SHAPE GRAMMARS: STYLE GENERATORS IN COMPUTER-AIDED ARCHITECTURAL DESIGN

SAMIR SADEK HOSNY*

ABSTRACT

Just as grammars for natural languages use rules to form grammatical sentences from a dictionary of words, grammars for architectural design use rules to make structures from a dictionary of shapes, properties, labels and other elements. Shape grammars are concerned with the generation of form through the application of defined rules which constitute a grammar, and which can be used to express the way that elements of a design are composed in a style. This paper addresses the concept that shape grammars, considered as one of the CAAD (Computer-Aided Architectural Design) generation tools, may be used to help the designer generate and evaluate design concepts after a specific style during the conceptual phase of the design process. An example of architectural grammar after Kisho Kurokawa's style for museum design is presented. Five examples of Kurokawa's museum designs are analyzed. The extraction and formation of his architectural grammar is presented. The implementation of the grammar is introduced through a set of rules governing the Kurokawa's style for museum design, these are put in a shapes matrix through which different design ideas, concepts and configurations are generated and explored. The paper also opens up new frontiers for future research work in this field.

KEYWORDS:

CAAD, Generation of Form, Architectural Language, Style, Grammar, Shape Grammars, Shape Rules, Kisho Kurokawa

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1. INTRODUCTION:

The generation of form in architectural design is one of the significant research areas in design computing. Prominent among generation models in Computer-Aided Architectural Design (CAAD), which provide a basis for the computational generation of form, are transformation models, or more explicitly; grammars. In such models of generation, design knowledge is encoded as transformation rules. According to Taura et al [1], the application of rule-based formalisms to encode syntactical knowledge of architectural designs is well founded in CAAD.

The most well-known and successful type of grammar used in design is the shape grammar, in which shapes are represented and transformed [2]. Grammars are the most well known formalism, which can be employed in transformation models of design [3].

2. THEORETICAL APPROACH:

2.1. Architectural Language:

According to the Webster's New World Dictionary, 3rd College Edition, the definition of language is a special set of symbols, letters, numerals, rules etc. used for the transmission of information. Similar to natural language components, architectural language components are: *semantics* (meaning and context) and *syntax* (structure and form). Language has its own syntax, that is, it has its *alphabet* (primitive elements), *vocabulary* (elements composed from the alphabet, words, phrases and sentences) and *grammar* (legal composition of vocabulary, rules and operators). These are concepts that could help to eventually enable computers to undertake design tasks on the level of an architectural language. Although many buildings may not be designed and built in a pure identifiable architectural language, thus defying the use of shape grammars, luckily enough, there are few exceptions.

2.2. Vocabulary:

Architectural alphabets (points and lines) are the smallest units of which architectural words or symbols in a design language are composed forming a vocabulary. In order to be meaningful, this vocabulary must occur in the appropriate context. The set of primitive graphic symbols that are depending on their specific domain, take on different meanings. The interpretation of symbols or graphic words can range anywhere from navigation signs to architectural concept outlines. Architectural symbols, although they may be placed at the bottom of the language hierarchy, they do carry meaning. They are not neutral and cannot be used in a context free manner.
Shape grammars are concerned with combining words into entities, or sentences, to form a composition. The application of three concepts is necessary to achieve this composition: *relationships*, *rules* and *grammar*.

2.2.1. Relationships:

In architectural languages relationships between forms are responsible for the design composition. By analyzing this design we can have the relationships that underlie its structure. In order to generate a particular design, the computer needs the information of this relationship between the different components of the design. This relationship can be formalized by way of transformation rules to form a grammar. The grammar is then used to form the language.

2.2.2. Rules:

Rules in architectural design are the representation of the underlying relationships between the different components (shapes) of that design. Transformation rules in their simplest form use the If-conditional format, the rule consists of a left hand side (LHS), which contains the condition, and the right hand side (RHS), which contains the needed action when the condition is true. In this sense, a transformation rule has a

LHS that describes the facts or the configuration of a design state, and a RHS that describes the facts or configuration to replace the LHS facts to reach another design state. Design rules in this approach are represented graphically.

2.2.3. Grammar:

Shape grammars are concerned with the generation of form through the application of defined rules which constitute a grammar (analogous to a grammar in human languages) and which can be used to express the way that elements of a design are composed in a particular design style. The formal definition and basic properties of shape grammars have been clearly defined and applied by Stiny [2-3] and March [4]. It is possible then to examine existing works of architecture in an attempt to extract the design rules that may have led to their particular design solutions, generalize these rules and formalize them into a shape grammar. These rules may recreate the examined building, or they may create many different others that the grammar can generate according to a particular style. The most notable examples from architectural design include, Palladian Villas [5] and Frank Lloyd Wright's Prairie-style houses [6], from furniture design, Hepplewhite-style chair backs [7] and from painting the work of de Stijl [8].

3. THE MODEL OF THE DESIGN PROCESS

The design process is divided into three main levels:

Level one, the Conceptual phase, deals with the main configuration of the plan in an abstract form; it's masses and their relationships to each other. The user starts by the initial shape, then specifies the orientation of the design and proceeds with the rest of the plan configuration.

Level two, the development or "adjustment" phase where the abstract form is checked for suitability for the architectural program. Zones are translated into spaces with internal relationships, also articulation elements are defined such as corridors and

staircases. Changes in proportions and positioning may be introduced whenever needed.

