CREATIVE APPROACH TO DESIGN FORMULATION
SHAPE GRAMMARS AS A TOOL IN ARCHITECTURE
DESIGN ANALYSIS AND SYNTHESIS

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CHAPTER TWO: CREATIVIE APPROACH TO DESIGN FORMULATION

2.1 DESIGN

“Design is a highly sophisticated skill. It is not mystical ability given only to those with recondite powers but a skill which, for many, must be learnt and practiced, rather like the playing of a sport or a musical instrument”

Lawson 2003

Design has been recognized as an important activity for more than 4,000 years. Approximately 2,000 BC, Hammurabi, King of Babylon, enacted a law which both recognized design and made it dangerous (Gero, 1996).

Designers’ role to improve the human condition, in all its aspects was appreciated, yet design remained a mysterious human activity not amenable to scientific exploration.

Figure (1) Hammurabi's Code, from an engraving on a Stella in cuneiform in the Louvre, Paris.

“229 - If a designer/builder build a house for some one, and does not construct it properly, and the house which he built fall in and kill its owner, then that designer/builder shall be put to death.”

Source: Gero J. 1996
The fact that design can be learnt (as cited by Lawson 2003) motivated researchers, thinkers, designers and even historical theorists to search for the most appropriate way to describe and thus to teach design. The whole 20 centuries efforts of researches developed two main concepts that deal with design in two different questions:

First, the “how to design?” question that combines all researches in thematic theories and design process. There are publications by designers on how to design dating back to Roman time, notably by Vitruvius, the first century BC architect and engineer who described the classic principles of design (harmony, symmetry, proportion, etc.) and tried to give guidelines on how to design (Morgan, 1960), also, the nineteenth century thinkers commenced working on articulating design as a process (Durand, 1802).

Second, the “what is design?” question that aims to explore the theories of design synthesis (Routio, 1999). And it was not until the 1960th that major research programs that transact with the notion of design thinking itself in its various aspects were analyzed, taken apart, developed and initiated (Jones and Thornley, 1963; Simon, 1969; Coyne, 1990). Innovative definitions of design replaced its classic model, and new vocabulary was introduced to describe and understand Self-conscious (associated with intent) design (1).

“Design is a purposeful activity, practiced by humans using a knowledge based approach to create forms to satisfy intended purpose”

*Rosenman 1996*

“Design is a goal oriented, constrained, decision making, exploration and learning activity which operates within a context which depends on the designers perception of the context”

*Gero 2002*

Even definitions that seem more algorithmic and symbolic were proposed to bring together pieces of the nature of design puzzle.

“A design is an element in an array relation among drawings, other kinds of descriptions, and correlative devices as needed”

*Stiny 1996*

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1 Although there is no general acceptance between thinkers and designers about the existence of unselfconscious design “Nature does not design” Rosenman 1996, there is wide agreement on considering design in researches a purposeful human activity associated with intent.
2.2 CLASSIFICATION OF DESIGN

The most common classifications categorize design in Routine and Non-routine although there are differences in defining what is meant by these classifications.

**2.2.1 Routine design**

Routine design can be defined as that designing activity which occurs when all the necessary knowledge about the design variables, objectives, constraints and process are all known. In addition, routine designing operates within a context that constrains the available ranges of solutions (Gero and Saunders, 2002), Figure 3.

![Routine Design Diagram](image)

*Figure (2) Design classification*  
Source: Bayoumi S, 2002

It has the characteristic of not being different in any essential way from previously produced designs in their class, they all exhibit the same properties but with different magnitude.
(Bayoumi, 2002). “That is not to say that routine design is necessarily always easy. The state space is usually very large and clever ways of navigating (searching) are required to arrive at desired solutions.” (Rosenman and Gero, 1993)

### 2.2.2 Non routine design

Non routine design may be defined as those designs that are recognized to be different in some substantive sense from previously produced designs in their class. It can be subdivided into two further groups: innovative design and creative design. The difference between these two groups is not always clear and successive innovations can lead to a different product can be called creative design (Coyne, 1990, Rosenman & Gero, 1993).

**Innovative design** is that designing activity that occurs when the space of known solutions is extended by making variations or adaptations to existing designs so that unexpected solutions become possible, Figure 4.

Innovative designing processes produce designs that recognizably belong to the same class, there are no departure in kind from previously designs of the same type but are also “new” (Gero, 2002).

![Space of possible designs vs Space of innovative designs](image)

**Figure (4)** The space of innovative designs is a subset of the possible design

Based on: diagram by Rosenman MA and Gero JS, 1993

**Creative design** can be defined as the designing activity that occurs when one or more new variables are introduced into the design (Gero, 2002). It incorporates innovative design but involves the creation of products that have little obvious relationships to existing products.
While innovative design involves the generation of new subtypes, creative design involves the generation of entirely new types (Rosenman & Gero, 1993), Figure 5 shows the extension of the state space of potential design.

Figure (5) *The space of creative designs is a superset of the possible designs*

*Based on: diagram by Rosenman MA and Gero JS, 1993*

Figure 6 shows the same idea in another way. The space of possible designs changes over time as the designer moves away from the current design state space.

Figure (6) *Creative designing involves new and/or changing the spaces of possible designs*

*Based on: diagram Gero JS, 2002*

Figure 6 shows the same idea in another way. The space of possible designs changes over time as the designer moves away from the current design state space.

A brief example was given by Gero and Rosenman, 1993 that conclude all differences between the three groups, routine, innovative and creative design:
“. . . with this definitions in mind designing an air-conditioner to meet certain requirements constitutes routine design, designing the first reverse-cycle air-conditioner constitutes innovative design whereas designing the first air-conditioner constitutes creative design”

In architecture another example was given by Bayoumi, 2002 where he considered S. Denis, Paris, 1135 and Bon Marche store, Paris, 1876 creative design regarding their role of introducing new types of buildings in their time.

2.3 CREATIVITY

“Creativity is the ability to produce work that is novel and appropriate”

Saunders 2002

There have been many attempts to develop models of the processes involved to define the nature of creativity; the difficulty of these tasks is clear from the number of definitions that can be found in the literature, for example: Taylor 1988 gives some 50 definitions. some researchers have concluded that trying to develop a single definition of creativity is a useless task and that this simple statement appears to be the only definition upon which there is so agreement among the research community (Boden , 1990; Partridge & Rowe,1994; Rosenman & Gero,1993; Sternberg,1988).

Creativity may describes both artifact and process (Coyne, 1990; Rosenman &Gero,1993;Gero. 2002 ). An artifact is creative if it has the properties of being novel, having value and/or richness of interpretation, all these properties are subjective and are relative to time place, and the observer.

A process may be termed creative if it introduce one or more new variable into the design, such processes do not guarantee that the artifact is judged to be creative, rather these processes have the potential to aid in the design of creative artifacts (Gero, 2002). It is however possible for creative artifacts to be produced by processes that are not in itself creative and are just well understood (Rosenman & Gero, 1993).

