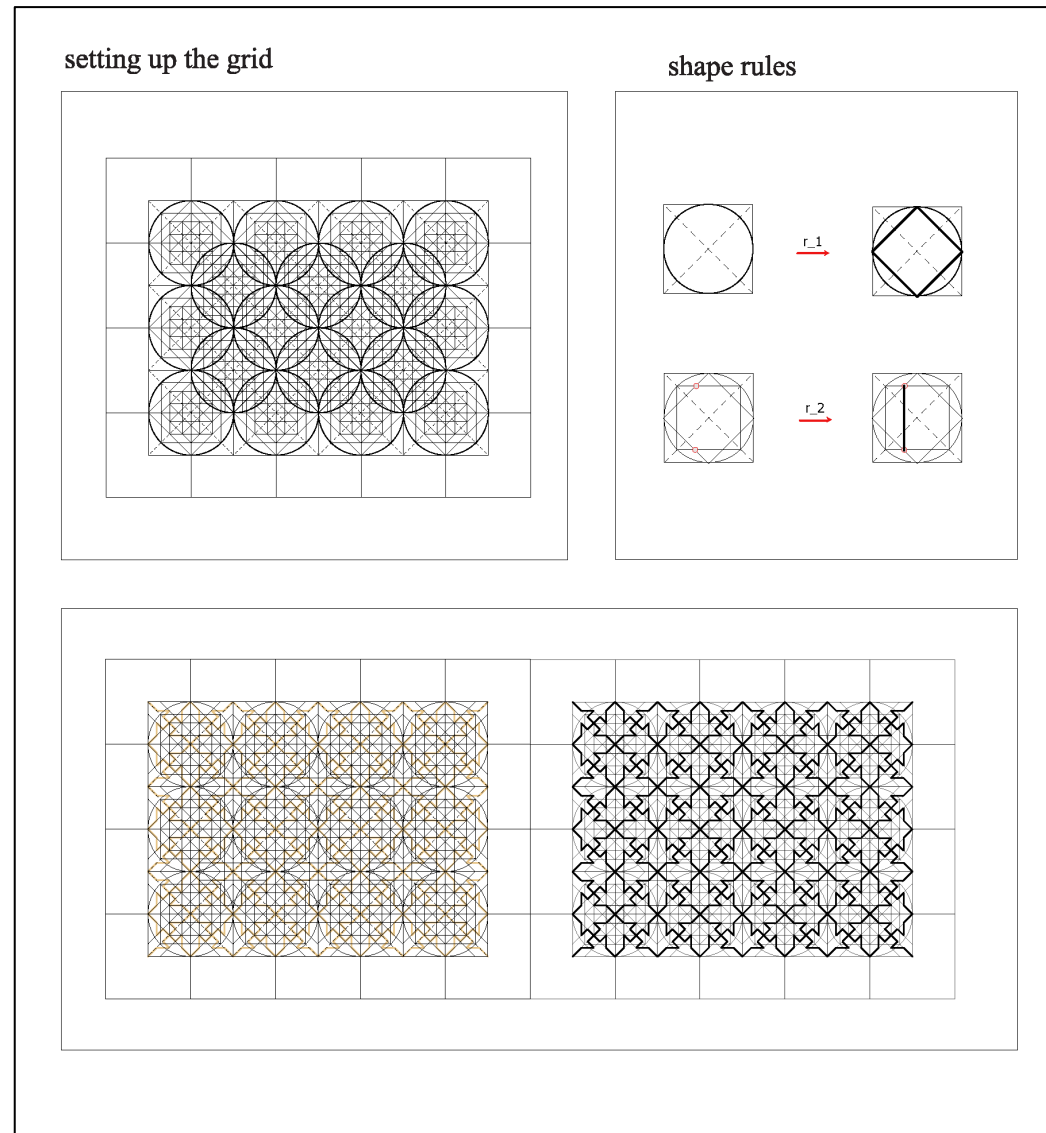


Figure 3.9 : Generation of pattern II from a different grid with the rules on the right