Level three, the detailed phase, where the final form has been developed and other rules or grammars are applied to refine the architectural features, with more details for walls, openings and other structural and architectural elements.

The current work addresses the first two levels of this design process; the configuration of the plan and its adjustment, as it clearly demonstrates the full capabilities of the suggested CAAD approach in the early phases of design.

4. CHOOSING THE CASE STUDY:

Influenced by Buddhism and by traditional concepts in Japanese culture, Kurokawa has developed his "Philosophy of Symbiosis," which stresses the interrelationships between time and space and between man and technology [9-10]. This philosophy encapsulates the paradigm shift from the "age of machine" principle to the "age of life" principle that has occurred during the 20^{th} century. This has been the main theme of Kurokawa's numerous major architectural and urban planning works throughout the world. The study looks at the spatial composition of Kurokawa's work rather than at decorative details. Kurokawa's museum designs have been chosen for their clear and obvious identifiable architectural language. The rules inferred in the study concern the interpretation of building volumes, the position of different functional zones and some important features of his designs such as the pergolas, the entrances and the pure geometric shapes. An explicit goal of the study would be to test the applicability of shape grammar formalism for the generation of new designs after a particular design style. The study falls into two parts:

1) An analysis of existing buildings by Kurokawa which is achieved by developing shape grammars that capture the underlying conventions and are able to reproduce the same designs, and
2) The design of new patterns or producing new designs that still maintain Kurokawa's style.

The selected works of Kurokawa are:

1. Saitama Prefectural Museum of Modern Art
2. Nagoya City Art Museum
3. Hiroshima City Museum of Contemporary Art
4. The Museum of Modern Art, Wakayama Prefectural Museum
5. Ehime Prefectural Museum of General Science

5. THE ANALYSIS:

The analysis of Kurokawa's museum designs in particular, shows clearly the presence of a special typology that is widely being adopted among his different designs.

5.1. Saitama Prefectural Museum of Modern Art

The building was designed in 1978, and completed in 1982. The building form is fundamentally a rectangle, but a deep slit opens up one side. In some sections the walls are recessed, and one portion of the exterior wall is projected outwards, creating an intermediate space between the main entrance and the lattice-like exterior wall. This enclosed garden evokes a sense of transition and continuity between the exterior and the interior. Refer to Fig. 1.

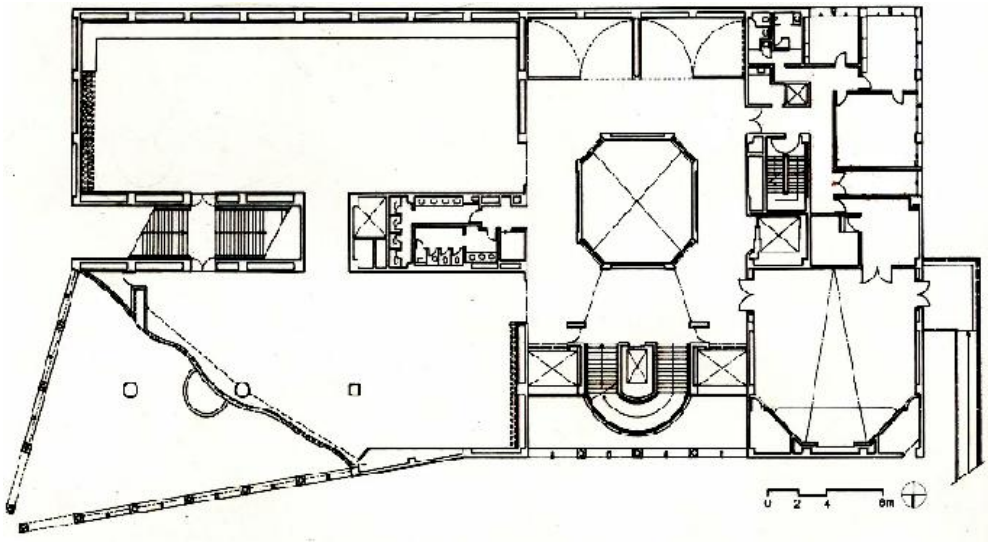


Fig. 1. Saitama Prefectural Museum of Modern Art

5.2. Nagoya City Art Museum:

The building was designed in 1983, and completed in 1987. Fig. 2, shows an independent architectural structure consisting of posts, beams and walls standing in front of the building as a symbolic gateway, that may be used for external displays. The basement level atrium/lobby continues beyond a frequently curving curtain wall into a sunken garden forming an intermediate zone, neither exterior nor interior.