The purpose of studying creativity as stated by Saunders.R, 2002 is to determine what processes are involved in being creative or finding out what is meant when something is described as being novel (original, unexpected, surprising)and appropriate (useful, valuable, aesthetic, adapted).
2.3.1 Personal and Social views of creativity

Approaches to studying creativity can be divided into two broad categories. First category, those approaches that emphasis personal judgment of creativity and study creative thinking and creative personalities. Second category, those approaches that go beyond the individual and believe that society, as well as the audience of the creative work, plays an important role in defining what is creative?

2.3.1.1 Unified models of creativity

Some researches have attempted to combine these two views of creativity into unified theoretical frameworks but the resulting frameworks often maintain the distinction between personal and socio-cultural notions of creativity (Saunders, 2002). Boden 1990 classified creativity into two kinds called (H-creativity) and (P-creativity). In design, H-creativity (Historical creativity) occurs when the design falls outside the range of design previously designed in a society. Whereas, P-creativity (Personal or Psychological creativity) occurs when the design falls outside the range of designs produced by that designer. Gero JS has extended Boden classification to include S-creativity (Suwa, 1999). S-creativity (Situated creativity) occurs in design when the design contains ideas that are not necessarily novel in any absolute sense or novel to the designer but that are novel in that particular design situation, this third kind of creativity emphasis the important role that context plays in shaping the creative process (Gero, 2002).

2.3.1.2 Csikszentmihalyi view of creativity

Csikszentmihalyi, 1988 developed a system view of creativity after turning his attention away from the question “What is creativity?” and instead asking, “Where is creativity?” (Saunders & Gero, 2002; Saunders, 2002).

Csikszentmihalyi developed the system view as a model of the dynamic behavior of creative systems that include interactions between the major components of the creative society. He identified three important components of a creative system:

- Individual – Who generates ideas
- Domain – Cultural or symbolic component
- Field – Social or interactive component
Figure (7) shows the connection between these three components at a conceptual level.

An individual’s role in the system is to bring about some transformation of the knowledge held in the domain. The field is a set of social institutions that selects from the variations produced by the individuals those that are worth preserving. The domain is a repository of knowledge held by the culture that preserves ideas or forms selected by the field.

In a typical cycle, an individual takes some information provided by the culture and transforms it, if the transformations is deemed valuable by the society, it will be included in the domain of knowledge held by the culture, thus providing a new starting point for the next cycle of transformation and evaluation.

In Csikszentmihalyi’s view, creativity is not found in any one of these elements, but in the interaction between them (Rosenman & Gero, 1993; Gero, 2002; Saunders and Gero, 2001, 2002).

Saunders and Gero have developed and implemented a computational model of artificial design creativity based on Csikszentmihalyi’s model. Figure (8) shows their interpretation of Csikszentmihalyi’s model.

![Figure 8](image)
they used this approach to study how creativity is generated and assessed within a social context and how creativity emerges from the interaction between design agents that are individually creative but whose creativity is not only assessed by themselves individually. The creativity of an individual is assessed by that individual and also by the other agents at the time each individual is operating.

2.3.2 Model of creativity

in order to articulate processes that support creativity in the design computation (formalization) as described later in this chapter, design schemas – knowledge structures – need to be initiated, and when cued will provide a framework with expectations of what is to come, it comprehend and explain some of the processes involved.

2.3.2.1 Design framework

Creative design deals with the formulation of new structure, that is, new vocabulary elements or new configuration of existing vocabulary elements in response to either existing or new functional requirement (Rosenman and Gero, 1993).

A vocabulary may be at one level the spaces and at another level, the building elements that serve to define or are included in the space.

Thus, it is convenient to use the conceptual schema design prototypes (Gero, 1990) which articulates a function-behavior-structure + knowledge framework to provide a framework for creative design.

It represents the state space of design in 3 subspaces or abstractions:
- The structure space, S (often called the decision space)
- The behavior space, B (often called the performance space)
- The function space, F (which defines the artifact’s teleology)

Once an object exists, it has a set of behavioral attributes and as result, can carry out certain functions.

Figure (9) shows these three subspaces which constitute the state space of design.
there are some works concerned with the transformations that map structure to behavior and vice versa (De Kleer and Brown, 1984; Kuipers, 1984), and others that map function to behavior and vice versa, but there are no transformations which map function to structure. The No Function in structure principle (De Kleer and Brown, 1984; Gero, 1990) assumes that the teleology of an artifact is not found in its structure but in the contextual interpretation of its behavior. So the behavioral attributes are the key to matching structure to function and vice versa.

2.3.2.2 Simple model of creative design

One view of creativity is that it is involved with the production of an unexpected result through the confluence of two schemas. The first schema provides a set of routine expectations; the second schema is needed to understand the unexpected result. The unexpected result can be produced in a number of different ways (Gero, 1996). A simple model of creative design is presented in figure (10); this model inheres no particular process but provides a framework for processes capable of producing unexpected design and finding schemas which support them.
Design is a human activity that eludes formal description. We wish to use computers to assist in the design process. Computers operate only with formal, repeatable, and rigorously defined processes. If we required a computer system to simulate some kind of design behavior then we must formulate models of design process

Coyne, 1990

In his book the science of the artificial, Simon, 1969 argued that such a thing as the “Science of design" can exist possible, and that some day it will be possible to talk about design in terms of well established theories and practices.

Two reasons for the formulation of design were mentioned by Stiny and Gips, 1978 in their book Algorithmic Aesthetics: First “It provides a common framework in which a number of central issues in aesthetics . . . can be investigated uniformly and can be related. Second, just the attempt to represent aesthetics ideas or specific approaches to understanding and evaluating, in terms of algorithms is salutary"
More recently, information processing models founded on artificial intelligence concepts have provided an impetus for renewed research that gives a better understanding of design.

2.4.1 Design and science

Science has been developed as a mean of attempting to explain and understand the world around us it commences with the description of the world and some behaviors and attempts to produce causal dependencies between them. On the other hand, the goal of the design is to change the world through the creation of the artifact (Gero, 2002).

Design and science therefore appear to be about different things. Simon 1969 makes the distinction that science is concerned with natural things, how they are and how they work, while design is concerned with how things ought to be. Natural science looks at the state of things and attempts to propose hypotheses that explain their state. Design looks at the results that are required and attempts to predict the states of things necessary to achieve those results.

Science attempts to formulate knowledge by deriving relationships between observed phenomena. Design, on the other hand, begins with intentions and uses available knowledge to arrive at an entity possessing attributes that meet the original intentions. The role of design is to produce form- a description of form – by using knowledge to transform a formless description into a definite, specific description (Coyne, 1990).

Kuhn 1970 argues that science must pass through several phases before it constitutes a formal discipline, and that the study of design is currently at a pre-science phase.

2.4.2 Approaches to formalize design

Coyne 1990 assumes that formulating design into mature science can be achieved by two major approaches to increase understanding of design: Case studies and models.

