Shape Grammars Reality (SGr): Computing in the Real World

by

Nikolaos Vlavianos

Master of Science in Advanced Architectural Design
Columbia University in the City of New York, 2014

Diploma in Architectural Engineering
National Technical University of Athens, Greece, 2011

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN ARCHITECTURE STUDIES
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2016

© Nikolaos Vlavianos. All rights reserved.

The author hereby grants to MIT permission to reproduce
and to distribute publicly paper and electronic
copies of this thesis document in whole or in part
in any medium now known or hereafter created.

Signature of Author: __

Department of Architecture
May 19, 2016

Certified by: __

George Stiny
Professor of Design and Computation
Thesis Advisor

Certified by: __

Terry Knight
Professor of Design and Computation
Thesis Advisor

Accepted by: __

Takehiko Nagakura
Associate Professor of Design and Computation
Chair of the Department Committee on Graduate Students
Shape Grammars Reality (SGr): Computing in the Real World

by

Nikolaos Vlavianos

Submitted to the Department of Architecture on May 19, 2016 in Partial Fulfillment of the Requirements for the Degree of Master of Science in Architecture Studies

ABSTRACT

As a rule, architects calculate, draw, annotate, write, diagram, model, map, photograph, animate, or simply visualize objects, spaces, territories, and processes. They make visual and verbal representations compiling ideas that they have "seen" from direct sensory observations and past memories. Shape Grammars Reality (SGR) allows architects to apply design rules in the real world, by utilizing the idea of calculating with shapes. The current applications of the computational theory of Shape Grammars use primarily sketching on tracing paper with conventional tools.

SGR proposes a user interface on the intersection between Augmented Reality (AR) technologies and eye-tracking research. By using Virtual Reality headsets, a designer is able to brainstorm-draft in real time, by applying basic schemas and transformation rules in the smartphone' SGr app.

The combination of shape rules and Augmented Reality of this thesis is unique since the current design tools within the ecology of Virtual Reality (VR) and Augmented Reality (AR) applications are not rule-based. The designer explores possibilities by inventing his/her own library of schemas through seeing. Given the fact that seeing is by definition a non-linear process, SGR allows the emergence of shapes in design via real time interaction between the reality of a space and the design intention of the user.

Thesis Advisors: George Stiny, Terry Knight
Title: Professors of Design and Computation
Acknowledgements

George Stiny for encouraging me to delve deep into the discourse of Shape Grammars, stimulating intellectual provocations regarding the role of computing and seeing in design and computation. His confidence about the vision of this thesis allowed me to expand my explorations and draw my future trajectories.

Terry Knight for her open culture, close collaboration, and constructive critique, which inspired me to formulate my own inquiry into Design and Computation. Her invaluable academic and personal support, shaped my thesis research motivation and empowered my experience in MIT.

Takehiko Nagakura for our close collaboration and thoughtful conversations around architectural representation and emerging technologies. His academic research inspired me to have a broader understanding of architecture by integrating state-of-the-art computational media.

The Office of the Dean for Graduate Education for awarding me a Presidential Fellowship towards the first year at MIT. The Alexander S. Onassis Foundation, the Foundation for Education and European Culture, and the Samourkas Foundation of NY for financially supporting my studies.
My dear friends from the Architectural Design as well as Design and Computation groups for their insightful conversations promoting an intellectual discourse. Special thanks to Asii, Theodora, Moa, Cagri, Onur, Dina, Paloma, Athina and Ki for your support and our long conversations.

My family for supporting me and making my dreams possible.

In honor of a great Man
A.H. II
Shape Grammars
Reality (SGr):

Computing in the Real World
# Table of Contents

## 1 Introduction  
1.1 Hypothesis  
1.2 Method  
1.3 Steps  
1.4 Intended contributions  

## 2 Background: Visual Calculation with Shape Grammars  
2.1 Seeing  
2.2 Schemas and Rules  
2.3 Embedding  

## 3 Visual Thinking  
3.1 Direct perception – direct sensory observation  
3.2 The influence of past memory on the perception of the future  
3.2 What do architects and non-architects see?  

## 4 Shape Grammars Augmented Reality  
4.1 Project Overview  
4.2 Virtual Reality, Augmented Reality  
4.3 Why rules?  
4.4 Why calculating as seeing?  
4.5 Interacting with SGR  

Shape Grammars Reality
4.5.1 Edge detection pp.45
4.5.2 Eye-tracking pp.46
4.6 Shape Grammars Reality (SGR) pp.48

5 Conclusions pp.66
5.1 Contributions pp.68
5.2 Concluding remarks pp.69
5.3 Future work pp.70

Bibliography pp.72
01. Introduction
As a rule, architects calculate, draw, annotate, write, diagram, model, map, photograph, animate, or simply visualize objects, spaces, territories, and processes. They make visual and verbal representations compiling ideas that they have “seen”. In this thesis, I propose a computational method of designing through Shape Grammar rules in the real world. My main research focuses on the advanced computational theory of Shape Grammars, which was invented in 1971 by George Stiny and James Gips. To do so, I reconcile a real-time interaction between the designer and a real space by using a rule-based generative approach. Moreover, by using the power of seeing in design, my goal is to establish a platform using the ambiguity, improvisation and the non-linearity of the design process as vehicles for a novel method.

