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CONTENTS

One of the most profound relationships between architecture and mathematics is related to patterns: the patterns of geometric decoration are perhaps the most obvious, but there are patterns in proportions, patterns in the generation of a series of numbers such as the Fibonacci series, patterns in the construction of geometric lengths, and patterns in modular constructions as well.

This issue of the *Nexus Network Journal* is dedicated to various kinds of patterns in architecture. Buthayna Eilouti and Amer Al-Jokhadar address patterns in shape grammars in the ground plans of Mamluk *madrasas*, religious schools. The Mamluk sultans were a series of rulers who reigned in Eygpt for nearly 300 years, from 1250 to 1517, and whose reign saw the creation of very beautiful art and architecture. In their two papers in this issue, "A Generative System for Mamluk Madrasa Form-Making" and "A Computer-Augmented Precedent-Based Mamluk Madrasa Plan Generator", Eilouti and Al-Jokhadar first compare the significant forms of the ground plans of Mamluk madrasas (by studying sixteen madrasas built in Egypt, Syria, and Palestine during the Mamluk period) to create a shape vocabulary, then formulate the operational rules that govern combinations of the forms (a shape grammar), and finally, create an interactive computerized plan generator. The shape grammar permits realization of a myriad of patterns based on the initial vocabulary that all lie within the framework of the madrasa program requirements.

Giulio Magli goes back further in history, to the age of Greek colonies in Italy before they were conquered by the Romans, to examine patterns in urban design. While most Greek cities were built in a rectangular pattern, as were the Etruscan and the Roman, constructed around a set of orthogonal axes (the *decumanus* and *cardus*), the settlements examined by Magli in "*Non*-Orthogonal Features in the Planning of Four Ancient Towns in Central Italy" exhibit radial patterns. Magli links this kind of radial urban planning to the radial patterns of the cosmos.

In "Traditional Patterns in Pyrgi of Chios: Mathematics and Community," Charoula Stathopoulou examines the geometric patterns that decorate the buildings of the town of Pyrgi, on the Greek island of Chios, and uses the research methodology of anthropologists to examine the relationships between pattern and community there.

"Curve Fitting" is a study of ways to construct a function so that its graph most closely approximates the pattern given by a set of points. Dirk Huylebrouck's paper, "Curve Fitting in Architecture" examines how a pattern of points extracted from an arch, or the pattern of points that define the curve of a nuclear plant, might be associated to a precise mathematical curve. Pattern definition in this case could help resolve the issue of whether or not the architect intended to describe a precise mathematical curve in his or her construction. For instance, are the arched gates and windows in Gaudi's *Paelle Guell* in the shape of hyperbolic cosines or parabolas? Comparison of the pattern formed by a set of measured points on the architectural forms with the graphs of the functions could provide an answer.

Patterns in the architecture of Frank Lloyd Wright have been studied for some time, both as plan generators, as in the Palmer House, and as decorative motifs, as in his window designs. Piet Mondrian's paintings are well-known examples of patterns in art. In "Integrated Function Systems and Organic Architecture from Wright to Mondrian", James

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Harris looks at the designs of these two masters to extract the rules of their pattern generation and propose possible applications.

In the Geometer's Angle column, Rachel Fletcher examines geometric constructions that square the circle. Her "Squaring the Circle: Marriage of Heaven and Earth" looks at the combination of square and circular patterns.

This issue is completed by B. Lynn Bodner's report of the annual Bridges conference, the 2006 edition of which took place in London in August of this year, Sylvie Duvernoy's report on the symposium "Guarino Guarini's Chapel of the Holy Shroud in Turin: Open Questions, Possible Solutions", and by Kay Bea Jones's review of the exhibit "Zero Gravity. Franco Albini. Costruire le Modernità" in Milan.

I think that this is one of the best issues ever of the *Nexus Network Journal* and I hope you enjoy it.

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Research

A Generative System for Mamluk Madrasa Form-Making

Abstract. In this paper, a parametric shape grammar for the derivation of the floor plans of educational buildings (*madrasas*) in Mamluk architecture is presented. The grammar is constructed using a corpus of sixteen Mamluk madrasas that were built in Egypt, Syria, and Palestine during the Mamluk period. Based on an epistemological premise of structuralism, the morphology of Mamluk madrasas is analyzed to deduce commonalities of the formal and compositional aspects among them. The set of underlying common lexical and syntactic elements that are shared by the study cases is listed. The shape rule schemata to derive Mamluk madrasa floor plans are formulated. The sets of lexical elements and syntactic rules are systematized to form a linguistic framework. The theoretical framework for the formal language of Mamluk architecture is structured to establish a basis for a computerized model for the automatic derivation of Mamluk madrasa floor plans.

1 Introduction

On the one hand, the study of design, its underlying representations, and the methods that can be used to derive new artifacts are important research topics in many disciplines, including engineering and architecture. Form-making entails design activities that have a direct influence on the appearance of the artifacts produced. Its study involves the establishment of explicit and systematic links between the form of an artifact, its visual properties, its compositional attributes and its generative considerations. In addition, form-making is concerned with the processes and considerations that precede and follow as well as those that produce the final form. Shape grammar represents a systematic method for studying the form-making layer of design activities. Studies in the area of shape grammars are well established. In many applications they proved to be powerful in shape derivation, analysis and prediction. However, many of their potentials are still far from being fully explored, especially in the area of understanding the morphology of architectural precedents.