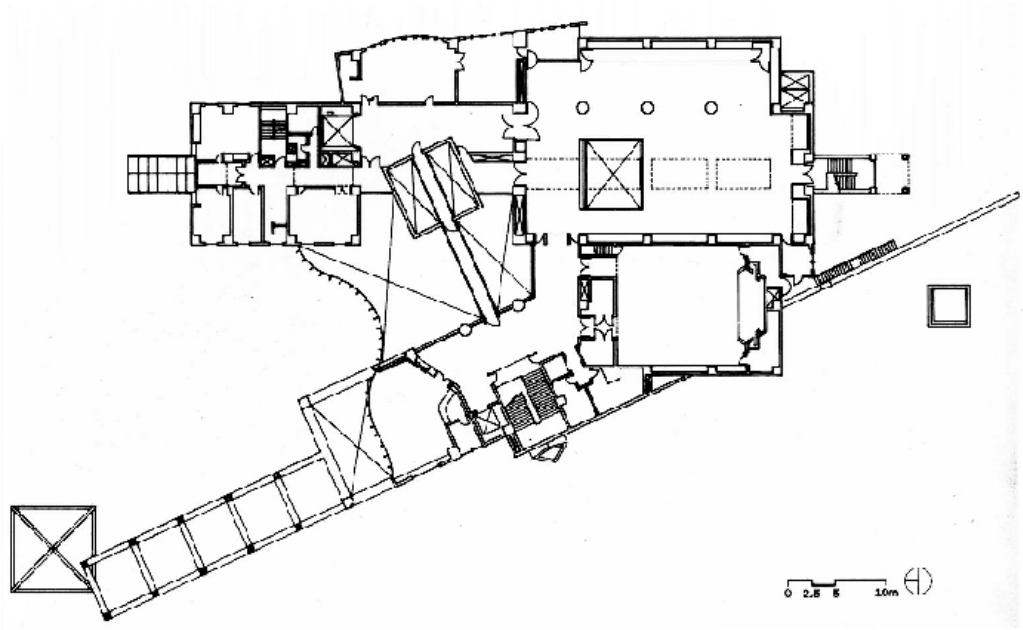


Fig. 2. Nagoya City Museum

5.3. Hiroshima City Museum of Contemporary Art

The building was designed in 1984 and completed in 1988. The building exceeds 200ms in length. The staircases are placed at the periphery to create a more artistic space. The building is characterized by its circular approach plaza in the center. The design of the roof and walls of the building are based metaphorically on the traditional Japanese warehouse. Refer to Fig. 3.

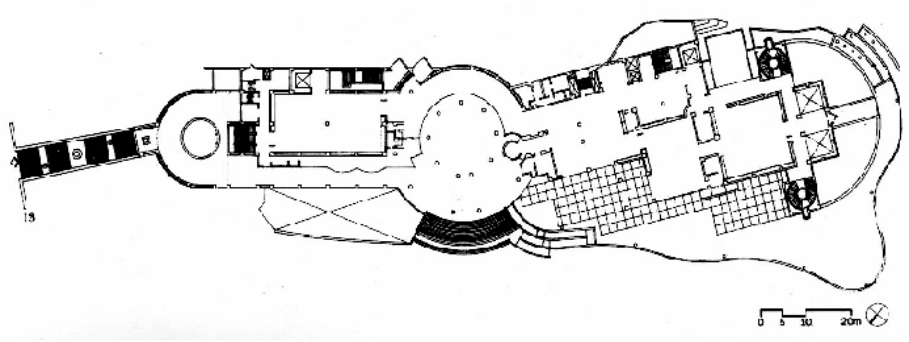


Fig. 3. Hiroshima City Museum

5.4. The Museum of Modern Art, Wakayama Prefectural Museum

The building was designed in 1990 and Completed in 1994. Both the Art Museum and the Prefectural Museum are designed using simple geometric forms. The geometric form of the entrance hall is an abstracted crescent. Fig. 4, illustrates the arrangement of forms which is carefully designed to express the traditional Japanese preference for asymmetry. The edge of the pond facing the buildings is linear, while the park side is designed with natural curved lines.

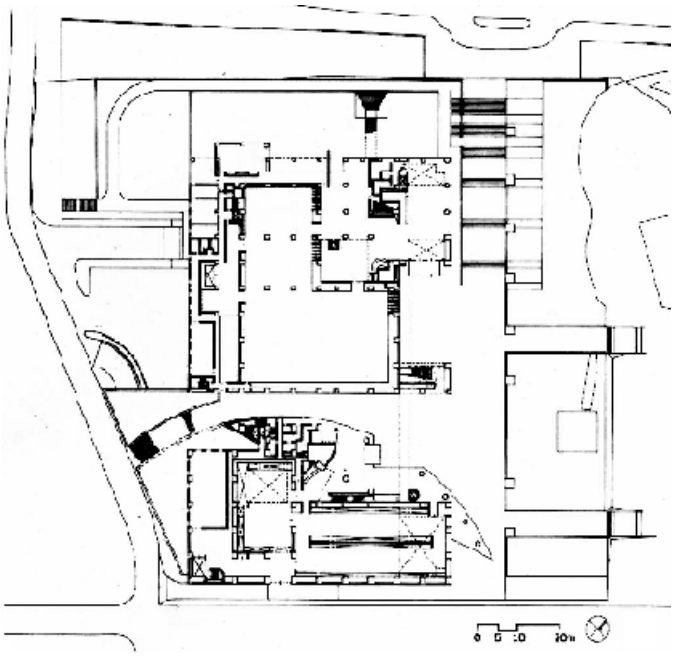


Fig. 4. Wakayama Museum

5.5. Ehime Prefectural Museum of General Science

The building was designed in 1991 and Completed in 1994. In order to create a symbiotic relationship with the surrounding area, the building is conceived as four fragments. These function as administrative facilities and a planetarium. Simple geometric forms, typical of Kurokawa's style for museum architecture, have been adopted: a crescent, a cube, a square, a cone and a triangle, as shown in Fig. 5. The layout of the fragments is designed in such a way to reflect the free arrangement of stepping-stones in a Japanese garden, which also expresses the Japanese traditions of asymmetry. The form of the exhibition hall is slightly shifted and tilted to emphasize the composition of four different square exterior surfaces.