The early applications of Shape Grammars use primarily pencil and tracing paper in order to apply schemas and rules. Shape rules are the materialization of the basic schemas $x \rightarrow x$, $x \rightarrow t(x)$ transformation, $x \rightarrow \text{prt}(x)$ part. Rules are intuitive and appear in the design space as the expression of design thinking. One of the most important contribution of Shape Grammars is the embedding relation, which describes how shapes can emerge out of different configurations based on the way we see things. Embedding operates as a “creative enhancer” promoting what designers mostly call contingency. In other words, embedding allows a designer to see, pick, and manipulate certain shapes by applying basic schemas and rules, while freedom engages on which, what and when embedding operates.

The motivation of this thesis is to bring Shape Grammars in the real world by utilizing embedding as the main contributor of a rule-based approach in design. This thesis attempts to help designers to understand it, though it is broadly used by definition in every single design. The problem is not to define what embedding does, but to create a thorough study of various moments that we as designers operate in a similar manner.
This thesis proposes an alternative way of using technology in Shape Grammars. By utilizing state-of-the-art eye-tracking systems and computer vision algorithms, I create an advanced computational system for designing through seeing. I use Shape rules to generate designs empowering the role of improvisation, ambiguity and discovery in order to generate emergence in design.

By using the Shape Grammar literature, I bring embedding in the real world as a computational method for real-time design brainstorming. The reason that this thesis uses Shape Grammars has to do with the rich culture of Shape Grammars and the fact that they engage computation through a wide angle. As a rule-based generative system, Shape Grammars allow designers to create emergence not as an obsession to generate the unexpected, but primarily as a need to see what design can produce. Although previous thesis projects as well as papers expand on the notion of embedding, I consider that this thesis has different methodological approach.

The analytical angle of this thesis is centered around the question: Who can we compute with rules in the real world? How do the rules come from? How does the designer see things that already exist in the design space with potential emergence? Do rules restrict the way we perceive design freedom and how does design intuition relates to past memories?

The main body of this thesis is developed in three steps: Background: Visual Calculation in Shape Grammars; Visual Thinking; Shape Grammars Augmented Reality. Chapter 2 expands on the literature of Shape Grammars and in particular the role of calculating with shapes rather than symbols. Shape Grammars are the very first computational design systems that are visual, tangible, and perceptual consisting of shape rules. The role of rules is important because they are explanatory, creative, experimental, and enable emergence in design.
What strikes my interest in Shape Grammars is the role of seeing, since every time we see a shape, we perceive different things or we calculate non-symbolically by looking and drawing.

Chapter 3, Visual Thinking, discusses the way that this thesis deals with the direct sensory observation and the memory of things in design. Designers constantly compose ideas based on past experiences and future design challenges. The way they perceive objects ontologically inscribes the potential impact of them to the design work. The term embedding is proposed to denote the importance of inquiry into visual thinking – visual calculation. This chapter also discusses the problem of seeing and assigning meaning.

Chapter 4, Shape Grammars Augmented Reality, presents a novel method for design on the intersections between augmented reality technologies and rule-based generative approaches in design. This chapter expands on the limitations and the challenges of the proposed computational system as well as shows the application at the façade of the MIT Simmons Hall, an undergraduate dormitory designed by the famous architect Steven Holl. In addition, this chapter discusses the use of computational media, such as eye-tracking technology, Virtual Reality (VR) and Augmented Reality (AR).
This thesis aims to problematize architects and designers concerning the use of rule-based generative media through computations in design. Considering that design education understands computing from a tool based logic, I aim to problematize concerning a broader definition of the idea of calculation in design. For the “tool-users” I will propose a tool for further speculation towards new means of using technology in architecture and design at large. For the “tool-makers”, I encourage their capacity to utilize and borrow knowledge from the fields of psychology, anthropology, cognitive science and computer science, in order to feed our field with broader ideas on how things work or could work. This thesis intends to articulate design ideas from a computational point of view by using the rich discourse around Shape Grammars, while inventing its own way to stand and create a new enterprise.
02. Background:

*Visual Calculation with Shape Grammars*
There is an emerging interest in the field of design and computation on how Shape Grammars work. In this thesis, I am using Shape Grammars, as one of the most advanced computational systems that is rule-based. Shape Grammars are spatial, dealing with shapes in a non-symbolic way. Shape Grammars support emergence in design by simply allowing the human eyes to see. This means that calculating with shapes is an open-ended process that acts in a non-deterministic way. Calculation involves seeing because the formation and the rule selection are made by the designer. Seeing requires an active engagement and by definition exists as a creative process in visual arts.