On the other hand, Mamluk architecture represents a significant period of Islamic architecture. It displays most of the aesthetic principles that underlie Islamic architecture. Most of the aesthetic values of Mamluk architecture are exhibited in Mamluk educational buildings (madrasas). The morphological structure that underlies the forms of Mamluk madrasas can be mathematically analyzed and syntactically systematized to formulate a powerful compositional language that may help in the understanding of the Mamluki style and the aesthetic principles of Islamic architecture.

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There is no systematic study of the formal aspects of Mamluk architecture that explicitly articulates the compositional language that underlies its design, and the procedural sequence of its form generation.

In this paper, the two strands of shape grammar implementation and Mamluk madrasa morphological investigation are studied and interlaced. The connection between the two strands produces a new language for the formal composition of Mamluk madrasas. This language summarizes a morphological analysis of Mamluk educational buildings in a concise generative system that can be used to derive emergent examples of this significant period in the history of Islamic architecture.

2 Background

2.1 Formal Languages

Shape grammar is that part of design study which deals with the morphology of the overall forms of products and their internal structures and with the incremental processes that generate them. It is concerned with the constituent components of a form and their arrangements and relationships. It usually emphasizes the *lexical level* (vocabulary elements) and the *syntactical level* (grammars and relationships) of the architectural composition, rather than the *semantic*, *symbolic* or the *semiotic* levels. When rules of a shape grammar are executed on a given subset of vocabulary elements, different alternatives of artifact forms are created. The set of all forms that are generated by applying given rules on given vocabulary elements constitutes a formal language, which may correspond to a visual style.

Studies in the area of shape grammar started in the early 1970s, but their roots in pattern language, typology and systematic design methods started earlier. Although shape grammars have good predictive, generative, derivative, and descriptive powers, they do not focus on the historical, social, functional, or symbolic aspects of the architectural compositions.

Using a step-by-step process to generate a language of design, a shape grammarian typically formulates a set of shape rules, that is, transformations and parameters that can be applied to a set of given vocabulary shapes in order to reproduce existing shapes and come up with emergent ones. Different types of shape grammars can be defined according to the restrictions that are used in their applications. They vary according to the format of rules, variable parameters, constant proportions, allowed augmented attributes, and the order of rule applications. All components of shape grammars (vocabularies, spatial relationships, parameters, attributes, rules, transformations, and initial shapes) provide a foundation for a science of form-making and for a theory of systematic architectural design and composition methodology through algorithms that perform arithmetic calculations on geometric shapes.

Stiny [1980] proposed a framework to define a language of design, constructed by means of shape grammars. The framework can be developed through applying the following five stages [Osman 1998]:

1. Vocabulary definition. The basic shapes of a formal language are defined. They function as the basic building blocks for design.
2. Spatial relationship determination. In this stage, the structure observed in a set of designs is investigated to deduce the spatial relationships that are used to connect the building blocks.

3. Rule formulation. Shape rules are formulated in terms of the spatial relationships identified in the second stage on the basic shapes listed in the first stage.
4. Shape combination. Shapes in the vocabulary set are combined to form initial and subsequent shapes. Shape rules are applied recursively to initial shapes to generate new shapes.
5. Shape grammar articulation. Grammars are specified in terms of shape rules, initial shapes and new shapes. Each shape grammar defines a language of design.

2.2 Mamluk madrasas

Visually speaking, Mamluk architecture represents a significant period of the Islamic architecture. It exhibits the major goal of Islamic architecture, according to which designers strive to achieve harmony between people, their environment and their creator. In general, there are no strict rules defined to govern Islamic architectural design. Designers of the major institutional buildings of Islamic cities used local materials and construction methods and applied abstract geometric languages to express in their own ways the character, order, integrity, harmony, and unity of architecture. However, when the great monuments and precedents of Islamic architecture are examined, their formal structure reveals a complex system of geometrical relationships, a well-designed hierarchy of space organizations and a highly sophisticated articulation of ornaments, as well as deep symbolic and semantic connotations. Geometry in Islamic architecture was developed into a sacred science. It has been structured to express the Islamic beliefs and views of the relationships between the world, man, and God [Himmo 1995]. In the Islamic perspective, the method of deriving all the organizational proportions of a building form from the harmonious recursive division of a basic shape is a symbolic way of expressing the oneness of God and his presence everywhere [Himmo 1995]. Compositions in the Islamic architecture have been transformed into highly abstracted shapes on which principles of rhythmic repetitions, unity, symmetry, and variation in scale were applied to create ordered yet dynamic effects. Shape in Islamic architecture is strongly related to the study of mathematics and other sciences.