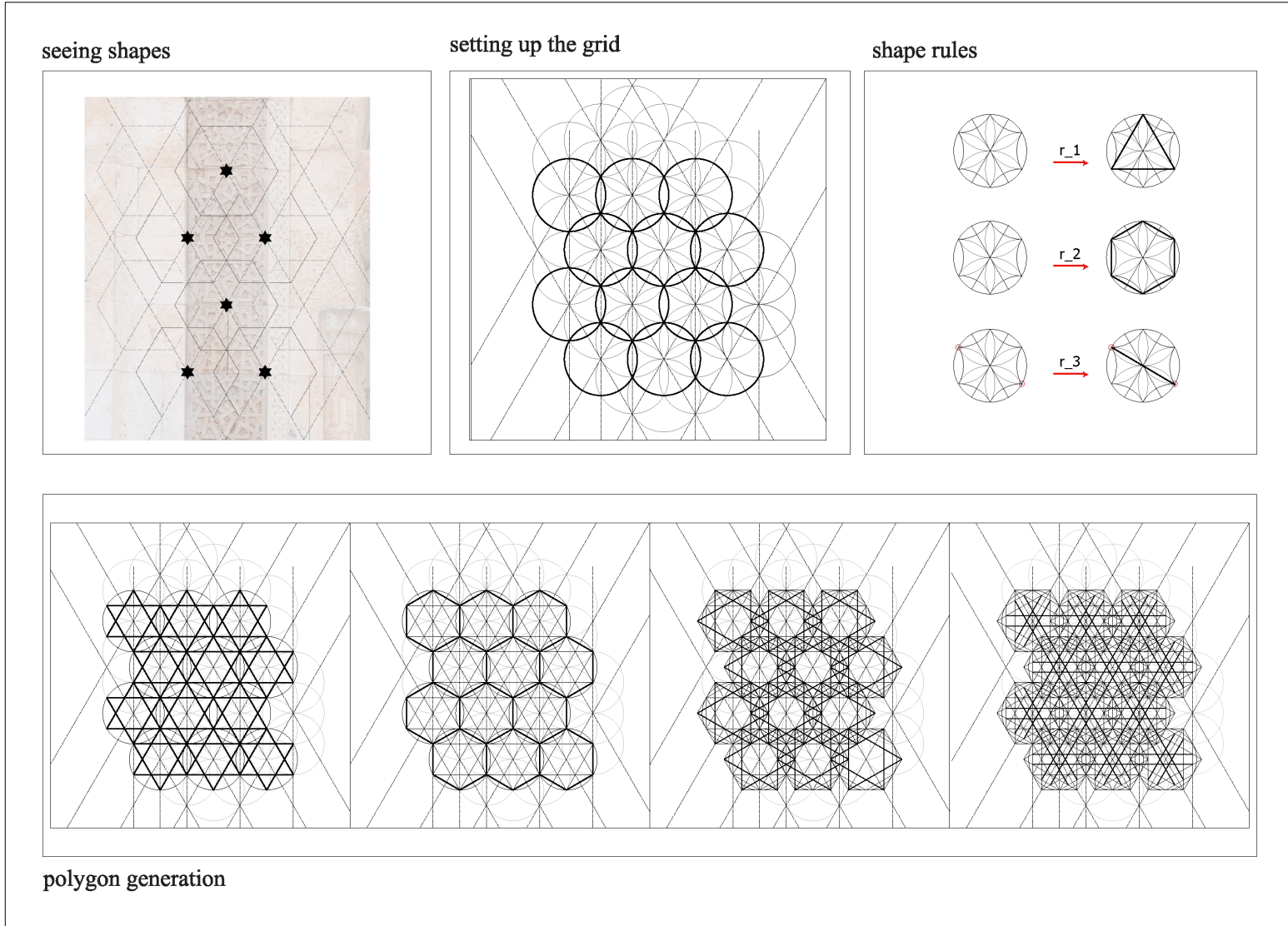


Figure 3.10 : Pattern generation stages of pattern III

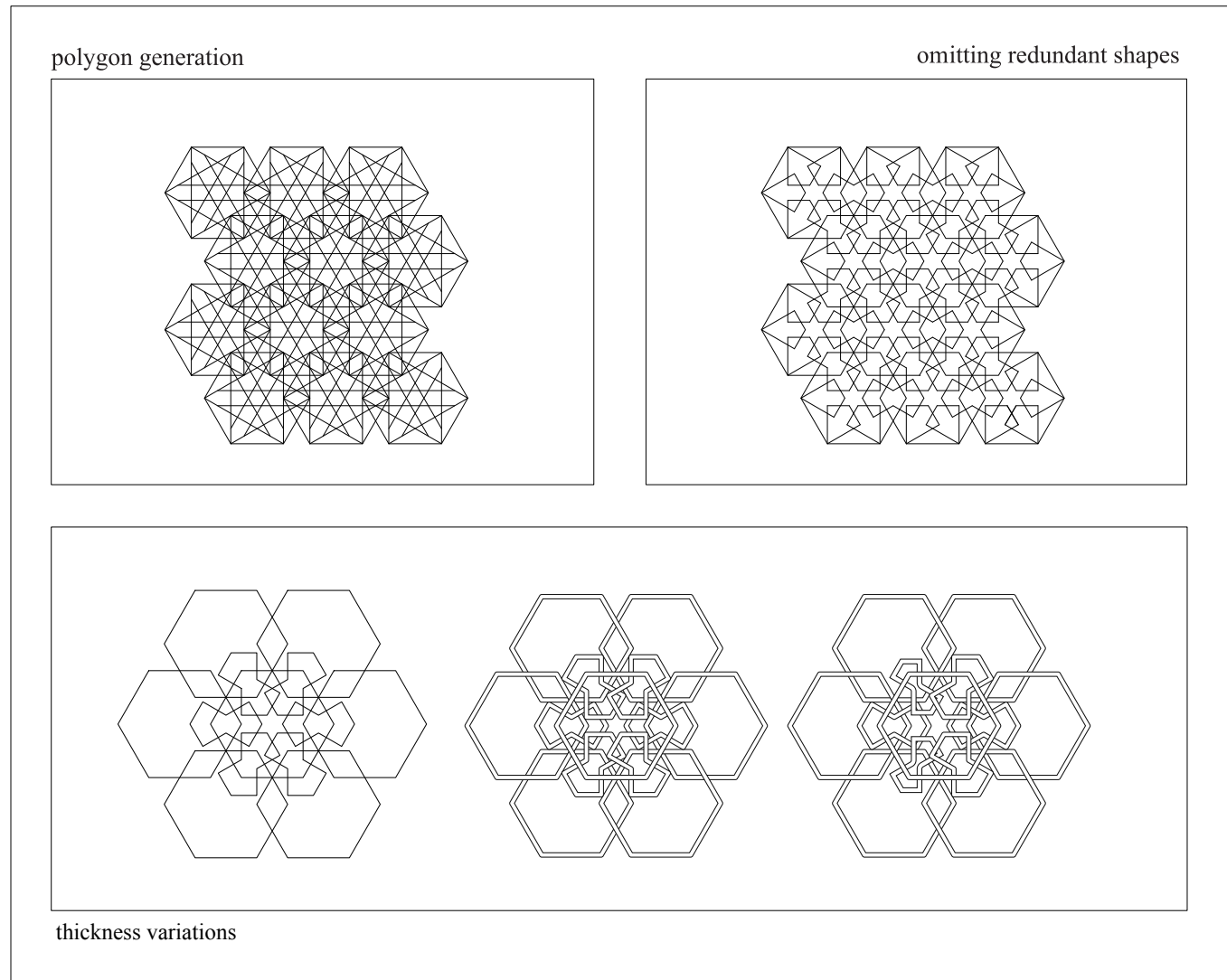


Figure 3.11 : Omitting redundant shapes and thickness variation of pattern III

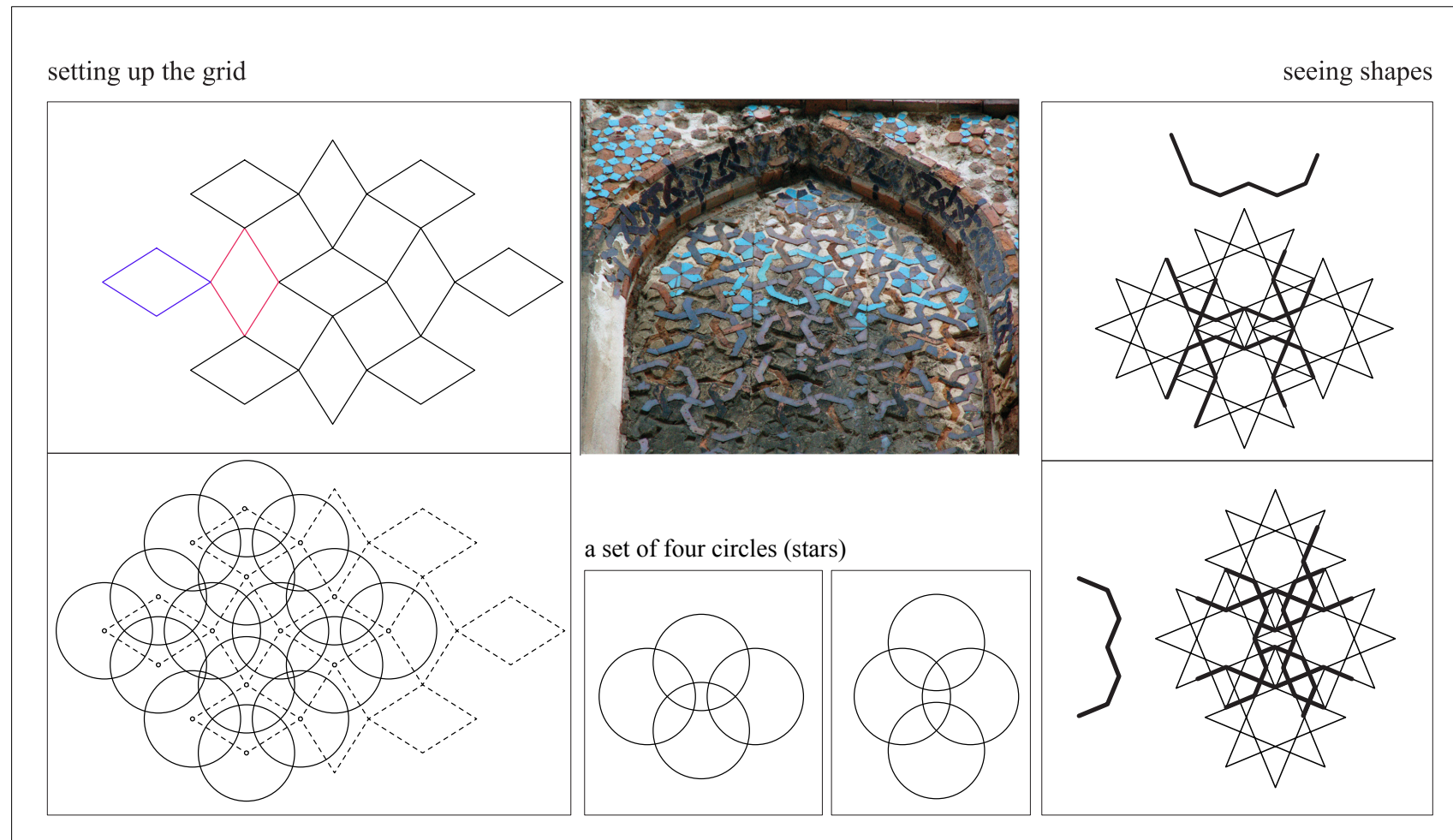


Figure 3.12 : Perception of shapes and discovering the grid of pattern IV

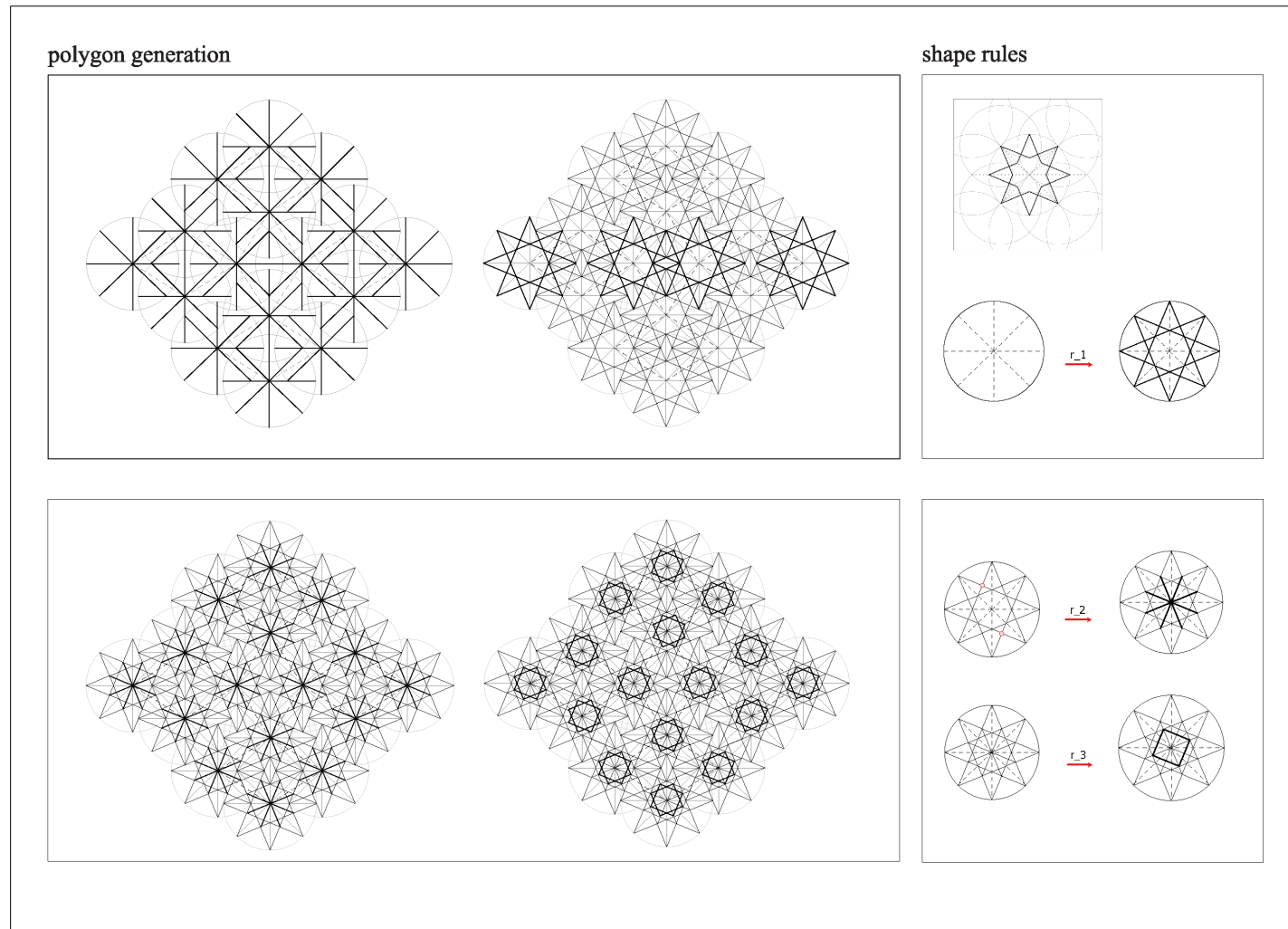


Figure 3.13 : Polygon generation stages and shape rules of pattern IV

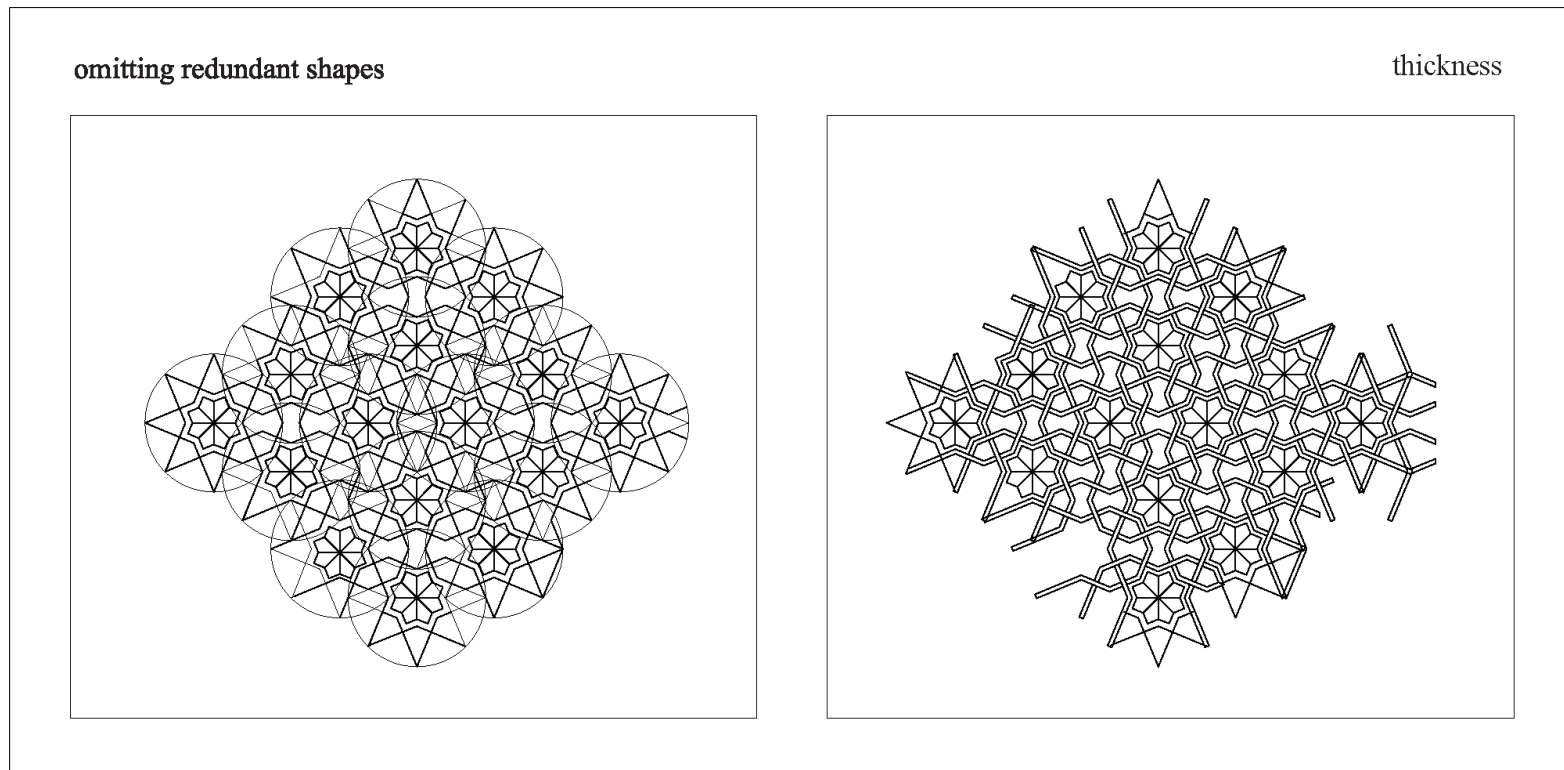


Figure 3.14 : Tracing and thickness stages of pattern IV

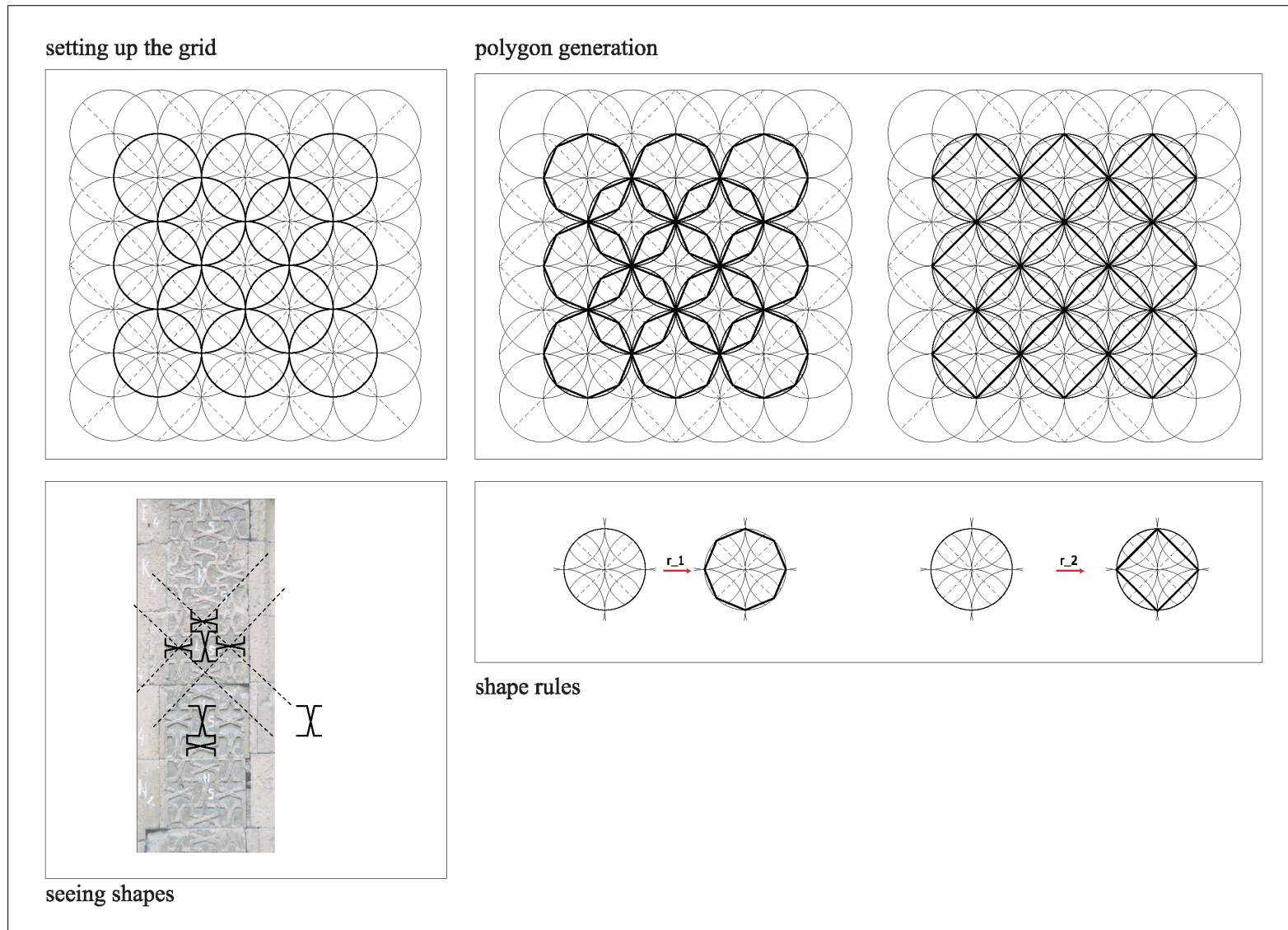


Figure 3.15 : Generation Stages and Shape Rules of Pattern V

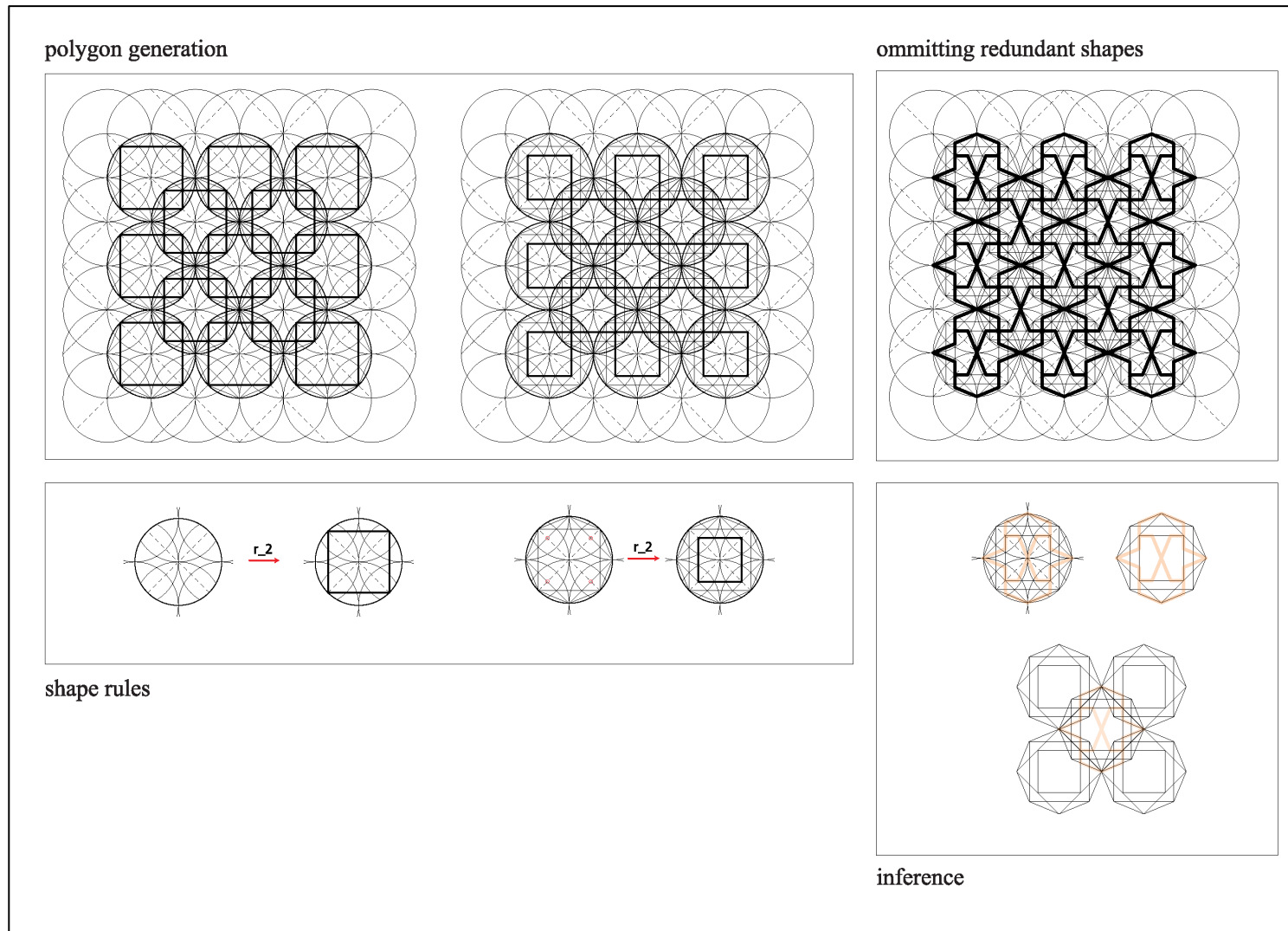


Figure 3.16 : Design Space of Pattern V

3.4 Visual Reasoning Abilities (VRA)

Thinking and perceptual images complements each other through problem solving of a human being. A person mentally constructs representations in mind of information received from the world with our senses. Looking at the same painting, different people create different perceptual images in mind. The filter of perception is the structure or interpretation of what is seen through our eyes. In the scope of this research, visual reasoning ability requires perception, transformation of shapes and their spatial arrangements of the given geometric stimuli. The abilities described below correlated in a way that in the absence of one, others cannot be improved.

3.4.1 Perception

Perception is the way a person sees the external world. In the deconstruction of patterns, recognition and identification of shapes are fundamental. The protocol study is examined for finding clues whether this ability has improved or not. Duration of seeing shapes stage in which perception is utilized for choosing repeating shapes and noticing underlying grid, differs in each pattern generation process. Moreover, number of unnecessary shapes is reduced in the progress.

Table 3.1 : Duration of SSS

	Pattern I	Pattern II	Pattern III	Pattern IV	Pattern V
Duration	6	17	8	6	3

As seen in the table, the duration as one parameter does not show a progress considered the duration of pattern I. When the complexity of patterns such as number of shapes and sub shapes embedded is considered, as a very simple example, only two distinct shapes is recognized. However, since designer lacks the experience in further steps, she also identifies a redundant shape, which emerges from the extension of a star shape.

After first pattern, duration gradually decreases with a considerable reduction between pattern II and III. The reason of great reduction is due to the fact that during SSS of pattern II, designer explores unusual shapes rather than star or named polygons with the presumption that tessellation of recognized “bow tie” shape can

form the pattern. However, without the underlying grid detected by the recognition of a star and hexagon, designer fails and fulfills the task indirectly.

The redundancy in the first pattern and the exploration in the second pattern shaped the way designer looks and sees.

3.4.2 Imagery

Kosslyn (1995) claims that imagery is used for two purposes, which are retrieval of information from memory and transforming a vision. Both purposes are used in pattern generation process, mostly in polygon generation stage as a mental representation for decision-making. The first function of imagery is less challenging than the latter. In transformation of a visual shape, in a situation the transformation of a shape affects the others and spatial orientation, designer experiences difficulty in fulfilling this task in mind and uses external representations as an aid.

3.4.3 Recall-Retrieve ability (RRA)

Recall and retrieve ability is essential for mental imagery to use relevant perceptual images from memory (Oxman, 2002). Imagery is associated with long term memory, which stores more information yet it takes more time to read and recall (Bilda et al., 2006). That is why external representations are essential in learning process as external memory aids. After learning through experience, restructuring the learned information in mind results in correlated intelligence and creativity (Verstijnen, 1998).