In the case studies approach, some design phenomena such as the design of a particular building, is observed and analyzed in an attempt to extract general principles. On the other hand, models are limited abstractions of particular phenomena, less determined than theories, whereas theories attempt to explain observed phenomena and predict behaviors that are somehow connected; models are content with explanation and prediction within a subset of connected phenomena.

In the Thesis, an adoption of the design models concept to formalize design is taken. Each design model varies according to its View (understanding) of the nature of the designing
process, yet three main views exist that postulate design is as a *problem solving process*, or could be discussed in terms of *logic*, or it could be treated as a statement in some complicated *multidimensional language system* (Coyne, 1990).

In **The Problem solving model** design is mainly a search process through a state space where the state spaces are the design solutions. It is like exploring a maze (Simon, 1983), figure (11) shows a maze where the intersections between the walkways are solution states, and it is necessary to make the right decision in a rational way to reach the goal (destination) in mind.

*Figure (11) Problem Solving can be compared to exploring a maze*  
Based on: Coyne R.D et al, 1990

**The Logic model** supposes that design is essentially a reasoning process, and that it is useful to consider it as a process of making logical deductions, about a set of requirements, similarly to the way mathematical or geometrical theorem are proven. Another example that explains it, the design of a building on a site for which planning regulations impose constraints. The set back from the street, the minimum distance from side boundaries and may be some complex incremental setback requirement, all those regulations shapes an envelope into which the building must be placed.
The linguistic model argues that design shares strong resemblance with natural language where design elements (columns, beams, arches...etc) are vocabularies and the compositional rules of configuring those elements are similar to the rules (grammar) that describes how words go together in language.

2.4.3 Creativity of the Grammar (linguistic) approach

Elton 1995, stated three main points that define the creativity of any design model
1) If it can produce computational systems that produce novel and appropriate works, e.g. scientific theories, musical compositions, architectural designs etc.
2) If it contributes to the cognitive sciences as it seeks to understand the mechanisms involved in human creative thinking
3) If it provides abstract models of creativity that are not tied to a specific domain or process for the study of creativity in its most general sense.

In accordance with the definition of creativity given before, the linguistic approach is seen as the most creative process among the three design models to formalize design, it has the potential to both automate the design process and allow greater exploration of design alternatives. It allows for a better understanding of the human design thinking and Architectural theories.
The grammar based approach itself may include both other processes of search and logic in the initial and final stages of design. It could use the reasoning (logic) approach first in defining the suitable shapes and forms that will serve as initial shapes in the grammar formulation regarding the relationships between forms and functions, it also constrains the selection of the specific rules (the grammar) that will generate the design solutions. This gives the designer the potential to evaluate a large number of alternative design solutions using the search approach through this large and complex state space to select the most appropriate solution that will lead to the required goals.

It is accepted to consider the grammar based approach a *creative process* to formalize design. Such process do not necessarily produce creative designs, but it has the ability of extending the design space by the design alternatives in order to achieve creativity, or generally Non Routine design (Alber & Rudolph, 2002).

On the other hand, a more complex and wide argument exists on the nature of the artifact produced by this process, whether it could be termed creative or innovative.

Most of the researches and papers that concerns the creativity of the grammatical model go around four main topics, upon them almost all arguments arise.

### 2.4.3.1 Innovative rather than creative

The first and prevailing opinion adopted by the creativity in AI researchers, motivates the idea that in order to produce creative design, the need for producing something very different from what has been before is clear, and since a grammar implicitly defines all the possibilities, then by itself a grammar can produce designs that are innovative rather than creative, they are all part of the space of domain solutions even though not known to designer initially (Rosenman and Gero, 1993).

And given that a grammar is determined by a set of operators (rules), then everything is defined by the universe of possible solutions and no solutions can be creative. Even if the grammar was extended, it is just like adding meta-operators (which operate on operators) so that the space of domain solution while enlarged is still implicitly defined, and it is just like a search but in a larger space (Rosenman, 2001).

This opinion is also supported by some design theorists who think that “*Rules comes a little later, and even less brilliant architects can base their work on it, and that *the first building where a new architectural style is exposed, is usually created intuitively, without the help of any rules or theories, just by the skill of a brilliant architect*” (Routio, 1999).
2.4.3.2 Design and Grammar process

The second Opinion agrees with the idea that grammar can not produce creative designs – by itself – referring to a lack between the grammar process and the main design process.

Mitchell 1994 proposed the diagram of design process in figure (13). From the initial state to final state, designer should make alternatives as many as possible and select the best alternative to proceed to the next design step (Kwon, 2002). Supposing that the designer used a grammatical application, the process is a sequence of designs beginning with an initial shape. Each design is created from the previous design by application of rules, that defines and constrains the design spaces, though it does not provide a method for exploring them (Loomis, 2001).

Figure (14) shows the gap occurred between the main design process and the grammar process.

Another explanation given by Krishnamurti and Stouffs (1993) that distinguishes between Design and Designing. A design is simply the end of some process and may well be the beginning of another. Designing, on the other hand, is the means to an end, and the choice of using shape grammars formalism is personal and has its aim to aid designing.

The effective designing process may combines blind generation of alternatives with highly effective selection, or employs such foolproof generation technique that there is no need for further testing to weed out mistakes, or divides the labor between generator and tester in
some appropriate way (Mitchelle,1991). And since shape grammar formalism provides an effective way to encode knowledge, then the need is for another testing tool to complete the generate-ad test process of design. Supporting tools from the field of artificial intelligence were suggested, such as Genetic Algorithm, an advanced search mechanism ideal for exploring large and complex problem spaces. Recent cases like developing a housing layout for the fishermen’s habitat (Kitchley & Srivathsan, 2005) converged shape grammars and genetic algorithm for this purpose.

2.4.3.3 Creativity of reasoning

The third opinion is supported by nearly all the grammatical design researchers, specially shape grammar teachers and scholars. They believe that creativity in grammar based design lies in the creation of the rules (Colakoglu. 2002)

In theory, shapes and rules can be anything at all and are limitless in number. In practice, the constraints of a design problem (site, economic or functional requirements, for example) and the constraints the designer brings to the problem (style or design philosophy, for example) motivate the selection of particular shapes and rules (Knight, 1999). So the designer controls form generation by defining the criteria for new designs that fit a given context.

2.4.3.4 Knowledge lean methodology

The last opinion contradicts the third one in that it calls for disengagement from restricted rules, based on Mitchell’s view 1993: “Any successful attempt to describe the mechanics of some creative design activity will have the immediate effect of redefining that activity as ‘noncreative’. The more success we have, the more we can be accused of dealing only with the noncreative aspect of design”. Some would even go far by using a knowledge lean methodology that proclaims that the lesser the knowledge about the relationships between the requirements and the form required to satisfy those requirements, the more the nature of the design problem tends towards creative design (Rosenman,1996).

Chase, 1997 asked the same question: are we restraining creativity by placing restriction on a grammar or a representation and obtaining an understanding of its formal properties? He extracted that descriptions and restrictions are only inhibitors of creativity if they remove
desirable design possibilities, and that creative design using a grammar does not have to be limited to a grammatical derivation; it also occurs in the development of a grammar.