In Islamic culture, education has always been closely connected to worship. Expressing this, from their beginnings Islamic mosques have been used for both praying and learning. Over time, the mosque experienced various transformations of functions, which resulted in the establishment of a number of related building types of social, educational and religious characters and with narrower functional scopes. The two interrelated functions (worship and teaching) of mosques eventually diverged. The separation resulted in a distinguished sacred mosque and a madrasa. The early madrasa buildings offered special open and closed teaching halls. The form and function of the early madrasas were similar to those of the mosques. Eventually, the architectural typology of the madrasa forms became so prominent that it visually influenced mosque architecture in the Islamic region during the twelfth to the fifteenth centuries A.D. [Bianca 2000]. The two main prototypes of madrasa layout shapes are the open courtyard madrasa and the closed or domed courtyard madrasa (fig. 1). The domed madrasas are usually smaller buildings whilst those with an open courtyard are generally larger and have central Iwans surrounded by arcades.

The most common formal prototype of the early madrasas is the four-Iwan plan. An example of this prototype can be seen in the Mustansriyya Madrasa in Baghdad. Although it is traditionally thought that madrasas provided sleeping and working accommodation for students, the extant examples show that this was not a rule and it is only later on the progress line of madrasa buildings that student facilities became accepted parts of a madrasa design [Bianca 2000].

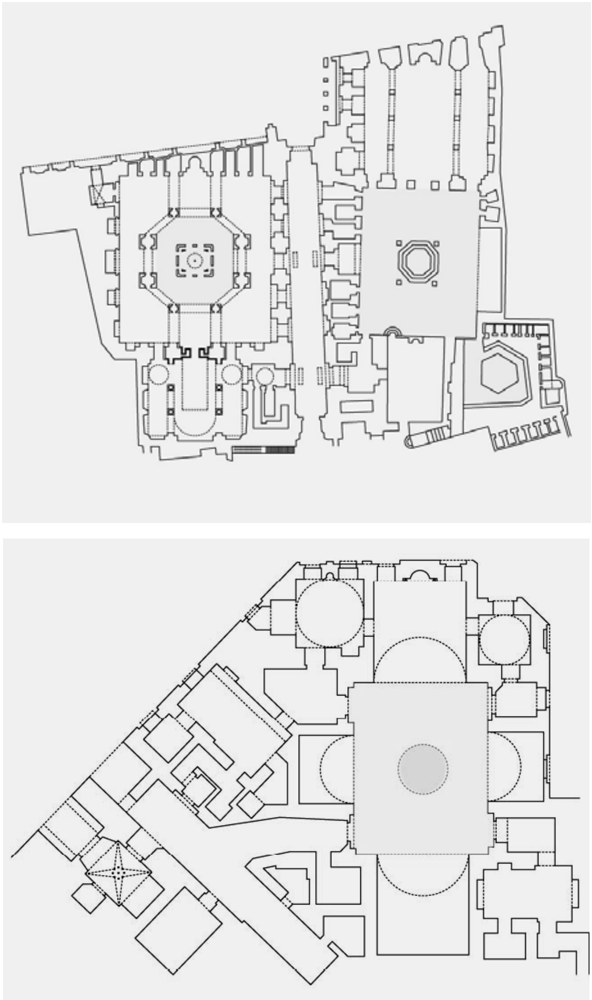

Fig. 1. The main madrasa layout types: a, above) The open courtyard madrasa type (al-Sultan Qalawun Madrasa in Cairo); b, below) The roofed or domed courtyard madrasa *dorqa'a* type (al-Sultan Inal Madrasa in Cairo). Reproduced by authors, from [Organization of Islamic Capitals and Cities 1990]

3 The morphology of Mamluk madrasa designs

3.1 Case studies of Mamluk madrasas

In order to develop a shape grammar for Mamluk madrasa design, a sample of sixteen cases has been assembled (Table 1). The sample consists of thirteen madrasas in Cairo, two madrasas in Jerusalem, and one madrasa in Aleppo. The madrasas in the sample have been selected for their important role as representatives of Mamluk architecture.

Type	No.	Case Study	Location
Type Two: covered court "dorqa'a"	1	al-Ashraf Barsbay Madrasa	Cairo
	2	al-Kadi Zein al-Dien Yehya Madrasa	Cairo
	3	al-Amir Kerkamas Madrasa	Cairo
	4	al-Sultan Inal Madrasa	Cairo
	5	al-Ghouri Madrasa	Cairo
	6	Umm al-Sultan Sha'ban Madrasa	Cairo
	7	Kani Bay Kara al-Remah Madrasa	Cairo
	8	al-Sultan Kaytebay Madrasa	Cairo
	9	Abu-Baker Mezher Madrasa	Cairo
	14	Tashtamar Madrasa	Jerusalem
Type One: open court	10	al-Thaher Barquq Madrasa	Cairo
	11	al-Sultan Hasan Madrasa	Cairo
	12	Serghtemetsh Madrasa	Cairo
	13	al-Sultan Qalawun Madrasa	Cairo
	15	al-Saffaheyya Madrasa	Aleppo
	16	al-Baladiyya Madrasa	Jerusalem

Table 1: The study sample for Mamluk madrasas classified according to their geographic locations

3.2 Common compositional features of Mamluk madrasas

Most of the Mamluk madrasas in the sample were erected on restricted sites. The exterior layouts of these madrasas respected the shape of the site they were constructed on. Thus, irregular ground floor plan shapes were almost always generated. However, considerable thought and effort were often given by the designer to make the building regular in shape inside. Basic shapes were used as the basis for generating all interior spaces. Most of the major interior spaces were oriented toward the "Qibla direction" (the prayer or Mecca direction). Intermediate spaces appeared between the perfectly regular shapes of the interior spaces and the irregular outer boundary of the site.