A naive question would be: how we see in order to be able to understand a design? In other words, the question implies that seeing and understanding go hand in hand. I do not really agree with this perspective of seeing, since it attempts to formalize and create a norm for seeing. Since seeing does not have boundaries for particular ways of observing, it can simply be used in this thesis as a basic way of observing things. In this sense, a designer will avoid to pay more attention on the technic of seeing but rather observing his design. There are many studies from psychology, anthropology, cognitive science, ophthalmology that captured my interest during the research of this thesis. I was debating to bring different theories and create an "epistemological" approach of seeing. "Epistemological" in a way that different fields define terms, make assumptions, organize experiments and prove certain things relevant to their initial premise. In the case of this thesis, I decided to use examples that made paradigmatic shifts on the way we understand seeing within the field of design.

On the following example, I tried to add two squares and draw the new shape. I immediately realized that by defining the initial two shapes as squares, I tried to name and restrict the output of this addition. In other words, I pushed myself to see in particular way and define what I see. In this case, I allowed myself to avoid

2 Background: Visual Calculation with shape Grammars

2.1 Seeing

\[ + \]
seeing in a strict way and I ended up refusing any naming or formal definition. I intentionally copied the same rule, since I believed that the previous one had already the assignment. Although I copied the equation, I was able to verbally describe what happened in a different way. So, I added two shapes, in order to create a new design. It was pretty easy to call again the new design as a shape, but this could have created the previous issue with its limitations for creativity.

There is an interesting way of seeing in this case. I personally see a rectangle, two squares, a few lines, or even more lines. Although the way I discuss my observation does not seem rigorous, I try to simulate a personal reading rather than offering a structured way. I am interested again to see the same equation and simply copy it. This time I do not really see anything, because I have already fixed my way of reading the emergent shape. Does this mean that my observation no longer engages the subject? A potential answer would be that there is not a subject or that seeing does not have a way to evaluate. Through this point of view, I consider that I see other shapes rather than the design that is produced. This type of observation of a non-existing shape could be my own way of explaining how rules appear and come into play in Shape Grammars and in design.

The moment that I start seeing something else or I make projections of something that does not exist gives birth to a new rule. Seeing in this case operates as an inventive vision device or a mechanism that intends to empower design intuition.
Shape Grammars have schemas and rules. The basic schemas contain rules enabling the designer to further manipulate them by assigning further rules. For instance, I want to apply a schema of $x \rightarrow \text{part}(x)$ while the part of $x$ can also be scaled up. Schemas allow more advanced design opportunities defining rules. By starting from an initial shape, a designer applies the rule using registration marks (red crosses on the example). The computation of the rule contains steps of the same rule or they can combine different rules in the process. The example on the side shows that a grid is created by squares, while a second rule assigns a more complicated design into each square. Although the process of Shape Grammars can be broken down into five steps (Shapes, Shapes Relations, Rules, Shape Grammars, Designs), it is ambiguous how different steps engage in the design process. Since we have already discussed the role of seeing in Shape Grammars, I want to highlight the fact that the application of rules is not strict, but it is driven by flexibility.

Once a rule is used the computation allows a new way of seeing the next step. This means that the designer is able to articulate further a type of transformation that fits more to his vision. The description or the unpacking of the design process at large seems problematic since the alternation of schemas and rules cannot be inscribed by any means of structure. As the designer proceeds, the history of the design disappears but already used rules can become handy. Even if we accept that the designer re-uses a rule, the application itself as well as the way he sees the design has completely different contingency. In this sense, every step has an instance and once the rule is applied a new design potential appears momentarily. Returning back to example of the next page, by the time I stopped the computation my desire was to completely alter the design. At the same time, by skipping a few steps (..) of the computation, I instantly realized design rules within the hidden steps. This implies that Shape Grammars 'rules are totally non-deterministic enabling emergence.
I have already extensively given a general explanation of embedding. Here, I want to give a few examples on how embedding operates in relation to seeing. As the rule shows on the example (right side of the page), I have two overlapping shapes. I can either perceive this arrangement as a shape that consists of maximal lines, or as two shapes that share on part. Either way, I am able to identify see a design potential and a new rule by simply observe the configuration. This allows me to apply a transformation rule on the overlapping part, since this part does not belong exclusively to the current setting. Therefore, I embed a shape by seeing the design potential on this part. Obviously, I started with seeing and I prioritize vision as the main faculty to comprehend the design.

Embedding operates as a way for the designer to assign meaning or find meaning. For instance, a great example of embedding is a conversation between people. In this case, embedding can be represented as a sort of consensus of ideas or the embodiment of ideas that are raised during the discussion. In other words, embedding emanates from the inside (emergence) giving birth to things that are in constant transformation or flux. I see something by applying a rule, but I tend to move forward or backwards in order to facilitate a different emergence. Given the infinite world of seeing things in design, each designer might have different way to embed. Personally, I consider embedding as a computational means of seeing the world instantly by prioritizing certain elements. Undoubtedly, embedding operates not only as a way to highlight, but primarily as a way to calculate with the eyes.