4. EXPERIMENT ON VISUAL THINKING

Protocol study reveals design space of the patterns which does not only contain knowledge to generate new patterns but also what is essential for learning reasoning processes to be able to transfer. It is evident that providing a designer with rules and shapes to generate a pattern is lack of transferring design knowledge of the designer who produced them. In the scope of this study, the essential component of learning is not a design product but the way to think to design that product. Focusing on learning design thinking, several abilities, which are required to fulfill pattern generation task, are examined in a way to comprehend how they function and can be improved.

Instead of asking subjects to generate a pattern with giving instructions on how to generate the selected patterns step by step, smaller tasks which test and record reasoning abilities are conducted. The aim of this method is to improve their reasoning skills making them understand the design intention behind shape rules.

4.1 Subjects

Subjects participated in the examination of design abilities are professional designers who are not familiar with the method, shape grammars or Seljuk patterns. Both designers graduated Istanbul Technical University with architecture degree. Subject I who identifies herself as a holistic is a professional designer with two years experience while subject II as an analytics has one year profession with a minor degree in interior architecture. Workspace and think aloud process of subjects are recorded while their sensory activities are observed.

4.2 Tasks

Subjects are given four different tasks performed in two different patterns, which are perception of shapes, spatial orientation, and part/whole shape estimation and omitting redundant shapes. Each task is intended to test divergent abilities of

individuals and improve visual reasoning. The four task using Mahperi Caravansary pattern is conducted firstly. After analyzing the results of the tasks a new pattern from Halifet Gazi Tomb is practiced.

4.2.1 Perception of shapes test

Given a photograph of crown gate pattern from Mahperi Hatun Caravansary and Halifet Gazi Tomb, subjects are asked to identify the shapes they see. As a second part of the test, they are asked to draw the shapes, which forms the pattern. The shapes subject I sees are six pointed star, hexagons and two tangent pentagon in which the tangent segment is omitted (bow tie) whereas those of subject II are quadrilateral, pentagon, hexagon and one six pointed star. Subject I focused on the bow tie shape and made the presumption that all the other shapes especially six-pointed star are form from this shape after the request of drawing the shapes she sees. What is significant is that, imagery is used to transform perceived shape to create other shapes before realization of variant orientation of the same shape. Imagery is not required for perceiving shapes in this context yet it results in creative discoveries.



Figure 4.1 : Photograph of crown gate pattern from Mahperi Hatun Caravansary taken by the author

Unlike subject I, focus of subject II is to find all the shapes she sees. However, she experiences difficulty in explaining the shapes, which do not have a name, and explains only the ones she can verbally express. When asked to draw the recognized shapes, she represents more shapes in sketching than verbal expressions. Numbers on the left of Figure 4.2 are the sequence of drawings. Since she was talking while doing, she started with drawing shapes with names and named other shapes. She called drawing number 7 ‘a rocket like shape’, number 8 ‘a thick arrow’ and number 3 ‘a bow tie’ and number 6 ‘a larger different oriented bow tie’. This reveals the correlation between verbal data and visual data. The drawings become symbols with their verbal associations as stars, triangles and squares.