Typically, the aforementioned four-Iwan madrasa was a dominant prototype. In this prototype, the four Iwans (South-Eastern Iwan or "Qibla Iwan", North-Western Iwan, South-Western Iwan, and North-Eastern Iwan) surround the central courtyard. The other spaces were located on the sides. In addition to each Iwan, facilities for many functions have been designed: a residential unit for the sheikh (teacher), small units for students, small court, *sabil* (free water fountain), *minaret* (tower), the tomb for the patron of the madrasa, corridors and transitional spaces, *sadla* (secondary Iwan), ablution space, and water closets.

Analyzing the sixteen case studies reveals the following major distinct elements:

- The dominant portal space.
- Great Iwans with vaulted roofing.

- Huge interior courtyards or *Sahns*.
- Sheikh's and students' cells.
- Large spaces covered with stone vaulting.
- Minarets that emphasize the portals.

3.3 Mamluk madrasa typology

In general, the floor plan of Mamluk madrasa exhibits a logical design with a vigorous articulation of clearly distinct elements. The design components include great teaching Iwans with tierce-point stone vaulting, huge interior courtyards, mausoleums under high cupolas, residential cells and polygonal minarets [Stierlin 1984]. The overall plan is shaped as a rectangular courtyard with an Iwan in the center of each side. Teaching takes place in the Iwans, and the students live in the cells arranged along the intermediate walls. The dominant architectural feature of this typology is the four Iwans built into the center of each courtyard side.

Later Mamluk madrasas tend to rise vertically in a number of stories, as opposed to the flat horizontal expansion of the early ones, which provided space for the multitudes on the same ground level. In addition, they tend to attach subsidiary units such as tomb chambers and *sabil-kuttab* to the main madrasa functions, converting their simple forms into large funerary complexes [Parker 1985].

3.4 Bahri and Burgi Mamluk madrasas

Mamluk sovereignty can be broadly classified into two periods: the *Bahri*, which ruled from 1250 A.D. to 1382 A.D., and the *Burgi*, which ruled from 1382 A.D. to 1512 A.D. [Parker 1985]. Mamluks spread extensively in Cairo, but they also reached Jerusalem and Aleppo.

Madrasas in the Bahri Mamluk Period are characterized by the following features (fig. 2a):

- The four Iwans surround the open courtyard, while other spaces are located on the sides and mainly in the first floor. This type has been used for teaching one or more legal rites;
- In addition to each Iwan, many facilities have been designed. These include a residential unit for the Sheikh (teacher), small units for students and small courts;
- In most madrasas, there was a tomb for the patron of the madrasa and his family;
- The portal space has been marked and emphasized by a minaret above it;
- The ablution and water closets are located in the back of madrasa for ventilation, and oriented to face the sun. Their level is lower than that of the madrasa itself.

Madrasas in the Burgi Mamluk period are characterized by the following features (fig. 2b):

- The madrasa consists of large and central open courtyard surrounded by four Iwans. These Iwans were divided into *riwaqs* (roofed halls), or covered by either pointed vaults or wooden roofs;

– The ground floor plan includes spaces for the family of the patron of the madrasa, and rooms for teachers and students;
– Another type in this period is the roofed courtyard *dorqa'a* which has been covered by a *Shokhsheikha* (wind ventilator) instead of the open court;
– The two lateral Iwans have been replaced by smaller Iwans;
– Most madrasas have a "*sabil*" (free water fountain);
– In many examples, the whole madrasa was used to teach one legal rite;
– The portal and vestibule space have been also marked and emphasized by a minaret above the main gateway;
– The ablution and water closets have been located in the back of madrasa.

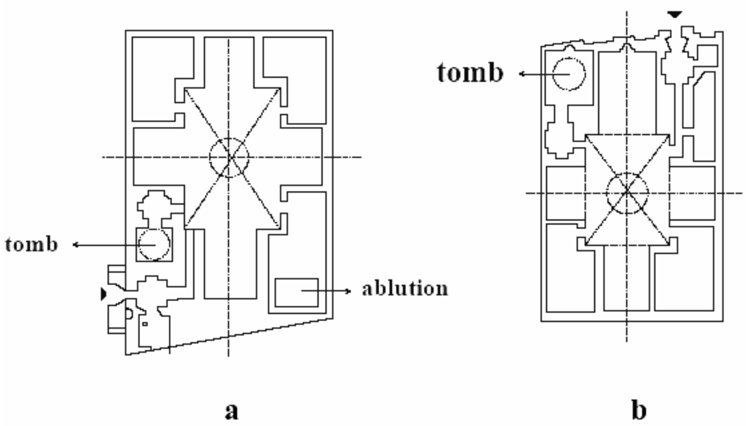

Fig. 2. Layouts of madrasa floor plans: a) in the Bahri Mamluk Period, b) in the Burgi Mamluk Period. Reproduced by authors, from [Organization of Islamic Capitals and Cities 1990]