In this framework, embedding ensures that rules operate and interact with shapes continuously. Designers have always the feeling that a design can be further developed by investing more time on the process and making. In this example, the non-finito state of a design materializes the design potential by the application of a rule and the emergence of shapes. It reconciles how we see the world and how important is to simply look at things.
"It is.."
"I see.."
"It might be.."
"It is..
"I see.."
"I am not sure..
"I cannot see it..
"It is.."
03. Visual Thinking
As I open my eyes, I find myself surrounded by a given world: the sky with its clouds, the moving waters of the lake, the wind-swept dunes, the window, my study, my desk, my body. It exists by itself without me having done anything noticeable to produce it.

Visual Thinking

The problem of seeing is the problem of creating a description of a scene that changes in every single moment. The particular visual machinery with which human beings are equipped and how do the eye and the brain actually carry out the job of visual scene description is a major issue. John P. Frisby (1980) proposes a theory regarding a symbolic understanding of vision. In this thesis, I am not interested to bring how vision works but rather understand what happens or what I see. In architecture, it is quite common for designers to give birth to ideas by seeing, talking, drawing or simply visualizing. I am interested at this point to return once again to a basic level of understanding architecture. Regardless of my personal experience, I argue that young designers become productive and advance their skills once they draw or once they are hesitant to draw by seeing. This means that a meticulous thinker in philosophy will start writing the essay once the ideas are sort of shaped in his brain. In visual arts, I consider that drawing, sketching or making have a prominent role for what the next step could be. This is related to Arnheim’s argument regarding implicit and explicit perception. So, visualizing an initial idea generates processes that promote visual thinking by integrating the perception of space, memories, experiences and projections. Plato in Timaeus argues that the gentle fire that warms the human body (physical process) flows through the eyes in a smooth and dense stream of light. Therefore, a tangible bridge (Arnheim) is established between the observer and the observed thing, emanating from the object and travelling to the eyes.
Visual perception is not a passive recording of stimulus material but an active engagement of the mind. The world of substantial objects (Arnheim) is generated once a sculptor imposes a shape upon innert matter, and the perceivable things inscribe a sort of universals by means of intuition of the observer. Shape Grammars clearly state that embedding assigns meaning into a design or an object in which we decide to baptize. The moment that one tree is falling at the forest does not exist unless the observer sees the action. This means that the observer embedded meaning into the tree that was moving towards the ground. Aristotle stated that in order for any perceivable object to come about a universal had to impress itself upon the medium, which was unformed and inert though it had the desire to be impressed. “Entelechy” for Aristotle was a state of perfection or in Kantian terms the point of reaching the “beautiful”. My personal reading is that as long as seeing engages, "things" are different and we perceive them differently. In this sense, I would prefer to use Kant’s definition of the sublime since the sublime is in constant flux; unformed, deformed, reformed. Perhaps Kant’s sublime avoids to give birth in favor of a state that is continuously moving towards an unpredictable direction appearing or disappearing in a non-deterministic way.

The way a designer sees what he just drew is the point that visual thinking starts to engage with creativity. In other words, the point of sketching or making an idea is similar to the moment that the observer was seeing the tree falling down. The action of seeing or perceiving directly allows the designer to give birth again and again to different ideas rather than fully trying to articulate one mentally. The understanding of a design as unstable “untitled” allows the designer to simultaneously accommodate the multiple unpredictable subjectivities, ensuring that the output is not actually an output but an instance of the naturalized assumptions. Thus, design is not an information processing of cognitive mathematical articulation but primarily perceptual, intuitive and non-hierarchical, or non-ontological structures.
Considering that designers try to visualize ideas by bringing back concepts, elements, designs from past experiences, I am interested to discuss the role of memory to perception and in particular its influence to design. For example, a designer who is visiting Le Corbusier’s chapel of Notre Dame du Haut in Ronchamp has already an idea of this space. He knows the nature of the shapes, the physicality of the form and perhaps particular spatial qualities in advance. John Locke used the term “ideas” to describe the perceptual as well as memory phenomena, by defining as “whatsoever is the object of the understanding when a man thinks” – phantasm, notion, species employed about in thinking. According to Arnheim this reading ignores the distinction between the percept (complex ideas) and the concept (abstract). The debate seems to be more broad though on whether we can think without images of thought.

I personally strive not to engage with the technicalities of this debate but simply understand what past experiences mean in design. Most times designers intentionally or not borrow elements from the past memory of walking inside a space or the form of a window or even the texture and the materiality of a space from the past. From a Shape Grammars point of view, I will go back to the idea of embedding and I can argue that combining past with present is a creative act that engages rules. It is commonly said in the field that the design of a building mimics another building generating discussions in the last century about the idea of replica or copying in design. Replica in a sense that I have a particular schema (Shape Grammars) in my mind and I try to transform it to something else. If my reading is legitimate, I will refer again to the definition of the “sublime”. I copy a building and I create a copy of it. Although this “sounds” odd, it misses the point of embedding. Even if we accept that the replica and the “original” co-exist the main difference lies on the way we see them. In other words, the existence of both does not necessarily relate to their actual reference as an “original” and a "copy".
3.3 What do architects and non-architects see?

In the framework of the MIT class, 6 XXX / 6.833 The Human Intelligence Enterprise (Professor Patrick Winston), I contacted an experiment about how architects and non-architects perceive designs. The intention of the project was to understand aspects of the human intelligence related to spatial perception and spatial cognition.