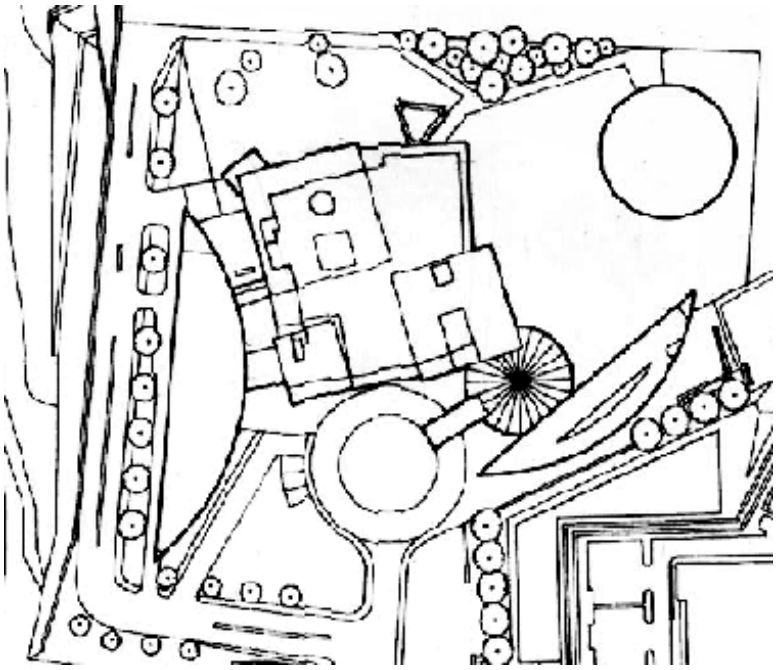
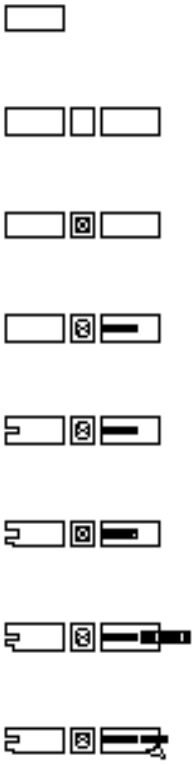
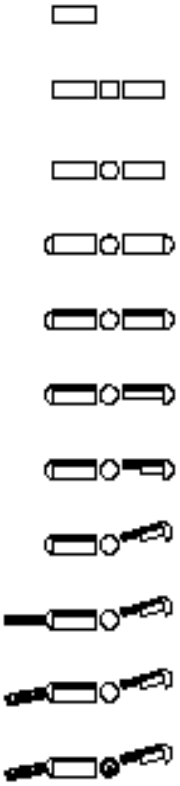
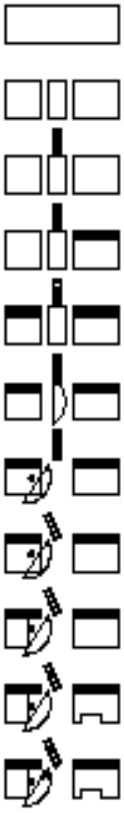


Fig. 5. Ehime Prefectural Museum

Table 1, shows the different analysis of Kurokawa's museum designs previously mentioned, showing the different components of his museum designs for the five chosen cases.

Table 1. Analysis of Kurokawa's Museum Design Language

Saitama	Nagoya	Hiroshima	Wakayama	Ehime
				

6. THE IMPLEMENTATION:

The following section of the paper addresses the implementation of the approach. The implementation proceeds in three parts:

1. Rules Derivation,
2. The Shapes Matrix and
3. The Proposed Design of the User Interface, and an architectural example developed out of the matrix of shapes.

6.1. Rules Derivation:

The rule has two components: the Left Hand Side (LHS) and the Right Hand Side (RHS). A rule thus describes an action that may be executed if a certain condition is met; i.e., if the LHS is true, then the RHS replaces the LHS, transforming the shape into a new shape. The rules take the following form:

If (condition) → then (action)

If (LHS) → then (RHS)

The following Tables 2 & 3 represent the derived rules for the five case studies in relation to their specific analysis.

Table 2. Shape Rules of Saitama Prefectural Museum of Modern Art and Nagoya City Art Museum derived from the analysis