2.5 CONCLUSIONS

The research presented in this chapter has provided three important insights that will shape the work presented in the remainder of the thesis:
1) The outline for the creativity model will help understanding and evaluating the novelty and usefulness of artifacts and processes.
2) A brief exploration into the design formulation history, reasons and methods .
3) Evaluating the design models used to formalize design, so as to choose the most creative, and thus providing a good introduction to the study of shape grammars theory and potentials.
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Chapter Three:
Shape Grammars Theory

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CHAPTER THREE: SHAPE GRAMMAR THEORY

3.1 INTRODUCTION

"Architects everywhere have recognized the need of ... a tool which may be put in the hands of creators of form, with the simple aim ... of making the bad difficult and the good easy “

Le Corbusier 2003

Grammatical design studies had their beginning in a seminar paper by Stiny and Gips 1972, (Duarte, 2001) in which they laid the foundation of a theory that was to become the most important algorithmic approach to design. The Shape grammar theory is concerned with the description of Vocabularies (shapes), the relationship between vocabulary elements (Compositional relationship between shapes elements), and the rules for generating designs (adopted from analysis of symmetry, proportion, and other principles of design discovered from human bodies and ancient buildings). therefore, it was considered a popular way to encode knowledge about Design principles, in the fields of architecture, production arts and mechanical design.

The most attractive feature of shape grammars theories is that it promises to store the design experience of projects, not at the level of the actual design (design cases), but at the level of the principles behind the details and the building parts, it means how the components in details and parts of buildings are actually assembled in three or two dimensional space in relation to other components. In this way it is possible to store the stylistic design principles and construction experience of particular architectural firms.(Seebohm & Wallace, 1997)

Since shape grammars were invented, researches were polarized into two camps, the theorists and the developers, who each tend to handle this theory in one of the following ways (Chase, 1997):

- Those interested in the expressive, generative power of grammars use the pure shape representations but make minimal attempts to deal with computational problems or develop a computer implementation.
Those interested in the computational prospects of the theory and wish to build computer implementations, dealing with the algebraic formulations of shape grammars in forms of equations and algorithmic.

The following chapters tend to explore the shape grammar theory and its potentials theoretically rather than algorithmic. And giving a glance on its algorithmic formalism, the thesis will discuss some of its computer implementations.

### 3.2 SHAPE GRAMMARS FORMALISMS

Emdanat & Vakalo (1999) extracted 7 benefits that were considered for the use of the shape grammars formalism:

1. It connects architectural form and meaning (Stiny, 1985).
2. It facilitates the articulation of aesthetics judgments (Stiny & Gips, 1972).
3. It facilitates the conduct of computations on shapes (Stiny, 1976).
4. It is a generative device that represents the search space of all solutions to a given design problem (Gips & Stiny, 1980).
5. It makes translations from one design language to another possible (Knight, 1981).
6. It is a device that defines architectural language in the same sense that grammars for natural language capture the structure of natural language.
7. It represents architecture style.

Shape grammar theory can be explained in terms of language formalism and algorithmic equations.

#### 3.1.1 Linguistic

In linguistic, a formal grammar (or simply a grammar) is that part of the study of language which deals with forms and structure of words (morphology), with their customary arrangement in phrases and sentences (syntax), and now often with languages sounds and word meanings (semantics) (Chase, 1996).
Phrase structure grammars provide the original idea for shape grammar (Badr, 1997). A grammar is essentially a deductive system of objects and rules of inference to generate sentences of a language. A grammar therefore contains a set of rewriting rules. These rewriting rules have the form A->B, both A and B are in the form of strings. The execution of a rule is that whenever A occurs in a string as a sub-string then this sub-string can be substituted by B and therefore the original string is changed. (Chomsky 1987)

For example, if a rule A->B, then a string of XAY can be replaced by a string XBY.

Some basic rules for constructing a sentence are shown below:

1- Sentence → Noun Phrase + Verb Phrase
   \[ S \rightarrow NP + VP \]

2- Noun Phrase → Article + Noun
   \[ NP \rightarrow Art + N \]

3- Verb Phrase → Verb + Noun Phrase
   \[ VP \rightarrow V + NP \]

4- Article → a, the, my, yours
   \[ Art \rightarrow a, the, etc \]

5- Noun → Girl, boy, picture, house
   \[ N \rightarrow Girl, boy, etc \]

6- Verb → Buy, run, draw, make
   \[ V \rightarrow Buy, draw, etc \]
As shown in Figure (16), a sentence of “The girl draws a picture.” Can be derived from applying the above five re-writing rules. A sentence can be substituted into a Noun Phrase and a Verb Phrase (rule 1). A noun Phrase can become an Article with a Noun (rule 2). A verb phrase can become a Verb and a Noun Phrase (rule 3). Sequences of substituting Article, Noun and Verb into appropriate elements then form a complete sentence (rules 4-6).

Similar to grammar, a shape grammar, instead of dealing with one-dimensional word strings, it deals with two-dimensional or three-dimensional shapes. For example, the starting point can be a concept of “House” and all the substituted elements can be architecture vocabularies such as columns, beams and roofs or rooms and space. A rule applied when a sub-shape from the left hand side matches a rule, then that rule can be applied to evolve a building design. For example, figure (17) illustrates some simple rules for generating a house with the architectural elements.
Figure (17) rules of shape grammar are:

1- House $\rightarrow$ Roof + Body
2- Roof $\rightarrow$ Roof tiles + joists
3- Body $\rightarrow$ Beams + Columns + Base

The bottom shaded part of “supported by” are the implicit assumption of functional concerns that can be expressed as “on top of.”

3.1.2 Algorithmic

Shape grammars allow for computation directly with shapes made up of points, lines, planes, or solids and symbolic items such labels and weights. In computational work in architecture and spatial design, shapes are typically comprised of labeled lines.

A shape grammar consists of rules of the form $A \rightarrow B$, where $A$ and $B$ are shapes. A rule applies to a shape $C$ whenever there is a transformation $t$ such that $t(A)$ is part of $C$. The result is a new shape $(C - t(A)) + t(B)$.

This computational mechanism can be generalized with the rule schemas of the form $x \rightarrow y$ where $x$ and $y$ are variables used to describe shapes. A schema $x \rightarrow y$ applies to a shape $C$ whenever there is an assignment $g$ of values to these descriptive variable such that $g(x) \rightarrow g(y)$ applied to $C$ (Colakoglu, 2001).

The Shape grammar algorithmic formalism can be summarized in the equation

$$C_{n+1} = [C_n - t(g(A))] + t(g(B))$$

In which $C_n$ is the shape in the design at step $n$, and $n > 0$ (Duarte, 2001)
3.3 STAGES OF SHAPE GRAMMARS DEVELOPMENT

Stiny (1980) has described five stages in a constructive approach to grammar definition:

1. A vocabulary of shapes is specified.
2. Spatial relations between elements in the vocabulary are defined.
3. Shape rules are specified based on the defined spatial relations.
4. An initial shape from the vocabulary is defined.
5. Shape grammars are specified based on shape rules and initial shape.