I asked a group of five non-architects to make a 2D representation of a given physical model. Each person drew one representation without time constraints by using a pencil and a piece of blank paper. Once, the subjects made five drawings, I asked them to tell me a story related to the design that they were observing (seeing-perceiving). Then, they voted two out of the five drawings as the most successful representations of the initial model. Another group of five non-architects had to pick a physical model by using the two most “precise” representations from the previous group. The given models where made as part of a design process showing each step of the development of the design studio (MArch 2018 Student: Ngan Ching Ying). Interesting enough that non-architects are able to perceive designs and represent their observations explicitly, but they are not fully aware what is important and what is not important to talk about. Therefore, this project gives birth to a personal exploration about seeing in design. As an architect with more than 10 years in the field,
I understood the significance of communicating ideas through designs. In the past, I was under the impression that non-architects were not able to understand the articulation of designs.

Another contribution of the project is that by asking people to draw, I subconsciously force them to see. In other words, learning in action and learning by doing as it is described in computation literature came into play in this experiment. Especially architects tried to narrate a story before using the pencil, while the story telling became way more thorough once they engaged with the design tools. In this sense, drawing operates as a constant brainstorming of changing ideas rather than as a means of representing fixed thoughts.
seeing
drawing
perceiving
The last contribution that is relevant to this thesis relates to the passion of non-architects to draw their own story while representing a fixed given model. They tried to brainstorm by adding trees or people to a 2D representation of a white physical model made by museum board. This shows the intention primarily of those who are outside of the discipline of design to actively participate by seeing a design potential.
I visualized a potential function of the mock-up... it is neither a building nor architectural space."

"I clearly perceive it as an object, in which form and function..."
04. Shape Grammars
Augmented Reality
In this chapter, I present a novel method to calculate or design through technology based on the theoretical framework of the discourse as it is presented in previous chapters. My aim is to introduce a novel system for real-time design and brainstorming, by using state-of-the-art algorithms of eye-tracking as well as an advanced rule-based generative logic emanating from Shape Grammars.

4.1 Project Overview
Using SGR to compute in the real world

SGR: Edge-detection filtering operates as one type of representation abstracting the world. Other types of representation from the actual image to color filterings have been tested.
The idea of real-time interaction in design has been widely studied through computation not only in the field of architecture, but also in psychology and anthropology studies. Quite recently, Virtual Reality (VR) systems propose real-time interaction between the designer and a VR space. Latest advancements in the field of VR, such as Oculus Rift or HTC Vive (2016) propose a creative engagement of “interaction” and “performance” between humans, tools and environments. This type of interaction that is based on action and perception renders a tight relation of creativity with cognition. Design improvisation in VR systems is definitely aligned to a pure performative way of acting in the design space. Designers and non-designers are able to visualize ideas and thoughts by using computational tools of VR.

In addition to the Virtual Reality implications in design, Augmented Reality applications has been broadly used in the field. The idea of augmenting digital information on the physical space creates an interesting approach in design. Current applications, utilize a pre-designed digital environment and superimpose it on the physical space by either covering parts or extending the dimensions of the environment. The main difference between VR and AR is that VR creates an immersive experience, while AR allows the interaction with the physical space.

However, design is by definition a non-linear process that cannot be inscribed by any means of predetermined structure. In other words, design utilizes processes that are not pre-structured, but they constantly change. In this sense, VR and AR as they are currently presenting their capabilities attempt to structure the design process itself and immerse the user into a different reality (a designed reality).
4.3 Why rules?

"A shape grammar is a set of shape rules that apply in a step-by-step way to generate a set, or language, of designs. Shape grammars are both descriptive and generative. The rules of a shape grammar generate or compute designs, and the rules themselves are descriptions of the forms of the generated designs."

*Shape Grammars in Education and Practice: History and Prospects*  
(Terry Knight, 1999)

SGR approach to design utilizes rules, refusing the combinatorial logic or any means of pre-determined structure in design. Shape Grammars Reality' rules are spatial, rather than textual, dealing directly with shapes without translating or interpreting symbols. They support emergence and they use shape operations of addition and subtraction, and spatial transformations (translation, reflection, and rotation). Rules appear and disappear according to what the designer wants to do. In other words, the designer interacts in real time by applying a rule.

The main difference of SGR with VR and AR lies on the use of rules. The obvious question is whether designing with rules in SGR has similar implications with VR state-of-the-art technology for design. The answer to this question has two parts. The first part can be explained by unfolding the way designers draw, sketch, annotate and visualize their ideas with the conventional tools in a piece of paper. I argue that the use of rules is implicit until we become aware that we actually calculate in design space and we apply different compositional rules at the same time. The conversation around rule-based generative systems in design belongs to a broader discourse in design theory and extends definitely to the visual arts. The second part can be explained by using examples of other rules based generative approaches in visual arts. Do we really decide on whether we design with rules or not? Do rules exist implicitly in our creative nature?
The choreographer and director of the Frankfurt Ballet William Forsythe has created a new genre of balletic performance combining technology, dance, contemporary and ancient artifacts, and even theoretical narratives of non-existent stories of the 20th century. Beyond dance, the invention of a rule-based generative logic witnessing a new mode of poeisis. The persistent interrogation between form and movement as encoded matters generates an intelligent moment far deeper than a generic critical creativity. Ballet in this case operates as a form of spatial hieroglyphics, mythical combinations of symbolic, figurative and phonetic elements that embed spatial configurations. Beyond an obvious stylistism, the most important aspect of ballet pedagogy is the subtle and sophisticated way of exploring, producing and interrogating the art form of an utter requalification of cultural praxis.