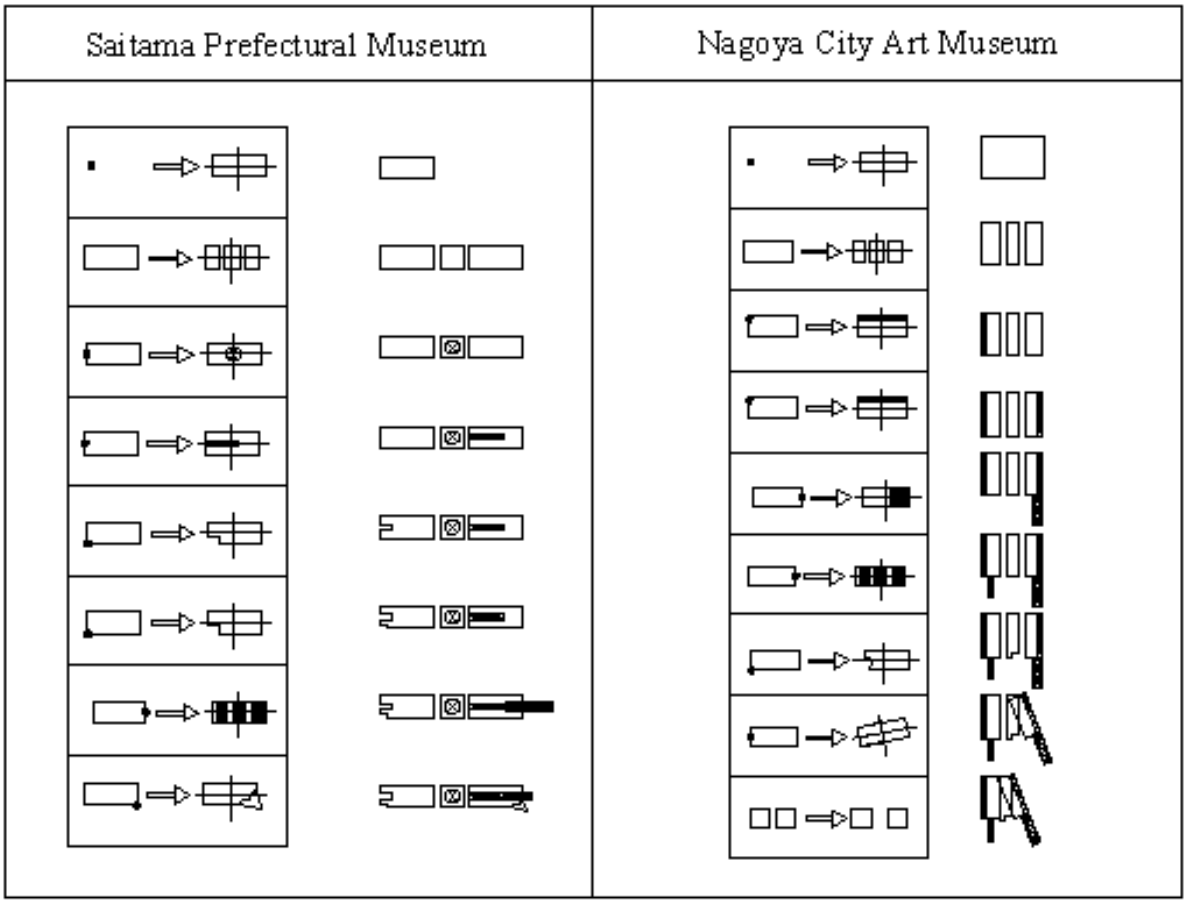
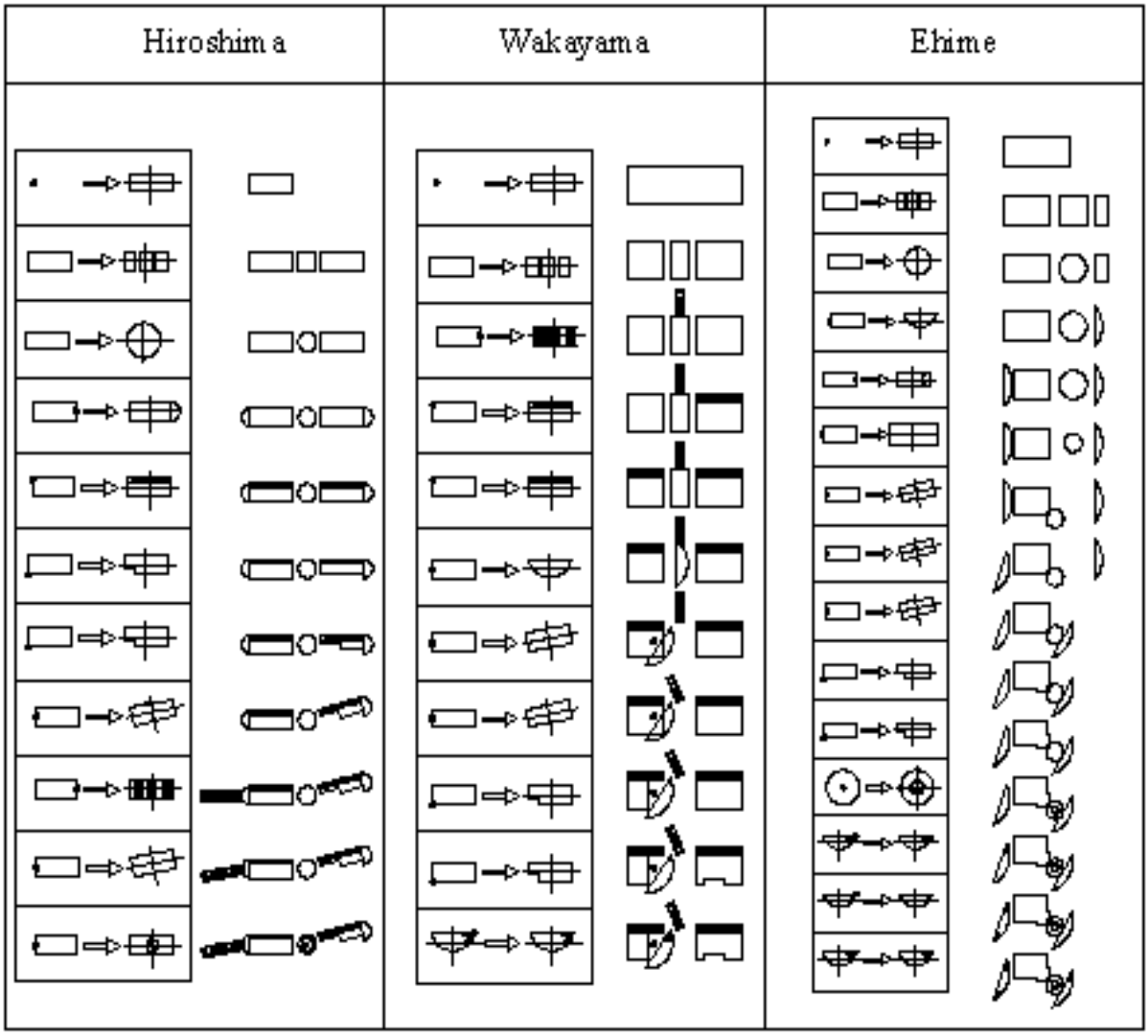