3.3.1 Vocabulary of Shapes

Shape is any finite arrangement of points, line segments, or bounded surfaces and solids defined in a Cartesian coordinate system. Line segments are bounded by points, surfaces by lines, and solids by surfaces.

A vocabulary of shapes determines the pieces from which designs may be made. (Knight, 1991)

Shapes in shape grammar could be:

2D shapes

![Figure (18) 2D shapes examples](image)

3D shapes

![Figure (19) 3D shapes examples](image)
3.3.2 **Spatial relations**

Spatial relations constrain the ways that a shape in a vocabulary can be combined with one another. They are simply compositional ideas and are the key to shape grammars. They also provide contexts to adding and subtracting shapes to create designs (Knight, 1999).

![Examples of spatial relations](image)

*Figure (20) Examples of spatial relations*  
Based on: Knights.T, 2001

3.3.3 **Shape rules**

Shape rules are transformations of one shape to another that allow parts of the shapes to be defined and changed recursively to conform to given spatial relationships (Cha and Gero, 2001). Each rule specifies a condition, and associates with that condition an action which may be taken in response.

To apply knowledge that is expressed in this form, it is required to find a match between the condition part of a rule. Then following the instructions in the action part of the rule (Badr, 1997)

![2D shape rule and its possibilities](image)

*Figure (21) 2D shape rule and its possibilities*  
Based on: Knights.T, 2001
A shape rule has two parts separated by an arrow:
A left hand side (LHS) shape or shapes, which contain a condition
A right hand side (RHS) shape or shapes, which contain the associated action.
A rule states that the shapes on the left side is transformed or replaced by the shapes on the right side. Given an initial shape, one transforms it using the rules of the grammar to produce a new shape or shapes. Transformations could include subtracting parts of the shape on the left side, adding a new shape to it, dividing it, or so on. (Loomis, 1999)

\[ \text{Rules: } A \rightarrow A + B \quad \text{Rules: } A \rightarrow A + B \]

**Figure (22) Examples of 3D shape rule**

The rules of a shape grammar do not have predefined structure. They can be modified at every stage of the design process (Colakoglu, 2001)

**Labeled rules**
Labels are symbols that say how to apply a rule. They could be numbers, letters or any kind of signs. Labelling the rule defined from the spatial relation is done according to the symmetry properties of the shapes in the rule. The transformations that determine the symmetry of the shape on the left-side of the rule can be used to identify the different way (the different transformations under which) the rule can be applied. The application of a rule can then be restricted to each one of these different ways by adding labels to the shapes in the rule. Each different labelling of a rule, according to the symmetries of the shapes in it, determines a different basic grammar. Each different basic grammar generates designs with distinct spatial properties. (Knight, 1991)

**Figure (23) Labeled rule**
3.3. Design

3.3.4.1 Derivations

Derivations are a sequence of designs where each design is generated from the previous design by applying a rule:

Design1 -> Design2 -> Design3 -> Design4 -> . . .

The size of the design space generated by application of a finite number of steps can be defined by a simple combinational equation:

\[ D = L^n \]

Where \( D \) represents the number of possible designs that can be generated after \( N \) steps, and \( L \) is the number of label positions which could apply to each step. The simple four-steps designs shown in figure 24 are two of possible 256 designs in figure 24, the illustrated derivations are two of possible 256 designs.

*Figure (24) (a) Four labeled shape rules (b) Derivations of designs*  
Based on: Loomis B, 2001
The example in figure 25 shows a 3D shape labeled rule and four of its (262144) possible solutions and derivation. This variation causes an exponential explosion in the design space, depending on how many times a rule is applied (Loomis, 1999).

Figure (25) (a) different labeling of the rule $A \rightarrow A + B$ (b) Derivations of designs

Based on: Knight T, 2001
**Interpreting shapes in design generation and derivation**

Emergence of shapes can be problematic for shape grammar generation and derivation because a figure can be interpreted in many different ways. For example, a cross shape can be ambiguous to read its sub-shapes as shown in figure 26.

![Figure 26](image)

Figure 26 shows several ways of interpreting a geometric shape.

(a) (b) (c) (d)

Figure 26a is the shape for pattern recognition which can be read as two overlapped rectangles, one vertical, one horizontal. Figure 26b interprets the cross figure as long and short horizontal and vertical lines. Figure 26c depicts the figure as sixteen equal length lines either horizontal or vertical. Figure 26d represents the cross figure as five same size small rectangles. Therefore each different representation will result applications of different graphic rules, and generate different grammar.

Figure 27 illustrates two rules applied in two different ways because of the emergence of generated shapes. The two generated designs are identical in the first three steps. Then they diverge and follow two different paths to produce two different design. Many other designs are possible with this grammar, and from the second step on, the rules can apply to either emergent L shapes or emergent squares.

![Figure 27](image)

Figure 27 shows an example on the shape grammar that varies with the emergence of shapes. Source: Knight T, 1999
3.3.4.2 Transformations

Transformation in shape grammar means changing the form of the prototype without changing its function. It refers to changes in the observable form of the object. It happens in three ways:

1- By changing the configuration of the form through Euclidean operations in figure 28 (Scale, Rotation, Translation, and reflection).

2- By changing the values assigned to the variables that define the components objects of the form (see Section 3.4 parametric shape grammars).

3- By replacing the vocabulary elements of the form with new ones (Colakoglu, 2001)

![Euclidean Transformations of shapes](image)

*Figure (28) Euclidean Transformations of shapes*  
Source: Knight T, 2001
3.4 PARAMETRIC SHAPE GRAMMARS

Stiny (1985) introduced two types of shape grammars: Standard (non-parametric, basic) shape grammars, and Parametric shape grammar. Both have a set of rules that are applied repeatedly to generate designs, figure (29).

A parametric shape grammar, like standard shape grammar, has a set of rules that specify how shapes replace sub-shapes of a composition. However, it uses parameters for shapes manipulation (Kwoon, 2003).

The parametric shape grammars proposed by Stiny introduced an example - a parameterized quadrilateral “q” with vertices of the points \((x_1, y_1), (x_2, y_2), (x_3, y_3)\) and \((x_4, y_4)\) and a labeled parameterized point \((x_5, y_5)\). Values assigned to the variables in the schema satisfy those conditions.

Such process creates shapes with more variation than the standard shape grammar.

Figure 30 (c) shows the result of a parametric version of the shape grammar shown in Figure 29 (c).
3.5 COLOR GRAMMARS

Color grammars were invented by Terry Knight 1989 as an extension of Basic shape grammars. They are developed in a similar way as shape grammars. First, a vocabulary of colored, 3-dimensional shapes is chosen then spatial relations between colored shapes are defined (Knight, 1989). In a color grammar, rules have also a color component. Colors in rules may stand for colors in generated designs. More often they are used as indices for other attributes, for example, materials, architectural elements such as doors and windows, or even changes to geometries of shapes (Knight, 1999).