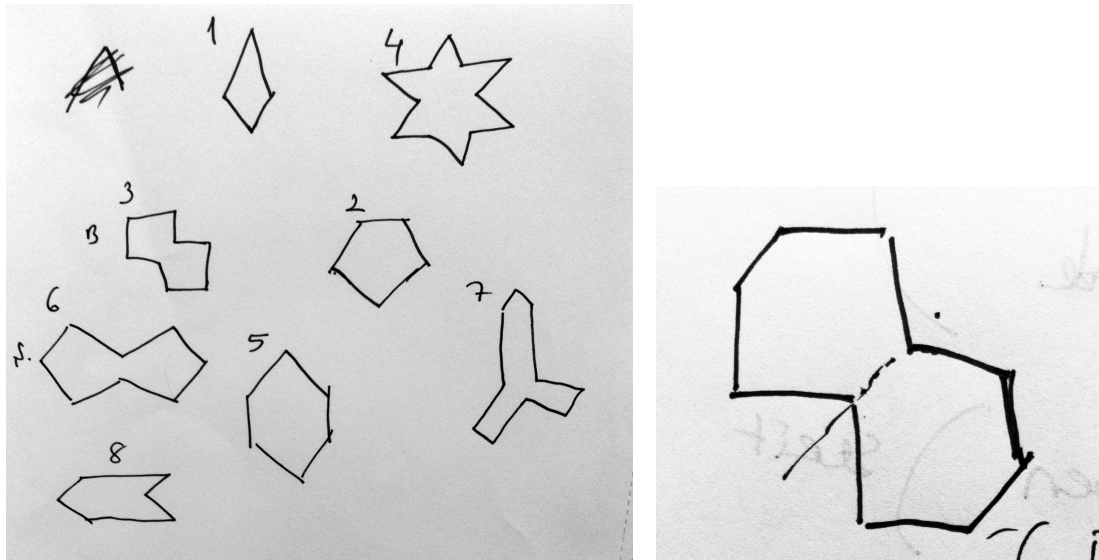


Figure 4.2 : Drawings of subject II on the left and subject I on the right

In the case of the selected pattern from Halifet Gazi Tomb, Subject I answers the question of “what are the repeating shapes in this pattern that constructs the whole shape?” as explaining X shapes, a half hexagon contour which is composed by two different sized triangle and a rectangle. As illustrated in Figure 4.3, she mentally adds new lines to decompose the shape shown in the middle into three known shapes. Attempting to reveal various perceptual shapes, she actually illustrates three different ways to construct the same pattern. It is visible in Figure 4.4 that recognizing white lines as half hexagons with different rotations or seeing black colored shapes instead with variations in their orientation emerges the exact pattern.

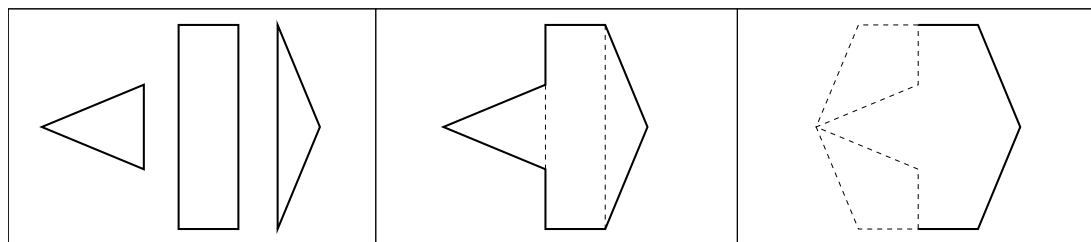


Figure 4.3 : Half hexagon subject I describes

Second part of the test, which is drawing the shapes in this pattern that constructs the whole shape, is represented in Figure 4.4. Electing the shape on the left of the figure, she draws the first shape and continues to draw rotated shapes in a way to compose the pattern. Using a higher level of perception, she draws not only the repeating shapes but also expresses the structure underlying the pattern as a tessellation. A high level of perception requires recognition of structure, mental imagery that associates with recalling from experience.

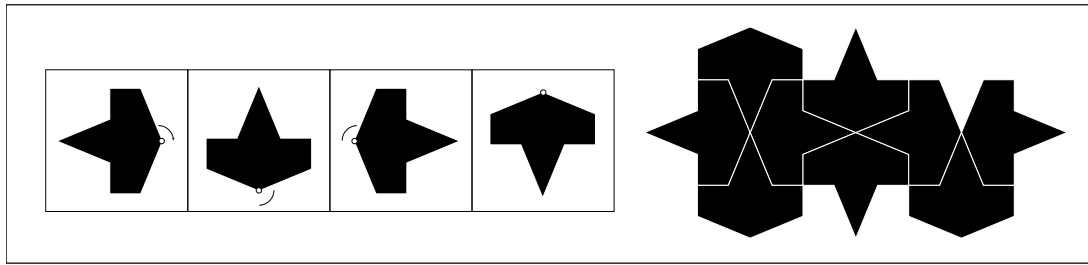


Figure 4.4 : Detection of the repeating shape and spatial relations by subject I

Subject II identifies the shape drawn in the Figure 4.4 and X shapes, which are aligned to perpendicular axis and connected by lines. She seemed to reveal more when it comes to draw the repeating shapes that compose the original pattern. Beginning with expressing underlying structure that exhibits spatial relations, an exemplary 4x4 grid is drawn (Figure 4.5). The grid is declared to be the main grid where the repeating pattern is tessellated. The middle image in Figure 4.5 has secondary grid that is for drawing X shapes. Used as starting points, two crossing lines are drawn to make an X. Consecutive cells of the main grid contains either vertical or horizontal version of the shape. Line connections from secondary grid points to the main, links X shapes and form the pattern.

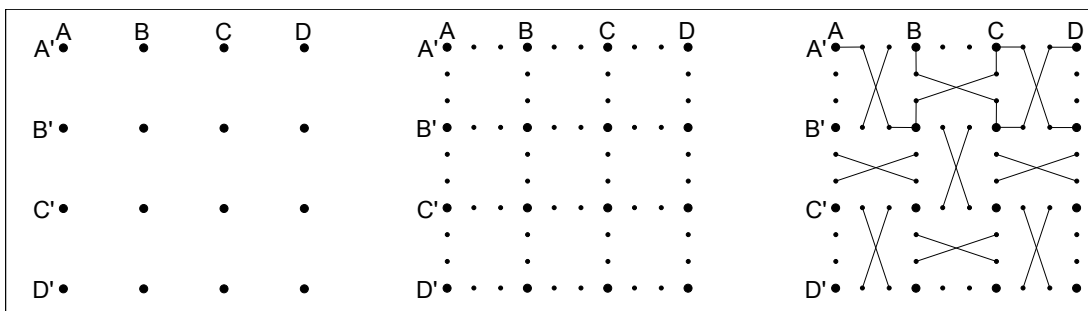


Figure 4.5 : Interpretation of X shapes by subject II

In test where Halifet Gazi Tomb is analyzed, both subjects show a higher level of perception. There is not concrete evidence that performing the exercise again in a different pattern improves their visual perception ability substantially since each pattern constitutes similar structures yet in various levels of complexity. However, revealing more than only what is seen through eyes, expressing one shape in various ways using imagery and understanding spatial relations give clues that subjects starts being interested in not only the shapes but also what those shapes are for.

4.2.2 Spatial orientation test

Subject is given a repeating part that can form the whole pattern and asked to generate the pattern explaining the method. She is expected to transform and order given shape in mind proceeding with drawings after perceiving the pattern.

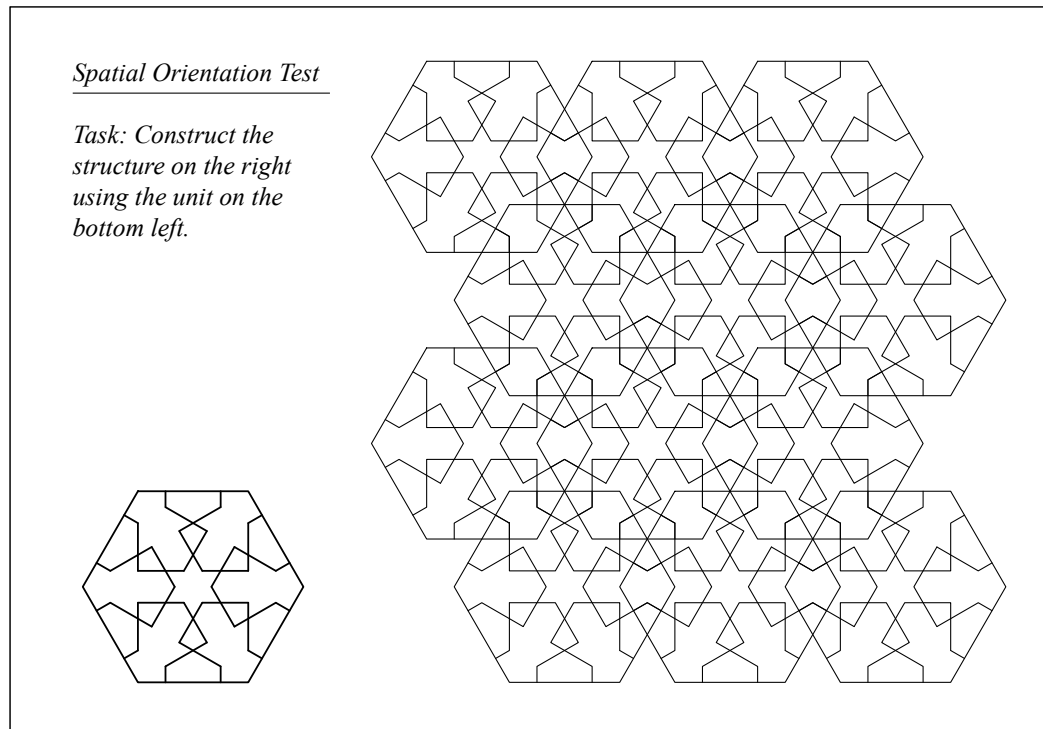


Figure 4.6 : Repeating unit and the whole pattern

Subject I starts by observing the whole to find a clue for the tessellation of the unit. The discovery of the bow tie shape and its different orientations as shown as grey fillings in part four and six of Figure 4.7 encourages her to “complete” the unit by composing bow ties in six vertices of hexagon. By choosing the middle points of incomplete shape, she starts by drawing a horizontal reference line (part 3 of Figure 4.7) that has a measurement as distance for displacement.

Whole pattern is generated by applying the same method of drawing a reference line for displacement of the unit in different directions (fifth and sixth part of Figure 4.7). Since she started composing the pattern from top left unit in the whole pattern, a diagonal and a horizontal reference line was enough for tessellation according to her. When asked to generate the pattern from starting a different position, she realizes that the reflection of the diagonal is required for another direction. Drawing the reference lines required for the spatial arrangement, a diamond grid is composed with

the cognizance of each contact point of the grid is the center of the unit for this spatial arrangement.

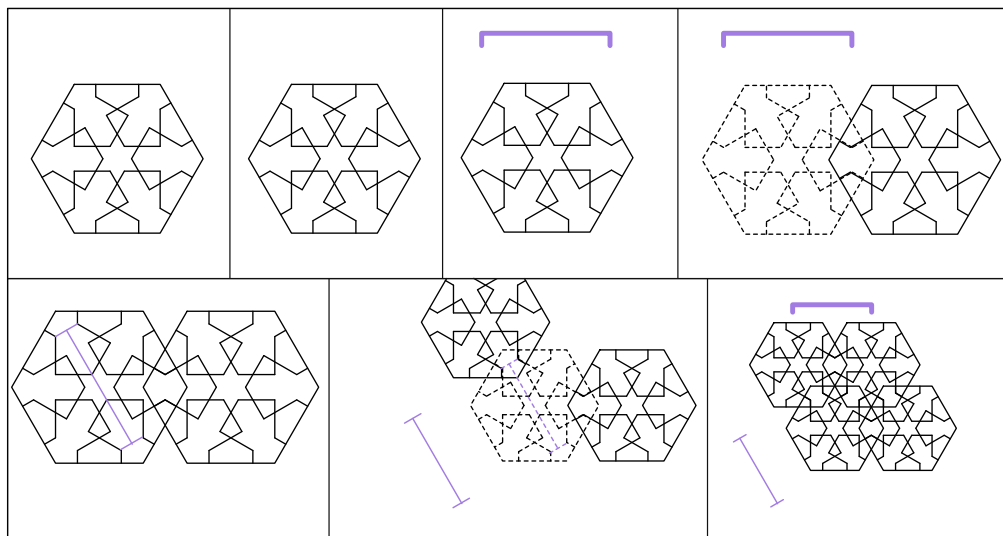


Figure 4.7 : Spatial arrangement way of subject I

Similar to subject I, subject two recognized a bow tie shape that emerges from the intersection of the units (Figure 4.8). However, different than subject I she saw the smaller one which is drawn inside the larger one. Starting with a similar vision, she moved the unit in the horizontal axis by choosing reference points as start and end point that would create a covert distance line in mind by forming the intended shape. Since she did not draw the reference line on the workspace, the drawing resulted in forming a diamond shape instead of bow tie. In the second estimation, the intended shape is constructed by choosing right reference points. Instead of externally representing the logic behind the displacement, she tries to apply it for another orientation of the shape. She fails in the first attempt not being able to transform the displacement rule for another direction. As a consequence of trying to fulfill each task that are the finding and transforming the rule of displacement and forming the shape, she acts intuitively rather than analytically. Instead of constructing a path to follow, she uses trial and error method.