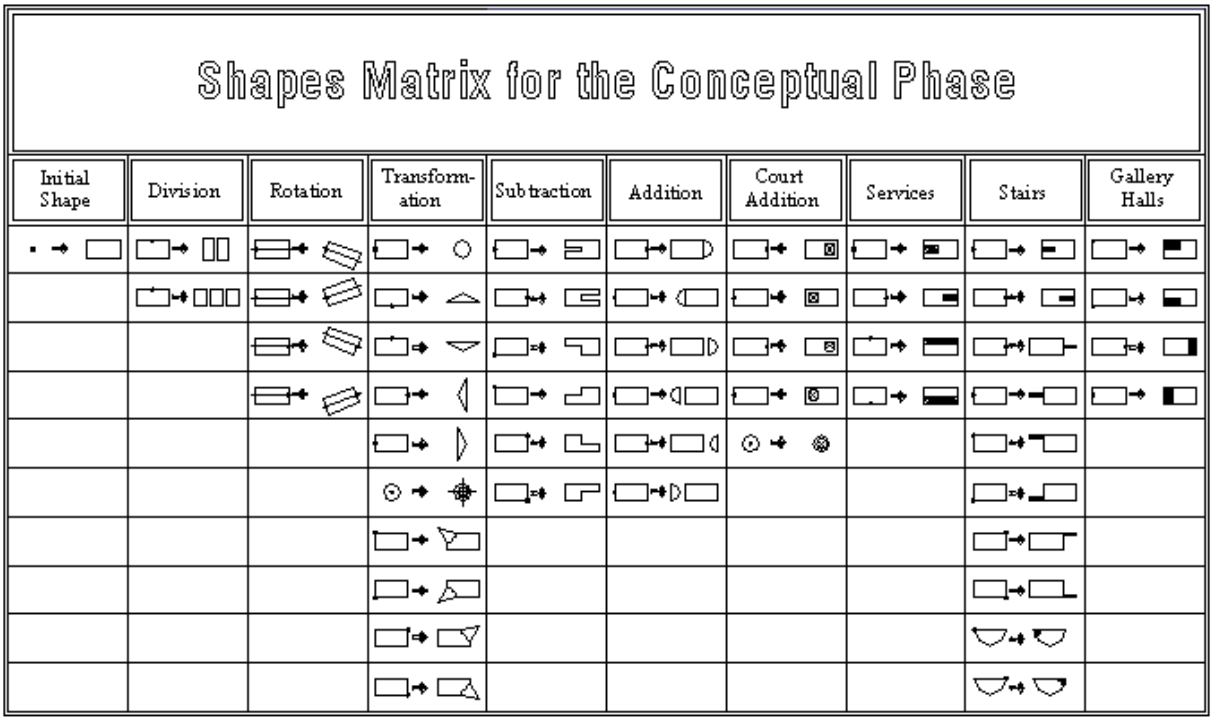
Table 3. Shape Rules of Hiroshima Museum of Contemporary Art Wakayama and Ehime Prefectural Museums, derived from the analysis



6.2. The Shapes Matrix:

Table 4, represents the shapes matrix for the conceptual design phase of Kurokawa's shape grammar prototype. It shows all possible alternatives that may be applied by the user to generate the same, or new designs after Kurokawa's style for museum designs.

Table 4. The shapes matrix for Kurokawa's Grammar, showing all possible alternatives that may be applied in the grammar utilizing 52 shape rules



1 Rule	2 Rules	4 Rules	10 Rules	6 Rules	6 Rules	5 Rules	4 Rules	10 Rules	4 Rules
Rule #	Rules #	Rules #	Rules #	Rules #	Rules #	Rules #	Rules #	Rules #	Rules #
1	2,3	4, 5, 6, 7	8,9,10 11,12, 13,14, 15,16, 17	18,19, 20,21, 22,23	24,25, 26,27, 28,29	30,31, 32,33, 34	35,36, 37,38	39,40, 41,42, 43,44, 45,46, 47,48	49,50, 51,52

6.3. The User Interface and an Alternative Generated From the Grammar:

The suggested interface for the proposed Kurokawa's Shape Grammar shown in Figure 6, employs AutoCAD's open architecture. It builds on AutoCAD's capabilities, and presents special tool bars for the different shape rules, through which

the user may access the grammar and starts exploring its capabilities, generating different design ideas, concepts and configurations after Kurokawa's style.