One of the most important pioneers of modern dance of the 20th century, Rudolf von Laban devised a system, in order to understand human movement. In his work Choreutics (Χοροτηκή), he developed a system of notation that records the movement of the dancer, using a series of geometric symbols. Defining the spherical space around the human body (kinesphere) and inscribing it into a cube, he explored the stability of a single central point in the body. However, Labanotation system does not work in a mode of poeisis such as the one of Forsythe. In the case that movement emanates from multiple centers, a series of points, a line or even a plane movement generates an infinite number of kinespheric points that operate simultaneously. The main difference between Laban’s perspective compared to Forsythe’s one is the movement of the body as a unified form of equilibrium. Forsythe explores moments of imminent falling, instability or disequilibrium as possible results of an unexpected failure. In other words, he utilizes the failure as a mode of actual balance, through the lost of control and balance. In this case, poeisis is materialized through a vertiginous exploration of spatial disorientation or a state of
instability that should not be formalized or interpreted by any system, since poeisis emanates through a personal rule-based generative logic.

However, the target of Forsythe seems to be not the disorientation per se but the exploration of vanishing moments hidden behind the loss of stability (rule). To specify he seeks to unveil those hidden moments of discontinuity in order to re-(de)compose them in a continuous flow. Greg Ulmer refers to the Greek term of instability-ilynx (vertigo) as an active agent of our desire to invent through rules. He also points out that in metaphysics spinning is a way to understand the right or wrong through the freedom of mind. For Forsythe, vertigo is the loss of strict order, categorization or classification in which residual aesthetic logic allows the emergence of poeisis through pure relationships. In this framework, it seems crucial to investigate the role of time and the process of composing through decomposition.

Heidi Gilpin states that disequilibrium and disappearance in Forsythe’s work is in resonance with the notion of ephemerality within the process of poeisis. In order to sustain the instability and vibration, Forsythe explores the potential of improvisation as a mode of decomposition. He alters the linearity of forms disintegrating or even resetting their order just before a performance (The Vile parody of Address in 1988). Beyond this process of altering things, he attempts to achieve the unexpected in performance dismantling the logical structure of coherence and sequence. But, the question is how he composes the decomposed moments of hidden instability with the sort of linear performance.
At this point, I want to return to the initial question concerning the role of the rules in SGR. Considering that seeing is by definition related to calculating, I want to understand how calculation operates in the design world. I am not interested to explain how vision operates from a physiological point of view or how ophthalmologists will explain the functions and capabilities of the human eyes. I studied extensively a couple primary sources about binocular vision and early research in optics through a 1972 treatise of William Charles Wells looking for the same thing. However, I think that seeing in design goes hand in hand with process of calculating, producing meaning and reason by a constant interaction with the surrounding environment.

Every time I apply a rule, I change the point of view and I interact with the design in a completely different way. The emergence of a rule allows me to re-think what should be next or what I could have done, implying an appetite for open-endedness in design. “Oh, I see it!” I calculate and I re-calculate trying to grasp and assign meaning through embedding. By constantly changing the meaning, I am able to embed different things either changing something or simply look exactly what is there. So, I again can express myself “Oh, I see it!”. Duchamp’s Fountain (1917) is aligned to the idea of embedding. He looked the fountain, and he decided instantly to look again in a different way without “acting” in a conventional definition of the term. Therefore, calculating as seeing could be unveiled by thinking the role of embedding in Shape Grammars. Are those Fountains on the right side of page one? What type of meaning do we assign to them?

4.4 Why calculating as seeing?

William Charles Wells,
An essay upon single vision with two eyes: together with experiments and observations on several other subjects in optics.
Marcel Duchamp, Fountain (1917, replica 1964)

The original Fountain by Marcel Duchamp photographed by Alfred Stieglitz at the 291 (Art Gallery) after the 1917 Society of Independent Artists exhibit. (wikipedia)
This thesis proposes an alternative way of designing through Shape Grammars’ rules and augmented reality applications generating encompassing aspects of embodied interaction, behavior, and communication between designers and computational machines. My aim is to bring Shape Grammars into the real world by utilizing shape rules and eye-tracking technology, engaging a reciprocal way of non-linear processes in design. In other words, this thesis proposes a computational method of on the spot, real-time brainstorming in design focusing on the exploratory aspects of design improvisation, ambiguity, discovery and “emergence”.