After constructing the whole pattern, she is asked to explain the way she arrange the unit. Urging her to explain how to ‘form bow ties in each intersection’ or seeing them as emergent shapes as a result of the way units are arranged assisted her to recognize the axis underlying the pattern. Drawing the extension lines made her

discover the simple path she was attempting to follow with reference points by highlighting significance of drawings as external representations.

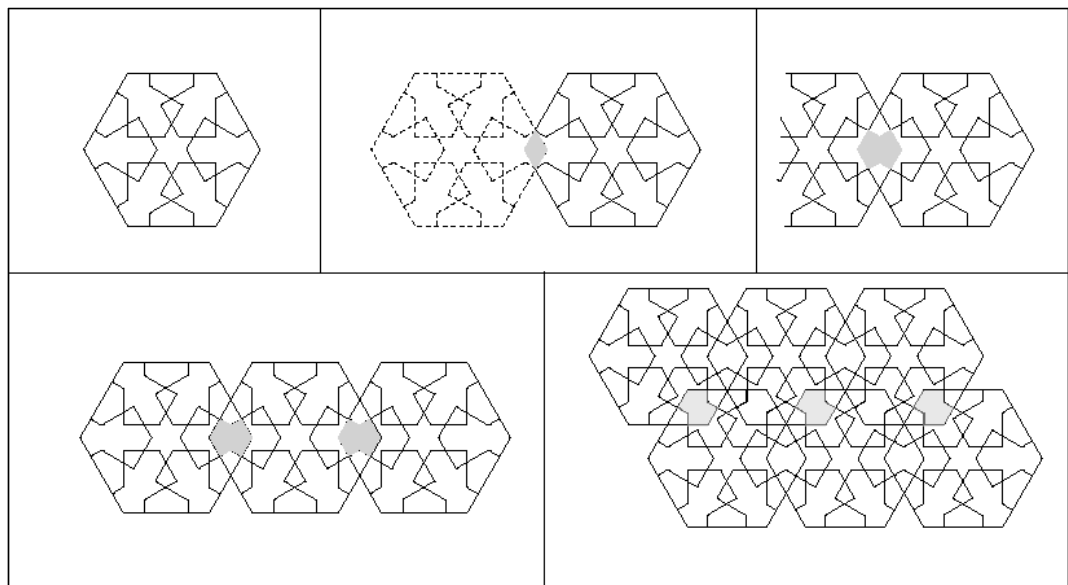


Figure 4.8 : Spatial arrangement way of subject II

As a second test for spatial orientation exercise, subjects are asked to perform the same way for the pattern from Halifet Gazi Tomb (Figure 4.9).

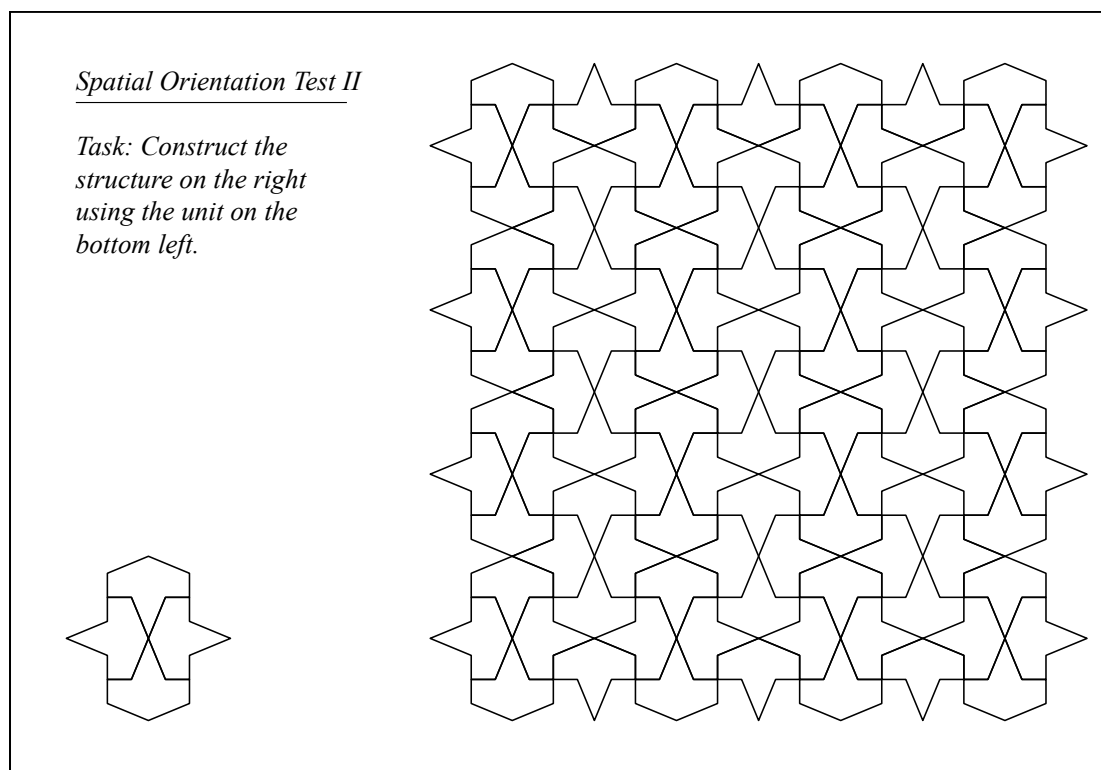


Figure 4.9 : Spatial orientation of the pattern from Halifet Gazi Tomb

Subject one identifies the unit in the pattern and assumes that between each unit there is a rotated variation of the same unit. Rotating the unit, she holds two modules to align like a puzzle as seen in Figure 4.10. Simply perceiving the unit as the combination of four sub shapes, which are topologically same, she rotates and fits parts, which shares the same orientation.

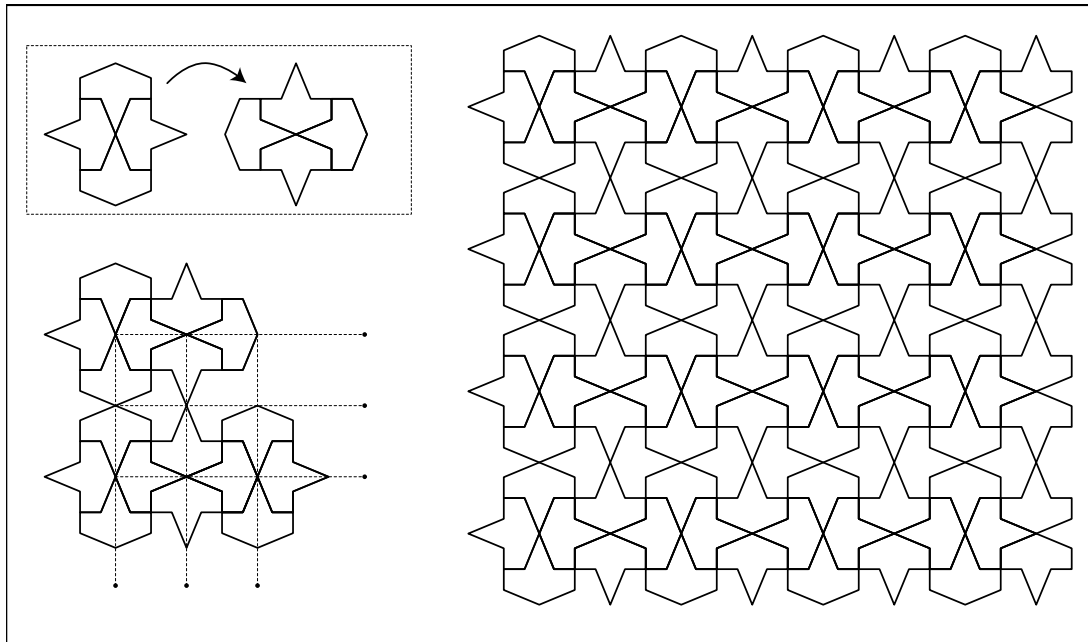


Figure 4.10 : Arrangement of pattern V by subject I

Subject two started by arraying the unit horizontally and vertically. Recognizing the hollow parts in the middle of the units as the contour of the unit, she simply places the unit in.

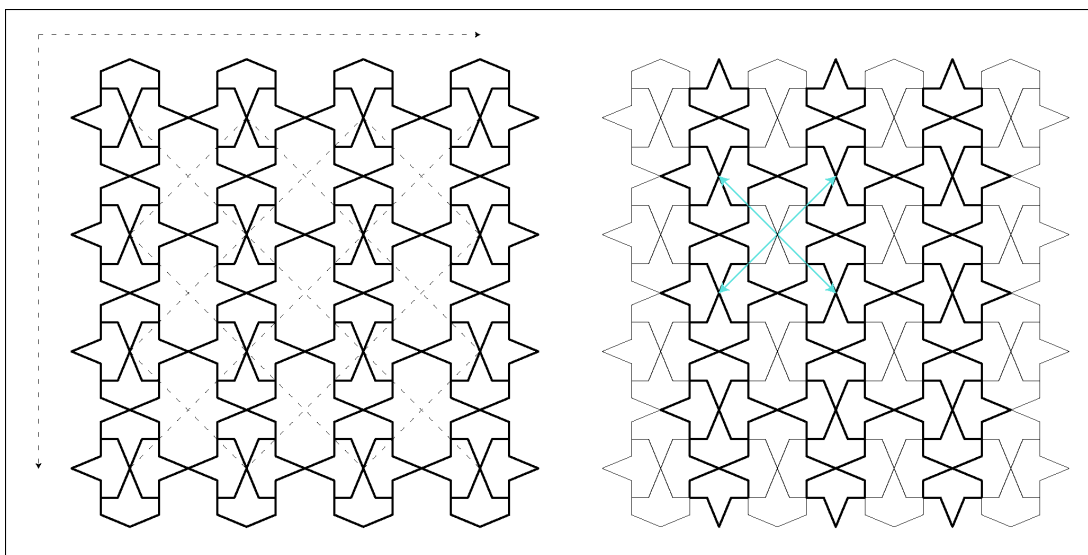


Figure 4.11 : Arrangement of pattern V by subject II

Second spatial orientation test is conducted rather straightforwardly. Managing to comprehend the underlying structure in the perception test, they were only repeating what they have learned recalling from experience.

4.2.3 Part/whole: shape estimation test

Embedded shapes in the pattern are constructed by polygon generation and omission of redundant segments as explained in chapter three in the context of this study. The shapes may be continuous yet they may be uniformed from the segments of divergent polygons. Recognition of parts of a shape is unchallenging regarding the first two tests. On the other hand, estimating a shape from its parts is more demanding requiring a higher level of imagery than perceiving shapes.

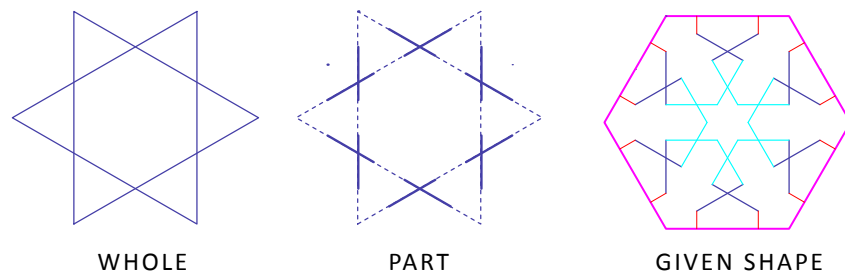


Figure 4.12 : Embedded sub shapes differentiated by color

In this frame of reference, the inquiry is to calculate from which shape or shapes the given sub shapes can emerge. As a part of exemplar design space, a repeating module of pattern III with different colored sub shapes is presented (Figure 4.12). The variation in the color indicates that the shapes with same color are formed from the same polygons. Subjects are asked to find out from which polygons the yellow X like shapes can be formed. Both subjects attempt to draw intuitive shapes such as rectangle and triangle tracing different colors. Tracing the same colored lines did not help due to the difficulty of decision making on empty parts.