Color grammars can be developed in two ways: First, starting from scratch, given a vocabulary of colored shapes and spatial relations between them, then generating designs from these rules. Second, starting with a basic (shape) grammar, in this case, basic grammars are developed first to explore alternative forms, color is then added to selected grammars to explore ways of articulating and elaborating these forms. Color is then used to explore ways of articulating and elaborating these forms.

Knight example, (1999) illustrates the four steps of development of basic color grammar, Figure 31.

![Parametric Shape Grammar](image)
The first step is the creation of a basic grammar, by creating a vocabulary composed of two pillars of different length, establishing a spatial relation, and then the creation of a set of rules.

In the second step, three colors (yellow, red and blue) were used in order to reduce the symmetry of the pillars from 16 to 1, each vocabulary piece has 16 possible repositioning where the geometric relationship between the pillars remains the same while color relationships change the geometric relationship between the pillars remains the same while color relationships change.

Third step is the creation a matrix of grammars, the number of different spatial forms obtained was $16 \times 16 = 256$ and each spatial form could receive 256 different colorings, which produced a matrix of $256 \times 256 = 65,536$ possible color grammars.

And finally picking a grammar that could fit the architectural program.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig31}
\caption{An example on Basic color grammar developments.}
\end{figure}

Source: Celani G, 2001
Grammatical studies have advanced over the years and included complexities of grammars beyond standard and parametric shape grammar and color grammar. Description grammars compute descriptions of design. Structure grammars compute designs as structures and sets of shapes. Attributed grammars compute designs with attributes and constraints on attributes. Parallel grammars or grammars defined in multiple algebras simultaneously compute different shape, text, or symbolic representations of designs (for example, plans, sections, and elevations together with verbal description of them). All of these extensions to the original shape grammar formalism have been developed in order to compute certain kinds of designs more easily or expressively than with a standard shape grammar. (Knight, 1999)

3.6 SHAPE GRAMMARS APPLICATIONS

In 1976, Stiny introduced two simple exercises that illustrated the unique characteristics of shape grammars. The first exercise showed how shape grammars could be used in original composition that is the creation of new design languages or styles. The second exercise showed how shape grammars could be used to analyze known or existing design languages. Both exercises helped motivate almost a quarter century of shape grammars work. (Knight, 1999). And both applications are constructive in the form generation stage of the design process (Colakoglu, 2001).

Since then, shape grammar applications have been developed in various fields including architectural design, landscape architecture, engineering, painting, furniture design, ornamental design and others (Economu, 2000).

The following chapters will discuss the potential of Shape grammars in the applications of analysis and synthesizing designs.

3.7 CONCLUSIONS

This chapter provides a summary and explores the theory of Shape grammars, its developments and applications, thus providing an understanding to the work done in the next two chapters of analysis and design as well as an introduction to a more detailed study of shape grammars in architecture.

Stages of Shape grammars developments will serve as a formula that abbreviate the numbers of steps between each application in the grammars presented subsequently.
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Chapter Four:
Role of Shape Grammar in Design Analysis

4.1 Introduction
4.2 Analytical Grammars History
   4.2.1 The Ice Ray Grammar
4.3 Analytical Grammars Strategies
   4.3.1 Subdivision
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   4.3.3 Grid
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CHAPTER FOUR:

ROLE OF SHAPE GRAMMAR IN DESIGN ANALYSIS

4.1 INTRODUCTION

“Those rules which I have observed, and now observe, in buildings;... that one may learn to lay aside the strange abuses, the barbarous inventions, the superfluous expense, and (what is of greater consequence) avoid the various and continual ruins that have been seen in many fabrics “

_Palladio 1570, cited by Routio 1999_

Some people say that the architect is an artist and, unlike engineers, he cannot base his work on rules. It is conceivable that as humans, we are inclined to repeatedly rely on our experience and our familiarity with certain known concepts and metaphors and apply them to our way of doing things, this is known as Technique, and even an artist has to have his technique. (Krishnamurti & Stouffs, 1993, Routio, 1999).

Typically in analytic applications, a set of designs is selected, abstracted versions of these designs are extracted to bring forward some aspects of the composition that are the interest to the designer of the shape grammar, spatial relations between parts are selected, shape rules are defined in terms of these spatial relations, an initial shape is selected to start the computation, and shape rules are applied successively to an evolving shape starting with the initial shape. Design generated by the grammar typically include the original set of designs that was chosen for analysis, and many other hypothetical designs that share the same spatial and functional characteristics with those of the original set. (Economu, 2000).

Analytical grammars draw much of their significance first from their capacity to generate descriptions that compromise well known designs and secondly from its educational potential. There are no better way to learn about styles or languages of design (at least compositionally) that by either studying shape grammars already written for languages or by writing grammars oneself (Knight, 1999).
4.2 ANALYTICAL GRAMMARS HISTORY

The first application with analytical shape grammars was given by Stiny 1977 in his paper “Ice-ray: a note on the generation of Chinese lattice designs”. This grammar set the standards for the shape grammars that followed (knight,1999). It was the first parametric shape grammars that describes and generates instances of a language, the Chinese lattice design style (figure 32) that was constructed between 1000 BC and 1900 AD and catalogued in 1937 by Daniel Sheets Dye. The grammar captures the compositional principles of lattice design into a set of drawings.

In this grammar, Stiny identified five parts for any parametric shape grammar \((S, L, R, I and T)\)

1. \(S\) is a finite set of shapes
2. \(L\) is a finite set of unordered sets of labeled points.
3. \(R\) is a finite set of shape rules of the form \(A\rightarrow B\), where \(A\) and \(B\) are labeled parameterized shapes: \(A=<u, i>,\) and \(B=<v, j>\). Any assignment \(g\) to the parameters in the parameterized shapes \(u\) and \(v\), and the unordered sets of labeled parameterized points \(i\) and \(j\), results in shapes \(g(u)\) and \(g(v)\), that are in \(S^*\), and unordered sets of labeled points \(g(i)\) and \(g(j)\), that are in \(L^+\) and \(L^*\) respectively.

![Figure (31) Ice lattice designs](Source: Stiny G, 1977)
(4) \( I \) is a labeled shape such that \( I = (w, k) \), where \( w \) is a shape in \( S^* \), and \( k \) is an unordered set of labeled points in \( L^+ \). The labeled shape \( I \) is called the initial shape.

(5) \( T \) is a set of transformations.

He also identified five simple rules for the Ice ray grammar (Figure 33). Each rule subdivides a shape by inserting a straight line.

The first shape rule states that any triangle with area greater than some given constant may be augmented once by placing a line between any two of its edges to form a triangle and a quadrilateral with approximately equal areas. The second and third shape rules state that any convex quadrilateral with area greater than some given constant can be augmented once by (a) placing a line between any two of its adjacent edges to form a triangle and a convex pentagon with approximately equal areas or (b) placing a line between any two of its non-adjacent edges to form two additional convex quadrilaterals with approximately equal areas. The fourth shape rule states that any convex pentagon with area greater than some given constant can be augmented once by placing a line between any two or its non-adjacent edges to form a convex quadrilateral and another convex pentagon with approximately equal areas.