Fig. 6. One of the suggested tool bars for Kurokawa's Shape Grammar for museum design

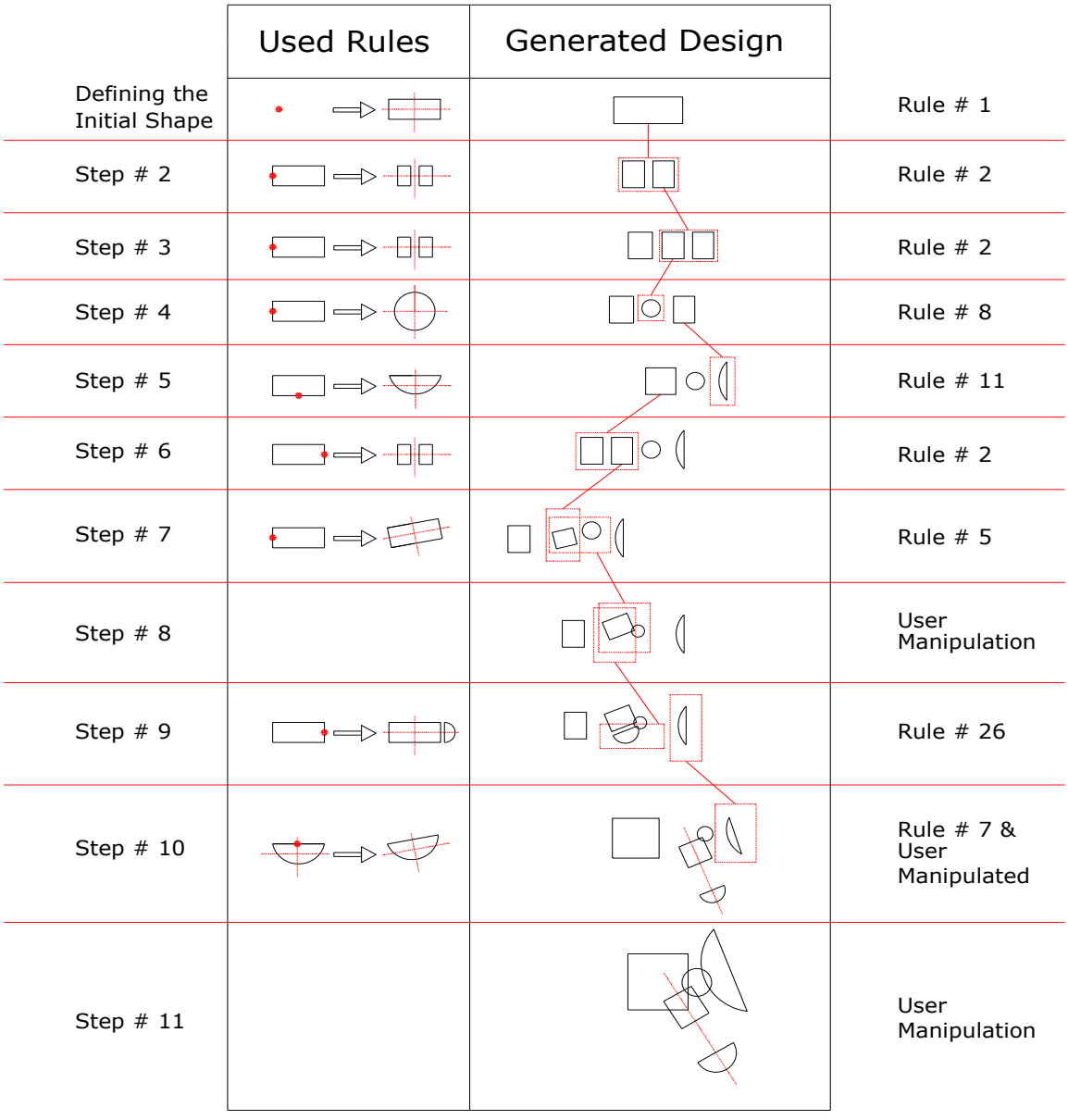


Fig. 7. An example generated from Kurokawa's Shape Grammar for museum design

In order to convey the flavor of the work with the proposed approach, a new design using the proposed Shape Grammar for Kurokawa's museum design is presented in Fig. 7.

The shape grammar session starts by defining an initial shape: a point anywhere on the screen.

Rule #1 transforms the point into a rectangle.

Rule #2 divides the rectangle into two rectangles.

Rule #2 is applied again to one of the rectangles dividing it further into two rectangles.

Rule #8 transforms the middle rectangle into a circle.

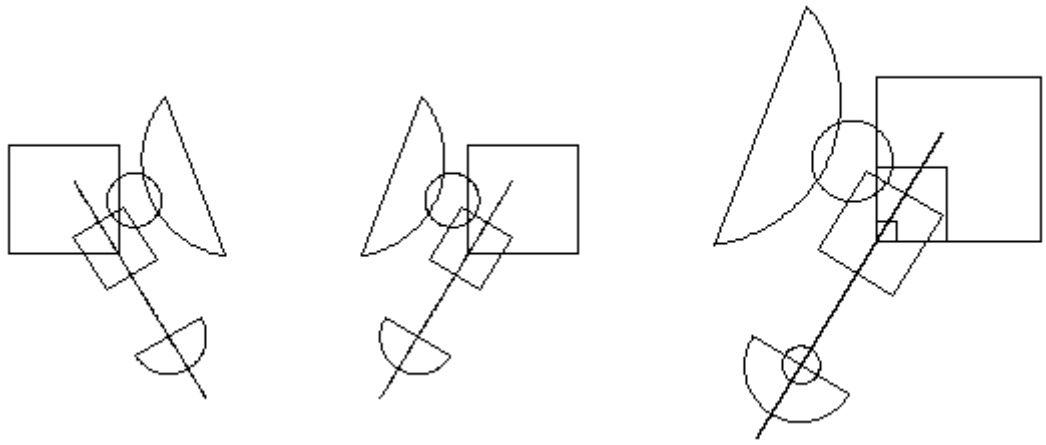
Rule #11 transforms one of the rectangles into a sector of a circle.