After realizing that these are a part of a polygon and other parts of the polygon are deleted but could covertly be seen, subject I extends the yellow lines and discover the extensions composes two identical but reflected triangles. The duration of this test is twice of the second test for subject I with more trial and error moves.

Subject II performed more systematically. She parsed each color group by offsetting the hexagon. Separation assists to focus on the yellow lines and she traces lines by merging collinear yellow lines. Extending traced lines till the hexagon, a triangle is

formed. With this knowledge, rest of the lines is traced by the subject to draw a triangle. She spends half of the time she spent on the second test.

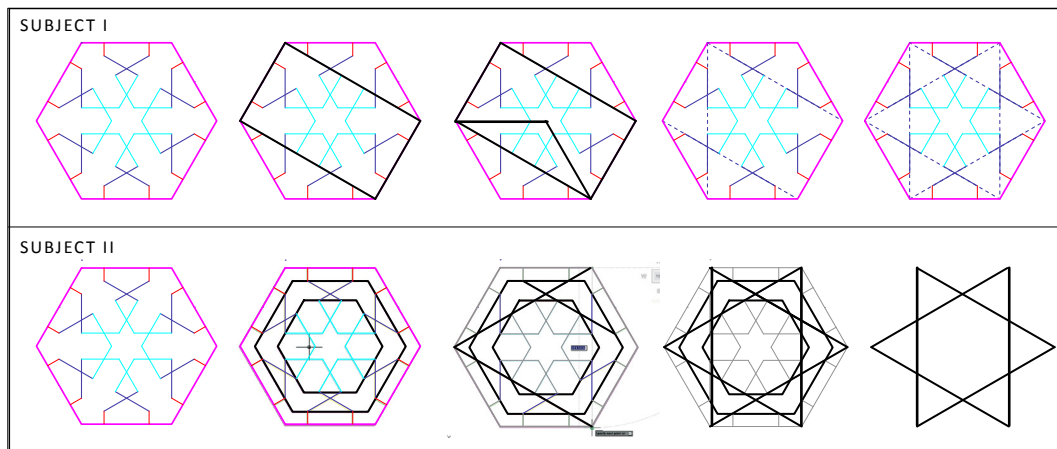


Figure 4.13 : Parsing colors and tracing collinear lines (subject I and II)

Given the repeating unit shown in figure 4.14, subjects deal with generating X shape aligned to the center of the unit. Unlike the shape estimation test above, lines are not colored due to the fact that the shape is formed by tracing the polygons and X shape is not formed by a polygon but connecting contact points with two crossing lines. Shape involves less number of lines with and drawn by subjects. The intention for presenting the module inside of a circle with extension points is to encourage the subjects to work on it.

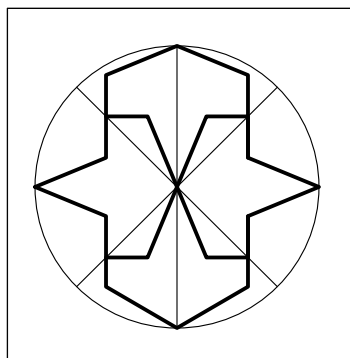


Figure 4.14 : A repeating unit from the pattern V

Operating on the given module with messy lines, both subjects started from scratch using the circle and extension lines as a base. Extending X lines or other shapes in the module do not give clues about shape that the X is a part of. Given module is mostly used for comparing the drawn lines to see if shapes fit. Subject one followed the steps explained below and illustrated in Figure 4.15. She draws a rectangle, an inscribed circle, a quadrilateral to create contact points, an octagon that overlaps with

the lines from the pattern, two adjacent triangle sides for final contact points and connects the points with lines that forms an X shape. The second and the fourth steps are resulted in redundant shapes. Four steps before generating triangular lines are spent to realize what could be the intrinsic structure in the pattern. Generating even redundant lines works as an aid for imagery.

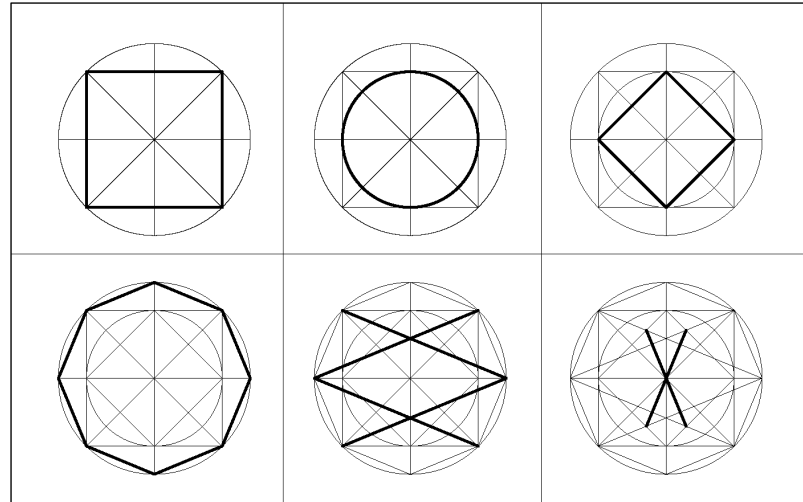


Figure 4.15 : Polygon generation stages of subject I to emerge X

Illustrated in Figure 4.16, subject two achieves drawing the X shape in more stages than subject I. She applies the same rules of drawing a rectangle and an inscribed circle as subject one yet repeating with 3 further steps. Intention of recurring the rule with the further step is to draw narrower shapes that could embody the contact points for X. Extending lines in the fifth step below, an intersection with the circle is generated for drawing the shape. Since the X does not fit the actual one, she continues to create new shapes that intersect others. Drawing the last square, contact points of two crossing squares are obtained for X.

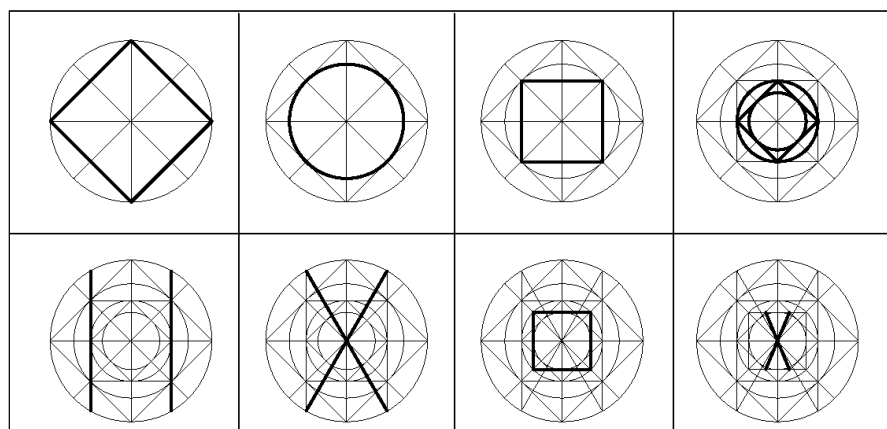


Figure 4.16 : Polygon generation stages of subject II to emerge X

Both subjects reached the solution beginning with same rules followed by distinct steps. Subject two generated more redundant lines. Despite thinking more systematically in the first exercises, she demonstrates more of a trial error method in this exercise. She seems fixated by applying the same rule to reach the X shape rather than seeing other shapes and contact points.

4.2.4 Omitting redundant shapes test

This exercise tests memory and retrieve ability of the subjects different than its purpose in pattern generation process. Last phase of the polygon generation stage of pattern III is given to the subjects to omit the redundant shapes and reach the unit in Figure 4.17 on the right. Omitted unit is only shown to the subjects for a sufficient time for them to memorize. The exploration in this test is the limits of visual memory and how visual modification evokes it.

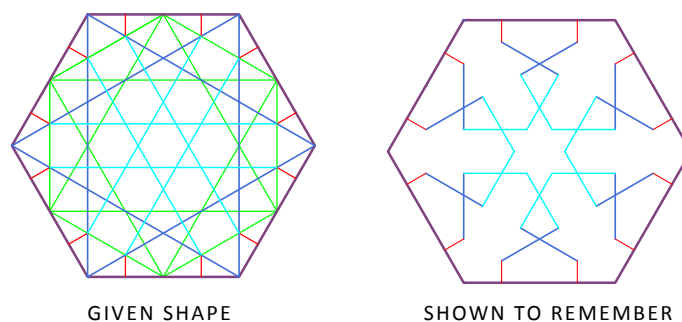


Figure 4.17 : Shape with redundant segments on the left and intended shape on the right

Islamic geometric patterns have been widely investigated by these analysis methods to comprehend how the artisans generate these shapes. In Bakırer's method, using compass and ruler, drawing a circle as an initial shape, a circular template, which constitutes the spatial relations of shapes, is constructed. methods to comprehend how the artisans generate these shapes. In Bakırer's method, using compass and ruler, drawing a circle as an initial shape, a circular template, which constitutes the spatial relations of shapes, is constructed. Both subjects acted systematically applying the same rules to the repeating shapes. They easily remembered and formed the star shape in the middle deleting the segments. However, the incomplete bow tie shape cannot be formed due to the fact that subjects see various bow tie shapes with different orientation and ratios. The yellow X shape is remembered by the subjects yet trimming the lines with the exact ratio was tough. Even though, they consider

they remember the unit, they cannot superpose what is constructed in mind with what is perceived. As they only recall which shapes the unit composed of disregarding their spatial relations, relative relations and extension axis, they simply fail to fit the shapes in mind.

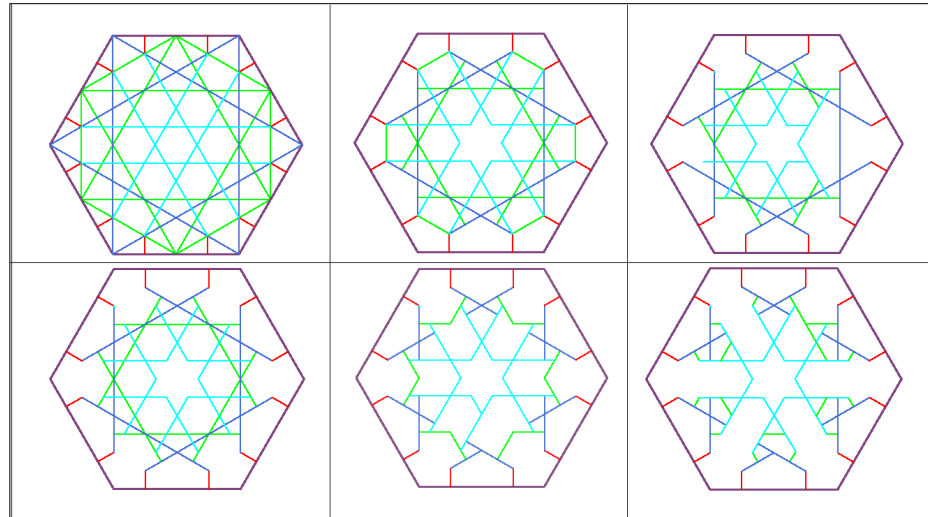


Figure 4.18 : Trials of subject II

A second exercise employing the shape in Figure 4.19 is conducted by subjects for their ability to remember the shape and recall from short-term memory. In contrast with the previous example, this section is completed with success. Both subjects managed to draw the shapes without use of redundant shapes. Instead of trimming unnecessary lines, both traced the shape on the given template (Figure 4.19).

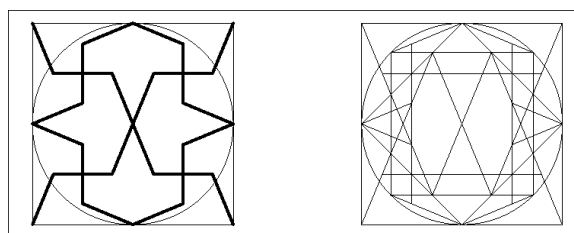


Figure 4.19 : Redundant segments on the right and intended shape on the left

Subject I traced the shape in mind and applied to the shape with redundant lines rapidly after removing the intended shape out of site. Based on the symmetry of the shape, she drew the mirrored version of the same shape as illustrated in figure 4.20. Even though the rest parts of the unit are actually the same shape with various orientations, subject fails to see that but remembers drawing a similar shape. Continuing tracing shapes, a mistake is visible in the third stage shown in figure

4.20. With realization of having chosen the right lines but wrong intersection in the same direction, drawing is corrected.