Mamluk architects repeatedly used certain features in their buildings that shared some common attributes in size and type. Thus, close relationships can always be found among these buildings in their proportions, geometric shapes, topological relationships of spaces and formal compositional aspects. Some of the common features that can be observed in the Mamluk madrasas are:

– The geometric features and proportions of the great and small arches of building's *Sahns* (central courts of madrasa) are similar;
– The position of Iwans may be identified by the fenestrations of the façades of the madrasa without actually entering the building;
– Externally, fenestrations, whether alone or in groups, were set back from the wall planes in recesses. The dimensions and shapes of the openings and recesses reflect the position and size of the hidden Iwan and provide the details necessary to identify the Qibla (Mecca orientation) Iwan;
– The massing configurations illustrate apparent recourse to asymmetrical compositions.
– The façade treatment exhibits skillful articulation of openings and detailing of ornaments;

- The case study sample displays well-defined vocabulary components such as gateways, courtyards, Iwans, domed funerary hall and minarets;
- Locations of the main components such as court(s) and Iwan(s) are similar;
- A proportional system of individual components and their combinations underlies the case studies;
- The overall organizational rules that govern combining the spaces are based on the principles of symmetry, axis position and rotation, and the topological relationships of spaces.

4 A generative system for the Mamluk madrasa floor plans

A morphological analysis of Mamluk madrasa architectural examples reveals the existence of underlying coherent geometric language on all scales. Within this language, architectural vocabulary elements along with spatial organization rules and aesthetic principles of the components and their compositions are defined.

The resultant formal language can be represented as a parametric shape grammar that is based on a set of points, lines, and labels. Multiple aspects of the formal language can be parameterized. The parametric attributes include the size and angle of the rooms, the position at which courtyard walls are attached to rooms, the size of the courtyard and the arrangement and size of the elements of the building. Such a parameterization of rules significantly decreases the number of the proposed rules. It also increases the predictive and derivative powers of the formulated grammar.

4.1 The vocabulary elements of Mamluk madrasas

In making any architectural statement, the designer calls upon a formal vocabulary drawn from his or her previous experience and from the background tradition or culture in which the design is being executed [Serageldin 1988]. Among the institutions *(khanqah, ribat, and madrasa)* that were common in Mamluk architecture the one that describes most of its architectural vocabulary is the madrasa. The spatial vocabulary elements shared by the case studies are illustrated in fig. 3.

4.2 The Grammar of Mamluk madrasas

4.2.1 The procedure of grammatical rule formulation. The grammar rules are formulated according to the following considerations:

- Rules are formulated to specify how sub-shapes of a composition in progress will be replaced by other shapes.
- A rule applies if there is a similarity transformation that will bring the shape on the left-hand side of a rule into coincidence with a sub-shape in the shape vocabulary list.
- Labels are alphabetic characters that are associated with points and shapes. These labels are used to control the application of rules. An example of these labels is the symbol associated with the qibla wall which controls the Qibla direction of madrasa spaces.
- Shapes have proportional parameters which will be assigned by the grammar description during the process of its application.

Fig. 3. The Vocabulary Elements of the Plan of al-Thaher Barquq madrasa, Cairo: 1– Courtyard (or *dorqa'a*); 2–North-Western *Iwan* (opposite to Qibla Iwan)*;* 3–Derka "entrance spaces"; 4–Small Cells for the Students; 5–Main Entrance and portal space; 6–Corridors and Transitional Spaces; 7–Ablution Space; 8–Sabil (free water fountain); 9–South-Eastern Iwan (Qibla Iwan); 10–Southwestern and Northeastern *Iwans*; 11–Tomb or Mausoleum for the madrasa's patron; 12–Minaret (see fig. 4); 13–Teacher's House (Sheikh's House); 14–Northern and Southern secondary *Iwans (Sadla).* (Reproduced by authors, from [Organization of Islamic Capitals and Cities 1990]

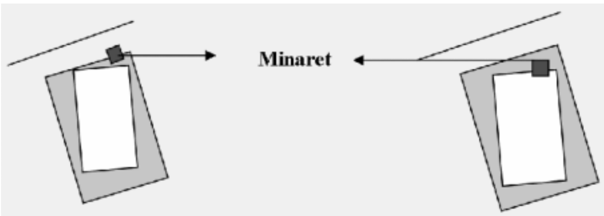

Fig. 4. A minaret that is: a) aligned with the street, while the rest of the building follows the angle of Mecca orientation, b) aligned with Mecca orientation

The morphological aspects, which include visual principles such as symmetry, proportion, geometry, axes distribution, addition and subtraction of spatial organizations, and shape transformations, are considered in the shape grammar development. These aspects are illustrated in fig. 5.

In general, the grammar derives the plans starting from organizing the exterior layout shape and the interior spaces, and proceeding down to the details of walls, doors, and windows. The grammar is formulated in a way that encourages a designer to start with the determination of the exterior layout. This point of departure is more efficient for controlling the overall shape, because the interior layout is more constant in its geometric shape and orientation. The overall structure of the formulated grammar is illustrated in fig. 6. The computational model is out of the scope of this paper. Its study is presented in a separate paper [Eilouti and Al-Jakhadar 2007].