The generation process continues only when the area of the shape is greater than some specified constant \( C \), and the angle of the parameterized shape should not be greater than 120 degrees.

Those two conditions were derived later to control the continuity of the generation process and the variations of shapes in lattice design.

Figure (32) the five rules for the grammar

Source: Stiny G, 1977
Figure 33 shows a derivation to generate a pattern starting from a rectangle shape. The rectangle is divided into two trapezoids using the third rule, and then the lower trapezoid is divided further into two trapezoids using the third rule. Finally, the upper pentagon is split using the fourth rule into a triangle and a pentagon. These subdivisions are applied recursively and generate a pattern in the Chinese lattice design. (Kwon, 2004)

Figure (33) A generation of the ice ray design shown in figure (31)b by means of shape grammars rules shown in figure (32)

Source: Stiny G, 1977
4.3 ANALYTICAL GRAMMARS STRATEGIES

Analytical grammars embody general design strategies that can be classified in:
1- The Grid strategy
2- Subdivision strategy
3- Composition strategy
4- Simple relations of shapes

Although strategies simulate design processes, they may not correspond to historical fact, that is it may have nothing to do with the way designs were originally conceived or the process by which they were originally created (Knight, 1999, Economu, 2000).

4.3.1 Grid

This strategy begins with a grid formed by rectangles; the generated grid carries out the designer or the style characteristics in its rectangles organization, proportion or dimensions. Spaces are then delineated within this grid to form the plan, and finally finer details are added to the walls and within these spaces.

*Application.*

The given application was the second analytical application and the first architectural application of shape grammars, the Palladian grammar by Stiny and Mitchell, 1978.


Stiny ad Mitchell defined eight stages of rules to generate the uniaxial villas plans (plans that was laid out with respect to a single axis). The stages are applied in this sequence:

1. grid definition
2. exterior – wall definition
3. room layout
4. interior – wall realignment
(5) principal entrances – porticos and exterior-wall inflections
(6) exterior ornamentation – columns
(7) windows and doors
(8) terminations

It has 72 production rules that generate all the villa plans that Palladio designed as well as new ones in the Palladian style. (Kwon, 2004)

Figure 35 shows how the 72 rules of this grammar are applied to each intermediate drawing and illustrates how Palladio’s villa Malcontenta plan is developed. The grammar starts from defining a single point, which shows a location of the plan on the site. A grid with rectangles is used as an initial layout and controls all subsequent stages of plan generation. The grid is used for generating external walls and rectangular spaces to form rooms in the plan. The principal entrances and columns are then added with windows and doors inserted in the walls to complete the plan.

Figure (35) A derivation of villa Malcontenta using Palladian grammar
Figure 36 illustrates some villa plans depicted with the rules.

![Villa Plans](image)

**Figure (36) Plans generated by the Palladian shape grammar**

*a) Palladio’s designs b) New designs*


The Palladian grammar does not pretend to reconstruct any of the design strategies and compositional tools historically attributed to Palladio (Economu, 2000)
4.3.2 Subdivision

The second strategy is commonly used when designs in a language are distinguished with the same exterior boundary or frame. The grammar then starts with the outer frame (boundary) as the initial shape, then subdivision operations occur dividing the space into smaller spaces by slicing through or parallel to the initial shape.

This process is also successively used when analyzing paintings or works of arts, as it is limited into a fixed frame.

![Diagram of Subdivision Strategy](image)

**Figure (37) Subdivision Strategy**

**Applications**

The first application is a Grammar for describing the structure of a painting style proposed by Kirsch and Kirsch (1986). Russell A. Kirsch is a pioneer of image processing, pattern recognition and chemical structure searching, his wife, Joan L. Kirsch, is an art historian. Together they wrote a grammar to analyze some late works of the celebrated artist, Richard Diebenkorn. Between 1967 and 1983, Diebenkorn painted about 135 very large abstract oil paintings; influenced by the luminosity, color, space, and architecture of the Ocean Park area of Santa Monica, CA where he lives and works.

![Samples of Diebenkorn's Ocean Park Paintings](image)

**Figure (37) samples of Diebenkorn’s Ocean park paintings**
They used the parametric shape grammars to develop the grammar for the structure of the Diebenkorn paintings. They borrowed labeling devices from programming language called the dispatchers U/S/R. The dispatcher is like property list in languages like LISP. "In a rule such as OPP -> Op/S the dispatcher S, is a property added when the rule is applied and inherited in all subsequent rule applications unless specifically removed by a rule" (Kirsch and Kirsch, 1986).

Then, by subdividing the initial shape they defined regions (R, W, N, Q and F) and set rules for the development of each of them in relation to the dispatchers.

The Coloring process occurs depending on the definition of each region, and when regions are colored, lines that traverse the region are ghosted as they would be by overpainting. After coloring is complete, some ghosted lines may be reemphasized by repainting with colors distinct from those of the two or more regions bordering the line.

Figure 39 illustrates five of the 42 production rules of the grammar to subdivide regions of a painting, similar to Stiny’s ice-ray grammar. Figure 40 illustrates a linear structure of the composition for Diebenkorn’s Ocean Park No. 111 by applying a sequence of some rules. Starting from applying Rule 7 to a rectangle, rules are selected and applied recursively to produce the final drawing. (Kwon, 2004)

![Figure (39) 5 rules from the 42 rules for the ocean park grammars](source: Kirsch R and Kirsch L, 1986)
Figure (40) Grammatical derivation of linear composition for Diebenkorn’s Ocean Park number 111.

Source: Kirsch R and Kirsch L, 1986
Another application from the field of architecture, the shape grammars for the central Asian caravanserais, developed by Sumbul and Chase in 2004.

The caravanserais were rest houses for caravans, built on trade routes between central Asian cities in the middle ages.

The grammar for the Caravanserai is developed in five stages. Stage A contains rules for the development of a generic design for the built zone of the building starting with the initial shape as a labeled polygon $P(0)$ which dimensions are based on multiples, $n'$ and $n''$ of a modular length, $m$. Then another polygon is created inside to generate a single or two built zone designs, then the design development varies according to each type.

Stage B allows the definition of the built zone with 12 rules that govern the generation and design development of cells in single and double built zone designs.

In Stage C, a generic design for the fortification wall is created, while Stage D contains rules for the stylization of the fortification wall. Stage E hosts termination rules.

**Figure (41) Examples of caravanserais, desert palaces and forts**
Source: Sumbul A & Chase S, 2004

**Figure (42) Stage A rules for building zone development**
Source: Sumbul A & Chase S, 2004
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Figure (43) Rules from Stages B, C and D
Source: Sumbul A & Chase S, 2004

Figure (44) Derivation of a caravanserai
Source: Sumbul A & Chase S, 2004
4.3.3 **Addition**

Unlike subdivision, additive process is useful when designs in a language have irregular or diverse kinds of boundaries. In this approach, a search begins for the common core for all designs in a language; this core may be either an element or a space. And when identified, the organization of spaces around it is then analyzed to extract rules for the grammar.