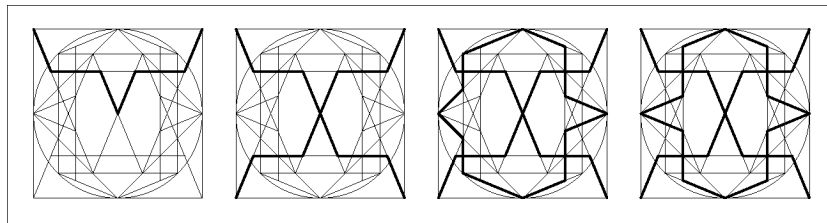


Figure 4.20 : Tracing lines from memory by subject I

Subject two followed a similar way yet chose to follow a different shape as in figure 4.21. After drawing the symmetrical version of the shape, she recognized the X in the middle and continued by connecting X to the previously drawn shape. Final symmetrical and identical part is generated with ease since starting and ending points of the shape is determined by the previous lines with fewer intersection points to try.

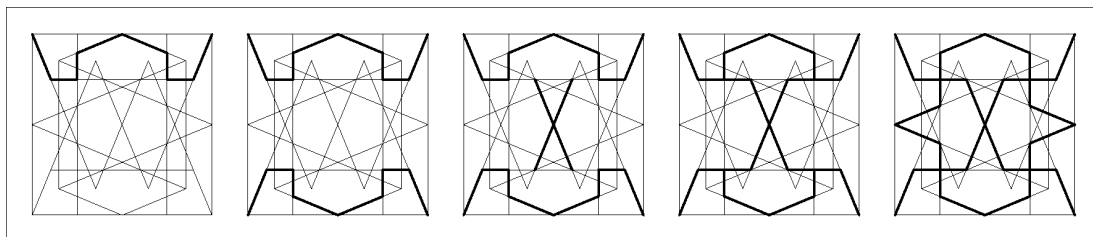


Figure 4.21 : Tracing lines from memory by subject II

The reason of the success in the second exercise may be due to the complexity of the patterns, understanding of the underlying structure better. The level of understanding the underlying structure is obviously higher when the actions and reasoning processes observed. Both subjects seemed to be more aware of what they are doing and what it is for. Moreover, the presentation seems to have altered the method pursued in omission of redundant shapes. Two methods as trimming unnecessary lines and tracing the required shape is both suggested to the subjects. In the colored version, subjects choose to trim the redundant parts while they trace in black and white pattern. The colors give clues about the relations of different parts embedded in the shape. The pattern practiced in the first exercise could actually be traced by following the same color sequence as shown in Figure 4.18 as red→blue→cyan→blue→red. Starting by red line, continuing to blue in intersection with it, follow cyan when blue and cyan intersect and continue tracing back with the symmetry of hexagon results in the repeating shape that actually forms the unit.

However, use of colors affected the perception of shape. Colors made the subjects focus on three different layers of shapes as if they are not connected but designed separately. Perceiving the repeating pattern that was seen in spatial orientation exercise as the part that forms the whole pattern and that can be formed by following red→blue→cyan→blue→red sequence was not possible with the distraction by the colors.

4.3 Designing a Pattern From Learned Rules

The exercises performed by the subjects are designed with the intention of giving an understanding of underlying structure of a pattern, the method used for construction, and intention of the moves and their reasoning. After achieving the exercises, a subject should be able to apply a rule, generate new polygons or lines using contact points, use a grid with various spatial orientations, see emergent shapes with repetition. In order to observe whether they improved their visual reasoning and are capable of practicing what they learned from the exercises, a small pattern design task is given.

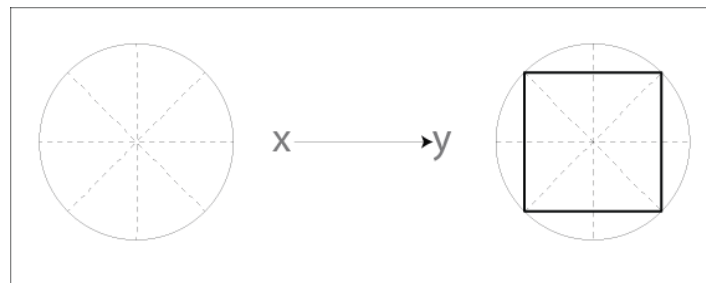


Figure 4.22 : Shape rule for designing a pattern

Shape rule illustrated in Figure 4.22 is applied to create contact points, recognized as a polygon that embeds various sub shapes by subjects many times. The diagonal grid shown in Figure 4.23 and 4.24 is also recognized and utilized as well. Subjects equipped with the rule in Figure 4.22 and the diagonal grid is asked to generate a pattern on a CAD environment.

Subject one started by placing the circles to form a template using the diagonal grid. Having applied the rule for four times, she stops and decides on the next step. After a moment of confusion, a repeating shape is drawn by tracing the polygons. Due to the tangent circle template, detecting the empty parts, she decides to use the extensions of grid connecting them with lines created from the contact points.

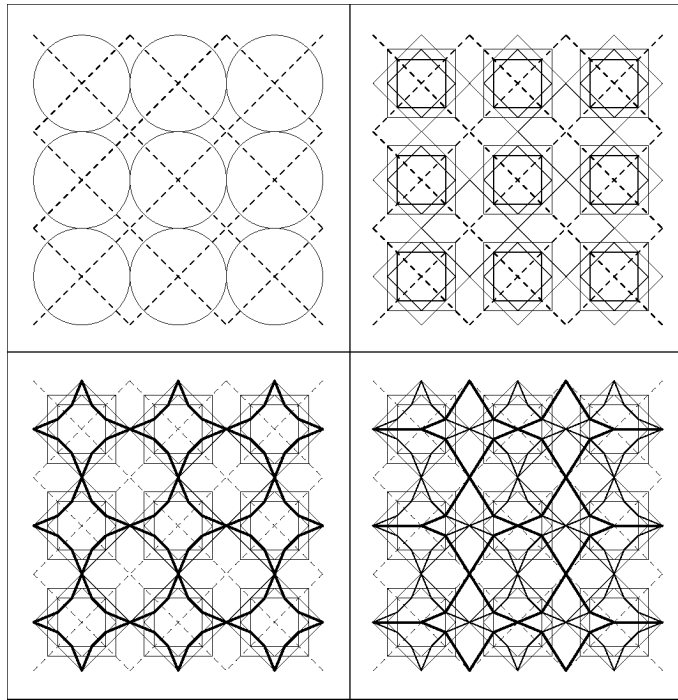


Figure 4.23 : Design of subject I

With the realization of missing circles in the grid, a new template is generated (figure 4.24). The same rules and steps are placed accordingly. Using the new template, a new variation is developed.

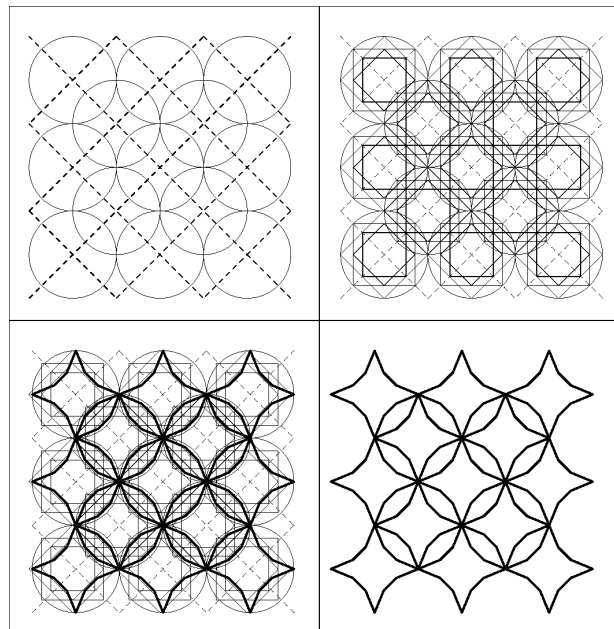


Figure 4.24 : Design variation of subject I

After developing the pattern, subject is asked to create new variations using the produced pattern. Coloring the repeating module or the embedded shape between the modules, she generated various tilings (Figure 4.25).

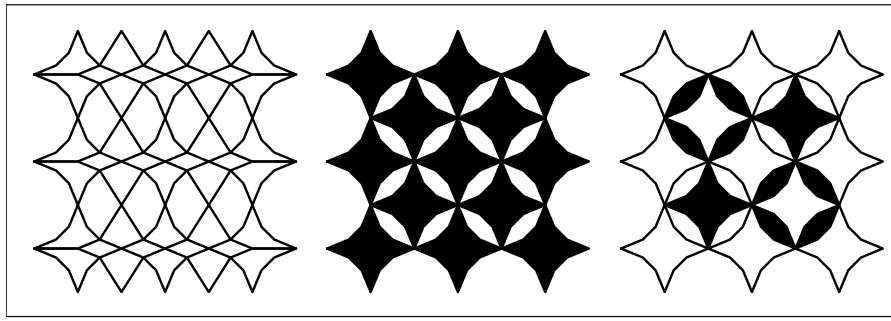


Figure 4.25 : Variations by color

Applying the identical shape rule on the same diagonal grid, subject II generated a very dissimilar pattern from subject I. Starting by drawing circles using the diagonal grid intersections as the center, a circle template where she used to generate varying sized circles, is structured. Even though she generated a circle template where she could produce a pattern, she kept on investigating on generating circles using the contact points method (Figure 4.26).

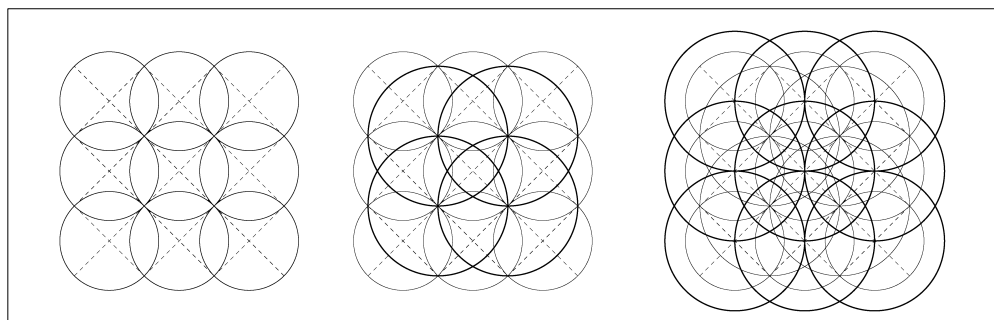


Figure 4.26 : Setting up the grid of the design by subject II

Having completed drawing the template, the recursion of the square rule is applied inside one circle and repeated in each one. After a pause spent on the consideration of the next move, intended shapes are traced and new lines are produced (Figure 4.27).