In order to develop the real-time design method, I implemented two different steps testing designers and non-designers intention to see shapes in the real world (edge detection – seeing boundaries) and eye-tracking system to articulate areas of interest in a design space.

The apparatus consists of a smartphone, a virtual reality headset cardboard and an application using Unity and Open Computer Vision libraries.

4.5 Interacting with SGR

Virtual Reality headset cardboard with smartphone for SGR

4.5.1 Edge detection

Arnaud Maillet in his book: “The Claude Glass: Use and Meaning of the Black Mirror in Western Art” (2004). I realized that the development of these mirrors operates similarly to the emergence of the unconscious. “We see, then, how the notion of the unconscious emerges partly in conjunction with the black mirror,” Maillet. Claude mirror was commonly used in 18th and 19th century by painters who want to draw in the manner of Lorrain (who want to see, who Lorrain was able to see).

The edge detection filtering is only one type of representation that was decided to be used at this step of the thesis. It was representing an initial attempt to filter the real world and make an abstraction. The impetus is to abstract the world similarly to the Claude Glasses of the 17th century.

A Claude glass is a slightly convex shaped mirror that is able to abstract the subjected reflected in it from the surroundings, simplifying the color tones and promoting a representation that looks like painting. Picturesque artists in England were drawing sketches of picturesque landscapes based on the representation that this small mirror was offering.

In SGR, edge detection transforms the real world image into a line drawing, black and white representation that keeps the boundaries of the shapes. The algorithm reduces the noise, finds the intensity gradient and removes unwanted pixels. Pixels check a local maximum in their neighborhood in the direction of gradient, in order to survive or disappear. The edges are created only if they are between a minimum and a maximum threshold (minVal, maxVal), while pixels are classified as “non-edge” elements if they are outside of the two threshold values. So, small pixels noises are removed allowing the formation of edges and long lines.
initial forms of representation
The idea of using eye-tracking was to facilitate an indirect type of interaction since the way we look the world can offer us an insight in design. By using Kinect device for windows, I collected Eye tracking data. While there are many different types of non-intrusive eye trackers, they generally include two common components: a light source and a camera. The light source (usually infrared) is directed towards the eye. The camera tracks the reflection of the light source along with visible ocular features such as the pupil. This data is used to extrapolate the rotation of the eye and ultimately the direction of gaze. Additional information such as blink frequency and changes in pupil diameter are also detected by the eye tracker.

For the initial experiments, I was using Kinect and tobii pro devices in order to understand how the frequency of retina motion will allow the creation of precise data. Eye-tracking systems have been broadly used the last two decades in military helmets. The decision of the pilot to aim and perhaps shoot on a particular target requires the elimination of errors such as imprecision or retina motion inconsistencies. The current version for consumer users have already integrate advancements regarding a series of issues. Sensing eye movements has also application in medicine, such as the EagleEyes by the co-inventor of Shape Grammars, James Gips. By detecting the user’s eye blinks and analyzing the pattern and duration of blinks, people with severe disabilities are able to move or pick things similar to the mouse clicker.

SGR uses the back camera of commercial smartphones in order to collect data from the movement of the eyes. It is quite important to highlight the fact that through computation, we are able to take advantage of this technology with low cost. This thesis is the first attempt to use the build-in camera for eye-tracking in design. UFocus by umoove company is an application that measures the attention of the user by applying a similar logic in terms of the software development.
Instances of using eye-tracking device to detect the areas of interest
SGR user-designer sees the world through the application and the VR headset, selecting rules and applying them in the real space. Once the designer tap the right side of the device, he changes the rules. Rules in SGR represent action-based commands, such as copy, rotate, scale, move, as well as commands that are identity rules or Shape Grammars' rules. The latter consists on the inverse boundary of a shape, the erasing rules, the part of shape, as well as the most important Shape Grammars' schema, which x̅x. Rule appear on the lower part of the interface and they rotate once the designer tap the device. The selected-current rule is highlighted with orange color. Once the designer picks a rule (copy), he is looking for more than 2 seconds on a shape defining its boundaries by looking the vertices. The shape is defined once he repeats the vertices and it shows highlighted on the interface. Then the designer taps the top part of the device, in order to confirm that he will perform the action. By looking the area (vertices) that he wants to copy the shape, he taps the top part of the device again. Instantly, a chosen shape is superimposed as a line drawing on top of the area that he applied the rule. If he wants to continue applying the same rule with the same shape, he can simply look directly to the destination area and tap the top part of the device. In this case, he can copy the same element multiple times.

Based on the experience of experimenting with people, SGR designers want to explore different design possibilities by constantly changing the rules. In this case, the designer has to pick a shape, select the rule and apply the rule, by adding the new shape in the current field.

Concerning the depth, SGR is based on the detection of actual vertices which allows the 3D perspective and manipulation of forms. For instance, the designer is able to approach the design space and articulate a detail, while maintaining the integrity of the overall design. Although SGR has been tested with individuals, subjects proposed the idea of participatory design by sharing
designs. This idea seems redundant given the fact that seeing and embedding engages to the creative enterprise. A design is exactly the same either as part of an individual’s work, or a collective engagement of various users. The reason is that the design output has different percept as different designers or one designer sees the design.