**Applications**

The most famous additive application of shape grammars is the Frank Lloyd Wright’s prairie house style for Koning and Eizenberg in 1985. It gained its reputation first from the fame of its architect and secondly for it was the first parametric 3D application of analytical grammar in architecture.

Koning and Eizenberg (1985) used 99 production rules, including 18 rules to arrange major cubic masses and 81 rules to add details to the masses. Figure 47a shows one of the massing...
rules. It extends one mass by attaching another mass to the right side of the existing mass. Figure 47b illustrates one of the detailing rules. It adds a terrace object to an existing building.

![Diagram showing massing and detailing rules for the prairie house grammar]

Figure 47c shows the steps of a derivation in the prairie house grammar. The house design starts from the fireplace and is organized around it. Then, a living zone is located around the fireplace creating a core unit. The prairie house plan is composed with butterfly-shaped extensions of the core unit. The house plan’s basic composition is completed with named function zones such as living and service areas, and porches and bedrooms. There are also rules to add terraces, a basement, and a second story. The final rule completes the generation of the prairie house by adding a roof and chimney. Figure 48 illustrates some variations generated by the Frank Lloyd Wright’s prairie house using the prairie house grammar. (Kwon, 2004)
Figure (48) Various results of the prairie house grammar
Source: Koning & Eizenberg, 1985

Figure (49) The Stiny house 1981
Source: Koning & Eizenberg, 1985
The Taiwanese temple (Shang-Chia & Krishnamurti, 1997) grammar is another application of additive grammar where the main design core is a space (the courtyard).

The grammar itself consists of 24 rules, 10 for the generation of the special temple layouts, 3 for the framing system, and 11 for porches and verandahs.

Figure (50) rules for the generation of the special temple
Source: Shang-Chia & Krishnamurti. R., 1997

Figure (51) A- Shape rules for the framing system  B- shape rules for dealing with porches and verandahs
Source: Shang-Chia & Krishnamurti. R., 1997

Figure (51) Some steps in the generation of a Taiwanese Temple
Source: Shang-Chia & Krishnamurti. R., 1997
4.3.4 **Simple relations of shapes**

Based on section 3.3, a conclusion of the initial shape(s) is accomplished and spatial relations between 2 or more labeled shapes were found, then rules are defined, applied and repeated recursively to generate designs in a language.

This strategy is not accurate, but it is commonly used for pedagogical reasons, in shape grammars lectures in order to analyze the main compositional rules used by in the language or the style with no deep study for details or functions in plans.

**Applications**

The lectures of Terry Knight about shape grammars in MIT (2001) included 2 educational applications that illustrate the simple theoretical application of shape grammars in the church plans and the Alva Alto’s office building.

**Figure (5.7) Simple Relations of Shapes Strategy**

**SHAPE GRAMMAR**

\[
	ext{rule} \rightarrow \quad \]

**DERIVATION**

\[
\begin{align*}
\vspace{0.5cm}
\end{align*}
\]

**OTHER DESIGNS IN THE LANGUAGE**

**Figure (54) the church plan grammar**

Source: Knight, 2001
4.4 A NOTE ON 3D ANALYTICAL GRAMMARS

Developing a 3D analytical shape grammar leans on two methodologies:

**First:** Identifying a strategy for the shape grammar if it is competent with the description or the analysis of languages in three dimensions from the beginning, using any of the former strategies. As seen in the Frank Lloyd Wright’s prairies houses grammar, the 3D grammar is very comprehensive and complicated as it interacts with the style spatially. Yet, no other 3D grammars were developed unfortunately and the given example is the most detailed application in analysis.

**Second:** 3D transformations to 2 dimensional grammars by reconstructing the vocabulary elements of the form, this methodology is based on preceding work on the language or the style in 2D grammar. A similar application is given by Sass ,2001 for the reconstruction of Palladio’s villas in three dimensions using computer modeling and three dimensional printing, based on Stiny & Mitchell ‘s Palladian grammar.
process of reconstruction starts from a two dimensional reconstruction, to a three dimensional representation and evaluation.

The reconstruction takes place in three stages:

1- Reconstructing the floor plan in nine steps:
   Assignment of spaces, ceiling notation, wall thickness notation, portico, columns and arches, stairs and stair pedestals, door notation, window notation and detail notations.

2- Reconstructing the elevation in nine steps:
   Initial shapes, walls and floors, cornices, portico steps, columns, Moldings, doors and windows, roof and pediment and details.

3- Constructing the villas model in twelve steps:
   Initial plans, walls, ceilings, cornice, portico, staircase, columns, moldings, doors, windows, details and roof.

*Figure (56)* reconstruction of Palladio’s villas stages (a) The floor plan steps (b) the elevations steps (c) the villas model steps

Source: Sass, 2001
4.5 DISCUSSION

The analytical work that occurs when defining rules for a language or a style is very sophisticated. Some say that it is seemingly like proving a theory or a mathematical equation. Its success is when it covers all sides and details of the language and has the potential to generate old (existing) and new designs in the language. An example like the Palladian grammar raised a lot of discussion between acceptance and disagreement. On showing it to one of the world’s leading Palladian scholars, a villa design produced automatically by the grammar was criticized on cultural and behavioral ground, as not being Palladian, or of his age and times. A further search of Palladio’s complete works uncovered a villa with an identical plan which had not been in the original corpus used to generate the shape grammars. The scholar didn’t respond to this new indicating evidence.

Despite the criticism that claimed that the rules of shape grammars do not correspond to historical facts. Contemporary designers that had their work analyzed, like Diebenkorn, accepted the grammatically generated works as being in their own style, yet unlike any specific work he had until then produced. A grammar like Alvaro Siza Housing System by Duarte (2001), was developed with the enthusiast support of Alvaro Siza himself, and with the anticipation that he will test and may ultimately use computer –implementations of the grammar and developing new houses.

This may be why most shape grammars authors do not view historical truth or practicability as goals for their grammars.” A well-crafted grammar, believable or not, may be used to classify designs and to predict unknown or hypothetical ones successfully. And it can serve as the platform for theories of style that go far beyond compositional issues, even so far as to explore historical issues” (Knight, 1999)

4.6 CONCLUSIONS

In this chapter, the potentials of shape grammars in design analysis are discussed through the analysis and definition of the analytical grammars strategies. Those strategies are mainly general design strategies that can be learnt, used and even applied in the creation of designs as well as in the analysis of forms.
The classification of strategies serves as a guide for the shape grammars users in case of analyzing a style or a language. This guide is based on the selection of the most appropriate strategies for each group of designs depending on the design properties (boundaries, modulation, or free organization of spaces).

This also minimizes the time needed to find the origin point to start for the grammar and limitating the next steps in three searching categories (finding the subdivision concept, or the logic of spaces organization, or the conceptual proportions of rectangles in a grid).
REFERENCES

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