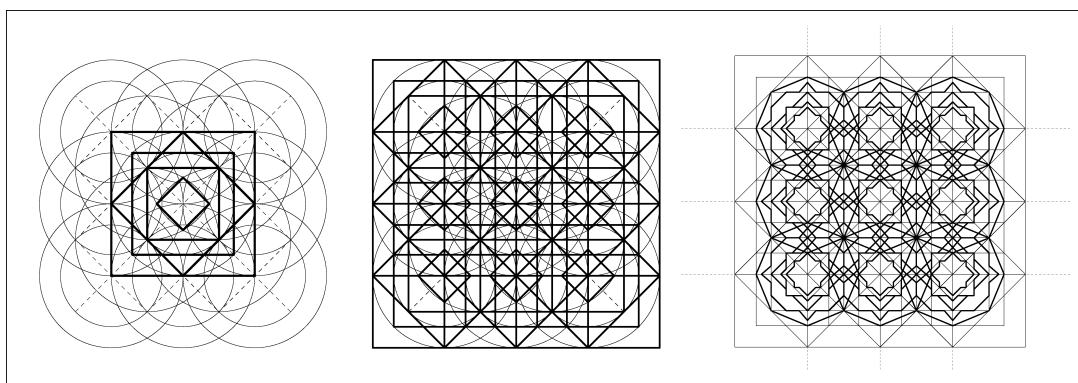


Figure 4.27 : Recursion of the rule and tracing the pattern by subject II

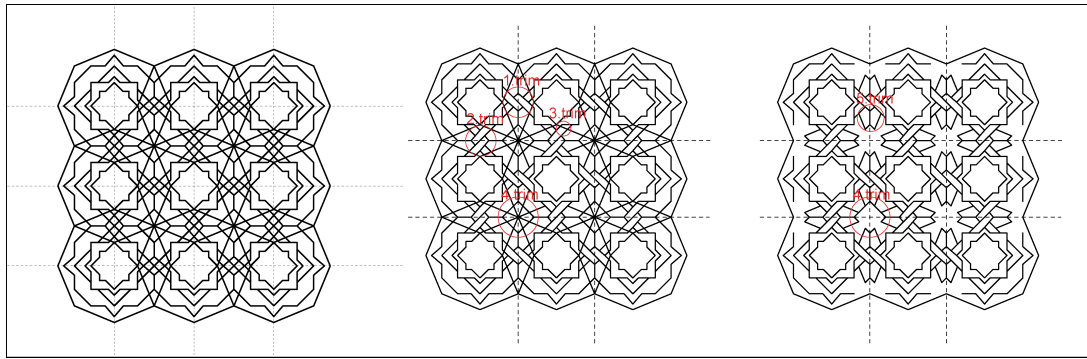


Figure 4.28 : Trimming the lines to form intended shape by subject II

After tracing the lines, the intersecting edges of the outer shape similar to eight-pointed star remind her of a knot. Trimming the redundant lines, a shape like a knot is constructed. With similar associations, she trims three more repeating segments. The fourth trimming is to generate a square image by deleting the middle segments and leaving the edge lines (Figure 4.28). The final design (Figure 4.29) with its production process reveals that subject II can apply the rules, see emergent shapes, and create her own rules with a design intention.

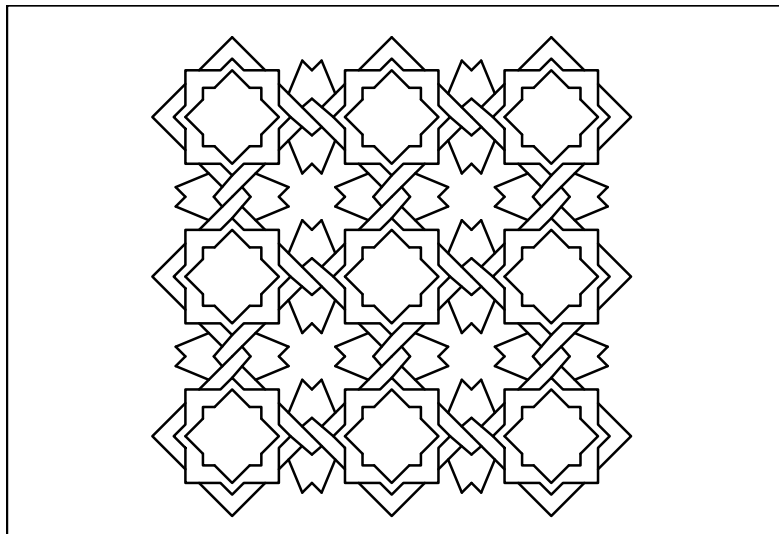


Figure 4.29 : Design by subject II

4.4 Results

Think aloud protocols for testing visual reasoning and recall-retrieve abilities of designers are conducted by two subjects. Perception in the first exercise, imagery in the second, imagery and retrieve in the third and recall-retrieve capabilities in the last exercise is explored consequently. Below the outcomes from these five tasks in relation with the corresponding abilities are explained.

First exercise reveals that both designers see various sub shapes, yet prefer to tell the shapes they can name and prior to them in the hierarchy they perceive. Whereas subject II explains most of the sub shapes embedded in the pattern, subject one chooses a shape that can construct the whole pattern producing sub shapes meanwhile. Moreover, they seem to explore more shapes while drawing due to the fact that drawing does not need a name yet subject II attempts to name them since she was talking while drawing. Perception is related with imagery and memory. Even though they see the same image, they perceive different shapes. The same relation is apparent in the second section of the exercise. Subjects both perceived the same shape yet with different interpretation by reaching a higher level of perception probably due to the memory of previously performed exercise. They do not only recognize the repeating shapes but also the structure of pattern shown in their drawings. In the first pattern they were not aware of what to do with the perceived shapes. Knowing what repeating shapes are about and spatial orientation is used; they seem to capture the essence of the exercise.

Second exercise explores the reasoning mechanisms of the subjects by asking a spatial arrangement task. As visual thinkers, they both recognize a bow tie shape at the whole pattern and arrays the unit in a way to emerge that shape. The significance of external representations is revealed as comparing subject II and I. Drawing the reference line, makes the task simple by assisting imagery to realize the mentally constructed image externally. Even though both perceive the horizontal and the diagonal axis, subject II can only construct the pattern after trial and errors without the aid of drawing the rule. Since they focused on constructing the bow tie shape, they investigated local connections and seeing the whole grid behind the pattern was challenging. In the second section of the exercise, seeing the grid behind the pattern was achieved by ease since they have already discovered the spatial relation in the perception test.

Third exercise is sort of reverse engineering of first test. Instead of perceiving sub shapes in the whole, the shapes/polygons that generates the sub shapes are searched. Subject II deals with this task with ease after isolating each color group/sub shapes. The isolation makes her more concentrated on the yellow x shapes whereas subject I experiences more challenging situations working only on yellow shapes. This exercise is more tricky than perceiving shapes since seeing and scanning what is

visible to eyes is easier than seeing a shape and try to construct it in mind in a way to define its properties without a dimension. It is obvious that drawing functions as an aid for perception of emergent shapes or for seeing shapes, which are already there. All the subjects use drawing as aid, yet the difference is analytical thinking by reframing the problem. In the second section, subjects perform a similar approach, which is the recursion of the same rule. However, subject two gets fixated on the rule that she does not use imagery and relies on the drawing.

Last exercise is mostly about visual memory and how drawings affect it. Since subjects do not know how to construct that unit, they simply attempt to memorize the shapes, rather than their spatial relations. They evaluate the given shape with redundant segments as a base that they can find the pattern in mind by tracing by the eye. Removing some of the redundant shapes assists them to find new paths to follow for reaching the final shape. However, both of them fail in omitting the right segments. Since they do not have the knowledge of generating emergent shapes from drawing various polygons, they do not seem to understand an overall arrangement of the pattern. In contrast with the first pattern, subjects performed successfully in remembering and drawing the shape. This might be due to improving their understanding of the structure of a pattern, alteration in complexity of a pattern. However, it is obvious that using colors affects the perception of subjects.

In each of the test, there is a requirement of each ability. All these abilities are related and dependent on each other even though some of them are more evident in different reasoning mechanisms. Observing the experience they gained from the exercises performed only two different patterns reveals even an alteration in the way of thinking, reasoning and structuring visual information.

5. CONCLUSION

This study intends to compose a computational framework for transferring design knowledge using pattern generation as a tool. Pivoting on learning, focus of design methodologies for learning such as design abilities, external representations, and shape relations are reviewed for understanding the components required for the intended framework.

The shift in the concern of design methodologies from design artifacts into reasoning procedures of designers leads to the research on what is essential for learning and what should be the medium of learning. Embracing the notion that a designer should hold particular abilities to develop for learning design, visual reasoning abilities such as perception, mental imagery, recall and retrieve abilities are reviewed.

Assuming that an individual develops these abilities while learning, exercises that are outlined to develop certain abilities may be practiced for learning design thinking as transferring design knowledge, which is considered to be the development of an ability. Sharing the argument that design is the computation of shape information, a tool which embodies basic design elements, develops drawing skills, helps to construct relations of shapes and shape rules is required in order to develop design abilities.

Seljuk patterns that constitute geometry knowledge, spatial relations, symmetry, hierarchy and order of abstract shapes are well suited for studying on visual computation and reflective relations of perception and action. Designed visually and generated by using compass-ruler, Seljuk patterns are analyzed in design education for teaching computational thinking by analyzing the geometric properties and relations of shapes as a parametric design tool. However, we focused on the relationship between shape computation and visual reasoning abilities rather than geometric properties of the shapes, in order to understand the reasoning mechanisms behind construction of these patterns, revealing the design process as a visual thinking process.

Conducting a self-protocol analysis, author analyzes own design activity during designing and learning repeating the design process of selected five Seljuk patterns. Recording design moves and relevant verbal or figural arguments accordingly, the reasoning mechanisms behind each move is explored and recorded. With a retrospective analysis based on the collected data, recurrence of similar behaviors revealed the stages required in the generation process. Stages which are seeing shapes, setting up the grid, polygon generation, omitting redundant shapes and thickness are examined to find out the relevant abilities required or developed in action. The stages that reveal the path to follow and the repertoire of shape rules that is required for generating all the possible polygons compose the design space of these five Seljuk patterns. Without the perspective of visual reasoning, the design space works as an algorithm to generate novel patterns. What is essential for learning to design a pattern is not only to follow shape rules and procedures but also and most significantly to have an idea of the intention of applying the rule. With this approach, having composed the design spaces of the patterns, corresponding abilities are investigated resulting in a new protocol study for testing what is learned and can be transferred.

Five different tasks about perception of shapes, spatial orientation, part/whole: shape estimation and omitting redundant shapes which constitute various ability sets are conducted by two different subjects. Each task is actually a significant part of the generation stage of a pattern revealing certain required abilities. Completed in two series that is, conducted two times on different patterns, these tests are searched for obtaining knowledge whether they provoke visual reasoning, and improve it. Relations of perception, imagery and memory with each task are revealed with observing the behaviors of subjects working on external representations. As observed in the tests, almost equal experienced designers seem to hold divergent results or methods in different tasks probably due to their learning styles. As a holistic or an analytic learner, the results may vary yet it is shown in the second section of the experiments they both show minor improvements.

In the first set of the tasks, results focus on correlation between shape computation, external representations and visual reasoning abilities such as how subjects detect shapes, whether they see the underlying orders of shapes, how they work on external representations of their mental visualizations and construct relations in mind using an

external representation rather than development of corresponding skills. Moreover, it is seen that these abilities are related and dependent on each other.

The second set of the tasks demonstrates improvements in the way subjects handle the tasks. In the perception task, subjects seem to have an understanding of structure of the pattern in addition to identifying repeating shapes. This shows a higher level of perception. Subjects draw shapes intentionally with a certain aim compared to the first shape estimation test in which subjects used trial and error method. In addition to the improvements in the tests, the effect of color on perception is explained in terms of alteration in hierarchy, order and symmetry, which seem to have an influence on recall and retrieve ability of subjects.

Having completed the tasks and holding results showing the improvements in the abilities, both subjects asked to design a pattern given the same shape rule and grid. The grid and the shape rule are chosen from the patterns they have already studied since the intention in making this exercise is to find out whether they are capable of applying a rule they know using an underlying grid and also, how they interpret this knowledge to reach novel solutions. Observing the designs they produced, they seem to capture the essence of generating a pattern even though it is composed of a very simple rule and a grid. Generating quite divergent designs, both subjects can apply rules, see emergent shapes, and generate their own rules in omitting redundant shapes and also setting up the circular template with a design intention.

The study constitutes some limitations on material, dimensions and number of patterns analyzed by the author, and the number of the tasks tested by the subjects. In order to reach more concrete and detailed results, the number of the subjects and patterns can be increased. Moreover, a longitudinal study may be conducted for recognizing the developments of visual reasoning abilities.

Material knowledge and third dimension as a part of the production process of a Seljuk pattern is not included in the research. How the shape rules can be transformed and utilized with the limitations and possibilities of material can be researched. In addition to this, a third dimension could alter the design process, limit the design rules and add a new stage in the process.

With a designer perspective, the study analyzes the Seljuk patterns in terms of visually produced designs providing a method for generating a pattern visually rather

than dealing with mathematical parameters. This approach give opportunity to unveil that two different pattern which may not be the variations of the same geometric parameters could be product of the same rules and the same circular template. The potential of Seljuk patterns both in terms of visual computation and thinking besides with drawing skills provides a basis for a computational framework composed by pattern generation to learn and teach design. Not only for learning how to design a pattern but for to learn design thinking, a methodology with the curriculum of visual reasoning and computation can be established.

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