The output of SGR is currently basic 3D model, with a main function of exporting 2D representations. Since SGR operates as a real-time brainstorming method, I believe that its nature has to maintain the draft character. In other words, SGR works as a sketch book of the designer that does not intend to fully comprehend design ideas. This point is extremely important, because sketching in design allows ambiguity and open-ended interpretations, which is the basis for a creative reading or seeing of a representation.

Rules in SGR do not have a fixed library but they are invented by the designer. Although the actions are already given, the designer is able to define his own agenda, by applying combination of rules and compose parallel computations. The idea of a shortcut that contains two or three basic rules in SGR already exist in the field of architecture and especially on the design repertoire of famous design firms. By tapping the device the engagement of the designer is not limited to the eyes, but rules change as a result of an embodied process that involve all senses.
05. Conclusions
Through this thesis, I was able to expand the discourse regarding the use of technology and computation in the field of architecture. I proposed a line of work that borrows knowledge from psychology, anthropology, computer science and cognitive science, underpinning the relevance of important issues addressed within the research territory of design and computation.

Shape Grammars Reality (SGR) was created as a computational method of designing through Shape Grammars’ rules in the real world, by which I sought to further develop the array of applications in shape grammars literature. As Shape Grammars by definition already are "in the world" the project was about making it (Shape Grammars) visible, as opposed to "applying" Shape Grammars to the world. In other words, the contribution is clearly to bring shape rules to the world in a direct way. In this sense, SGR development establishes a pedagogical contribution by articulating the role of embedding through seeing.

SGR is an initial step towards the integration of advanced computational tools to the design. The successful use of eye-tracking technology as well as algorithms for recognizing shapes in computer vision give birth the emergence of a new armature that not only designers but also non-experts are able to brainstorm, draft and articulate their ideas visually.

SGR is definitely a novel method of design interaction through seeing not only as a tool, but also as a means of highlighting visual thinking and spatial experience every time we “see” the world.

5.1 Contributions
5.2 Concluding remarks

SGR proposes a user interface on the intersection between Augmented Reality (AR) technologies and eye-tracking research. By proper adjustment of Virtual Reality headsets, a designer is able to brainstorm-draft in real time, by applying basic schemas and transformation rules in the smartphone’ SGR app. The combination of shape rules and Augmented Reality of this thesis is unique since the current design tools within the ecology of Virtual Reality (VR) and Augmented Reality (AR) applications are not rule-based. The designer explores possibilities by inventing his/her own library of schemas through seeing. Given the fact that seeing is by definition a non-linear process, SGR allows the emergence of shapes in design via real time interaction between the reality of a space and the design intention of the user.

By developing a series of experiments, I was able to provide an empirical evidence of the work, a model for real-time interaction in design and a tool that expands the territories of design and computation by integrating a rule-based generative approach. By using SGR designers are able to connect the influence of past memory on the perception of the future, merging the direct perception with past experiences. Considering that rules are non-symbolic and non-deterministic, SGR empowers the emergence in design through embedding.

Finally, SGR gives an answer to the problem of how architects and non-architects can visualize ideas in real time; what they see and what they want to see. In other words, embedding meaning through design becomes an open-ended process non-exclusively privileged by the superiority of any sort of expertise – a designer. SGR brings Shape Grammars into the real world for a creative emergence in design.
Further development of the computer vision algorithm will allow the eye-tracking system to identify the shapes. The difficulty lies on the definition of the shapes. Since every shape consists of pixels (computer), I need to create the framework according to which a particular shape can be identified. In addition, the definition of a shape relates to the way that the eye-tracking assigns the shape to the left side of the equation of the shape rule. The action based command of the rule application can also has more specificity given the complexity of performing in the 3D space of the real world. For instance, I want to copy a shape by picking a particular side as a reference point and copy it on specific element of the scene. Background and foreground can also have definitions for what happens if a design is behind a moving object. Given the fact that list of points, lines and planes can be attached elements the depth becomes complicated for arranging the population of existing or newly designed shapes.

In addition to the algorithm, SGR has to improve also the hardware since the philosophy is to run in every single smartphone device. The current distance of the back camera and the human eyes require a wide angle lenses that could be built-in or attached to the current devices. The current glasses use also lenses that allow the human eyes to focus on the smartphone screen. So, the computer vision algorithm has to take into consideration the distortion of the pupils behind the lenses.

Thinking the future of SGR in larger scale, I envision also the application by using VR headsets connected with drones' cameras. Current research in the field has already important steps towards unmanned aerial vehicles that fly over cities or large scale urban environments. Therefore, the pilot will have the chance to control the drone but also to use SGR for design brainstorming in larger scales and different design challenges (Urban Design, Urban Planning). In this sense, SGR is capable to be scaled and integrated to many design scenarios such as Architecture, Art, Building Industry, and

5.3 Future work
Urban Planning. SGR is the initial step towards a novel method of designing through seeing by using an advanced rule-based generative logic, promoting an open ended culture in design and computation.
Bibliography