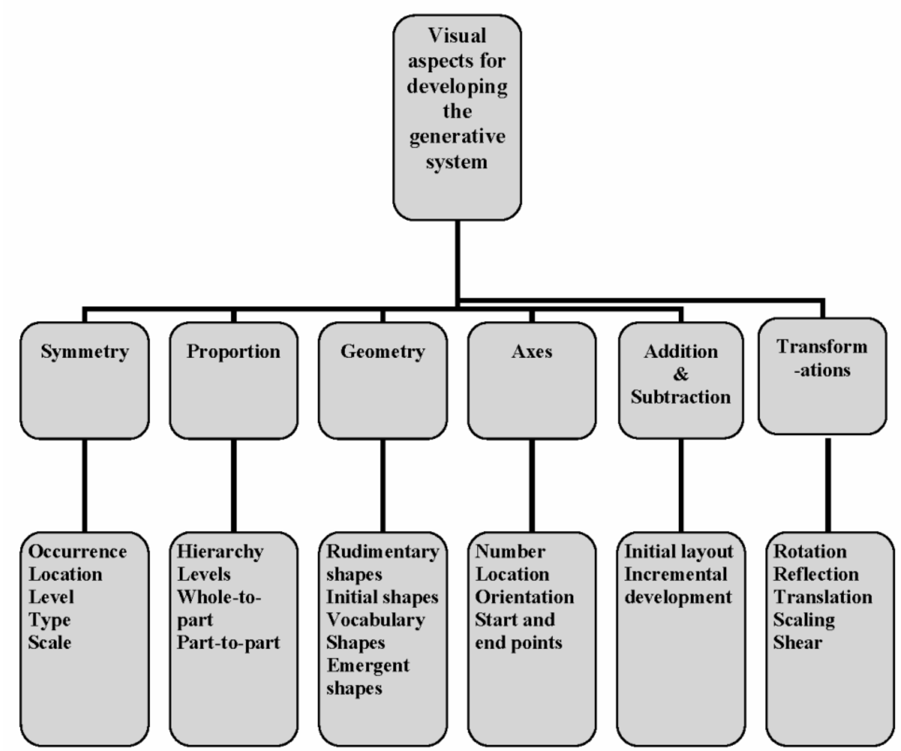

Fig. 5. Aspects used for developing a generative system for Mamluk madrasas

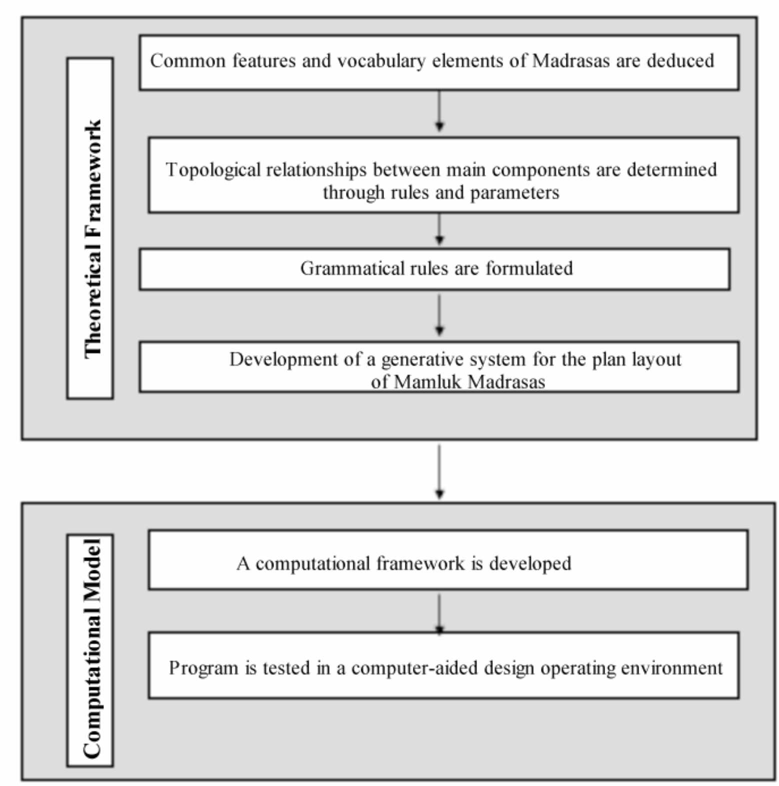

Fig. 6. A flowchart illustrating the different stages for developing a generative system for Mamluk madrasa floor plans

4.2.2. The grammar rules for generating Mamluk madrasa floor plans. All rules of Mamluk madrasas are numbered using the system X – n – Y , where:

X: is the name of the stage. The possible values of this variable are:
SL (Schematic Layout)
AC (Architectural Components)
WT (Walls Thicknesses)
OP (Openings)
TR (Termination)

n: is the rule's number in stage X.

Y: describes the sequential step that is associated with the rule (n). The possible values of this variable are:
PSH4 (the addition of a Parametric Shape with Four Sides)
or PSH5 (the addition of a Parametric Shape with Five Sides)
or PSH6 (the addition of a Parametric Shape with Six Sides)
or PSH7 (the addition of a Parametric Shape with Seven Sides)
or PSH8 (the addition of a Parametric Shape with Eight Sides)
or PSRF (the addition of a Parametric Shape and then Reflect it)

or A (the addition of a Parametric Shape - Arc)
or C (the addition of a Parametric Shape - Circle)
or M (Moving)
or R (Rotation)
or D (Division)
or S (Scaling)
or U (Union)
or L (Drawing Lines)

There are three steps for Mamluk madrasa floor plan form generation. These are:

1. Initial Shape Location:

The initial shape, from which all plans are generated, establishes a point labeled "A" at the origin of the coordinate system, as shown in fig. 7.

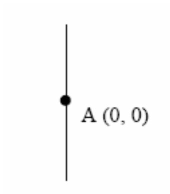

Fig. 7. The initial shape from which all Mamluk madrasa floor plans are generated: a labeled axis.

2. Exterior Layout Shape Determination:

The exterior layout shape is generated around the initial shape. Six alternatives for this set are defined. These are illustrated in fig. 8.

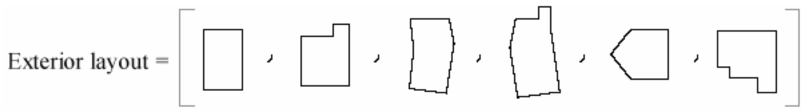

Fig. 8. The Exterior Layout Shapes

3. Grammar Rule Application:

The formulated grammar consists of 93 rules distributed as follows:

Rule type	Number of Rules
Rules for generating schematic external layout shapes	12
Rules for generating architectural components:	
Rules for generating interior spaces	2
Rules for determining the orientation of spaces	1
Rules for generating Iwans and courtyards	3
Rules for scaling Iwans and courtyards	3
Rules for generating spaces between Iwans	2
Rules for generating lateral spaces	4
Rules for generating mihrab in the Qibla-Iwan	3
Rules for articulating interior spaces	4

Rules for generating the tomb or mausoleum	13
Rules for generating ablution spaces	2
Rules for generating cells and rooms around the courtyard	4
Rules for generating the main entrance and Derka	18
Rules for determining wall thickness	9
Rules for generating openings	9
Termination rules	4

5 The derivation process of Mamluk madrasa floor plan

In order to demonstrate the shape grammars developed so far, an example is illustrated. It is selected from Type 2 (see fig. 1b), which has a roofed courtyard *dorqa'a*. This case is al-Ashraf Barsbay Madrasa in Cairo (1425 A.D.). The main components of this building are the central open courtyard surrounded by two large Iwans. The Qibla-Iwan is the largest one. There are also two other small Iwans, *sadlas*. The total area of this madrasa is approximately 1550 m^2, and the area of the central courtyard is about 230 m^2. Thus, the proportion between the total area and the area of the courtyard is 1:6.7. Other spaces that are represented in this madrasa are the mausoleum in the Eastern-North side, *sabil-kuttab*, and a minaret above the main portal.

The main entrance of this example is characterized by the vestibule space. The main gateway of the madrasa does not allow immediate access to the indoor spaces, but leads into a passage with a 90° turn, so that it is impossible to see the courtyard from the outside. This indirect access enhances the creation of calm learning environment inside. Another compositional feature is the division between the ablution space and other rooms. The main reason for this is the orientation to the wind, ventilation and sun.

The derivation process of this example is organized into five major stages. These consist of the generation of the exterior layout, the generation of architectural components, the determination of walls thicknesses, the assignment of the openings – doors and windows–, and, finally, the rule termination stage. Within these stages ten more detailed stages can be identified. Figs. 9-12 illustrate the ten stages through which the overall ground floor plan of al-Ashraf Barsbay Madrasa was derived. The ten stages are:

1. Determining the shape of the Exterior Layout by applying the rules: SL-1-PSH4, SL-2-A and SL-13-M (fig. 9a):

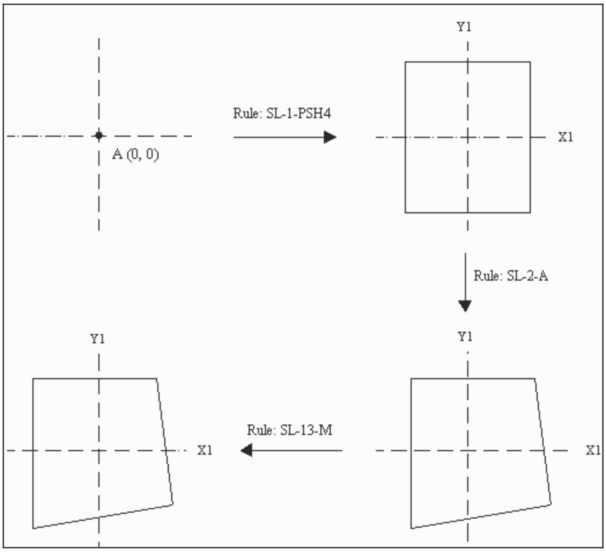

Fig. 9a

2. Outlining the Overall Interior Spaces by applying the rules: AC-3-R, AC-2-M, AC-1-PSH4 (fig. 9b):

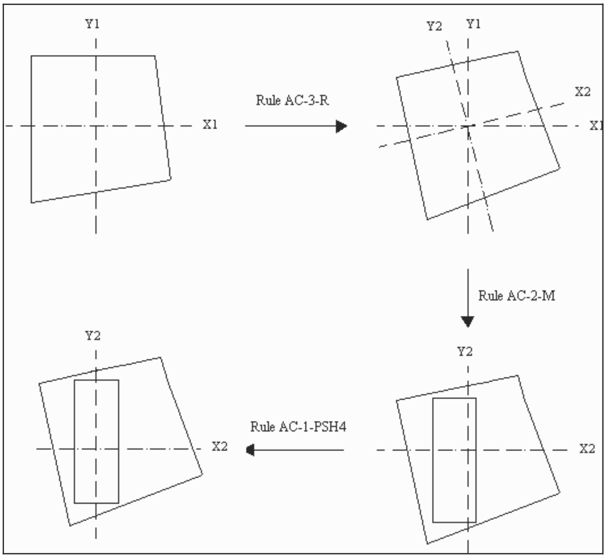

Fig. 9b

3. Generating the overall interior spaces by applying the rules from (AC-4-D) to (AC-9-S) (fig. 9c):

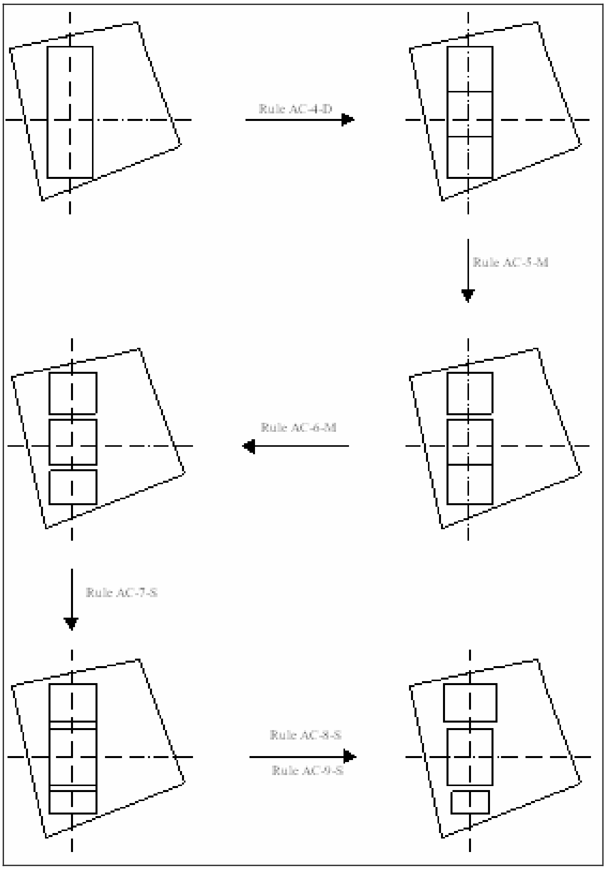

Fig. 9c

4. Generating the courtyards, Iwans, and minbar by applying the rules from AC-10-PSRF to AC-21-PSH4 (fig. 10a):

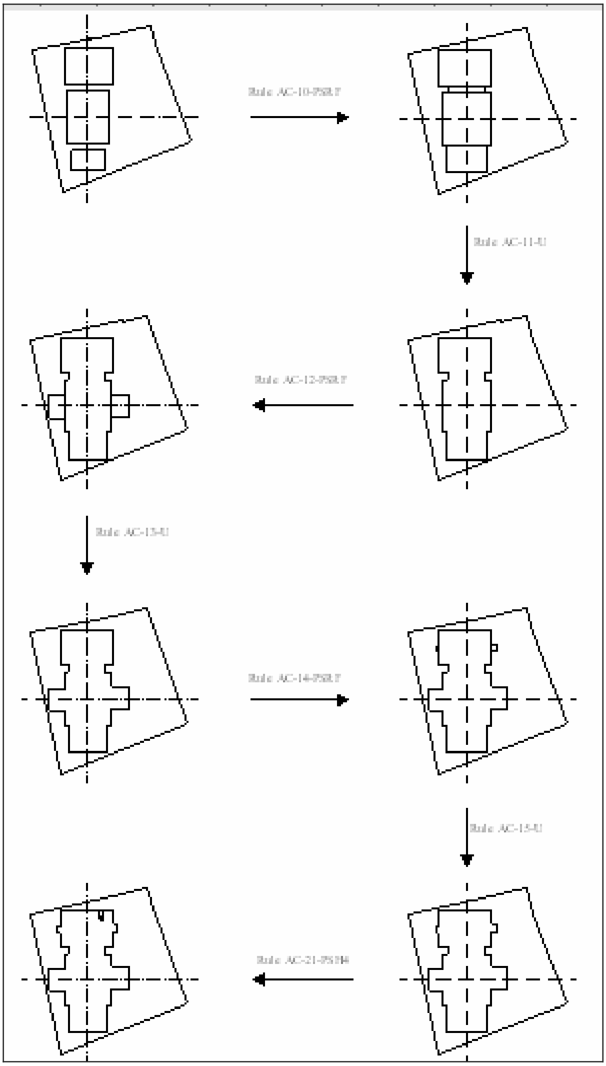

Fig. 10a