Rule #2 again divides the rectangle into two rectangles

Rule #5 rotates one of the rectangles

Rule #26 adds a detached semi-circle to one of the rectangles

Rule #7 rotates the sector of the circle



a) generated design b) mirrored image c) user elaborated

Fig. 8. New design generated from the proposed grammar

This new design derived from the proposed Kurokawa's grammar in Fig. 8, shows clearly the resemblance with Kurokawa's design for Lauvin-La-Neuve Art Museum

shown in Fig. 9. which assures the stability of Kurokawa's style in addition to the correctness of the proposed grammar.

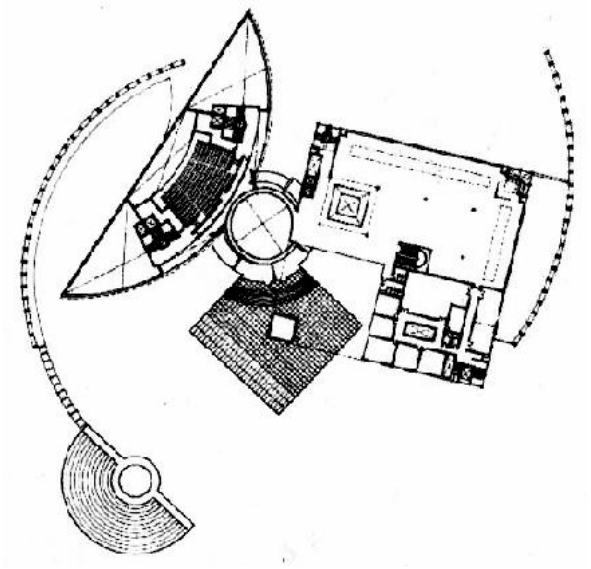


Fig. 9. Kurokawa's Design for Lauvin-La-Neuve art museum

7. DISCUSSION:

By placing restrictions on the designer through using a specific grammar, are we restricting creativity?

According to Mitchell [11], "*creative design*" encompasses all the things that designers do for which we cannot specify an effective and efficient mechanism. This represents a paradox, in the sense that any successful attempt to describe the mechanics of some *creative* design activity will have the immediate effect of redefining that activity as "*noncreative*".

However, descriptions and restrictions would only be inhibitors of creativity if they remove desirable design possibilities. Creative design using a grammar does not have to be limited to a grammatical derivation, it also occurs in the *development* of that grammar. The application of Kurokawa's grammar presented in this paper shows enough flexibility to produce many designs according to the users needs but still follows Kurokawa's style.

On the other hand, using a grammar in natural language, for example, is never meant to be an inhibitor, on the contrary, it guarantees the correctness of the product, however, be it creative or not, is a function of the user's knowledge, background and perception. Using the same shape grammar, any two designers may produce completely different artifacts, of which one may be considered creative and the other may be not.

Shape grammars also offer the following advantages:

- They provide a method for representing existing design styles.
- They provide a capability for the generation of new design forms after a specific style.
- They are considered to be useful style preserving tools, especially if the founder of this style has passed away, or in other cases if a part of a stylistic urban fabric has been destroyed and there's a need for a restoration with the same style.
- They help in the re-creation of drawings for old buildings in courses like history of architecture, i.e. they may be used in educational purposes.

However, shape grammars do not explain the reasoning of the architect/designer or even the founder of a style regarding the design itself, as this knowledge is implicitly embedded in the rules themselves. Considered as a drawback, this may be remedied in future studies by employing AI (Artificial Intelligence) techniques through the use of an expert system module interfaced with the present work, to be used as an explanation facility to explain (on request from the user) the different design decisions related to particular designs or rules, and on what basis did the architect/designer (Kurokawa in this case) took his decisions.

8. CONCLUSION:

Shape grammars have been shown to be a sophisticated and useful method of generating designs after a specific style. As a well-structured method, they seem to lend themselves well to computer implementations, thus augmenting the computer use in the early stages of the design process.

It is believed that the value of this approach lies not in the "*cloning*" of designs as such, but rather in the mechanism it presents to open up frontiers for producing and generating new designs after specific styles.

Such work is characterized by the following:

- Clarifying the underlying structure and appearance of known instances of style;
- Supplying the criteria necessary to recognize whether any other design is an instance of the style; and
- Providing the compositional mechanisms needed to generate new instances of the style.

A representation of Kurokawa's Museum Design Language is developed; through comprehensive analysis of his selected work, shapes are then derived, upon which, operations and relations are defined in the form of design rules, a matrix of design rules is then presented for the designer to navigate through, and finally an architectural example (a schematic plan) is presented to demonstrate the applicability, value and advantages of the approach, in addition to pointing out directions towards new research issues.

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قواعد الشكل: مُوَلِّدات الطُرُز فى التصميم المعمارى بالاستعانة بالحاسب الآلى

مثلما توجد أجرومية (قواعد للصرف والنحو) فى أية لغة من اللغات المتداولة للتخاطب والتى يمكن على أساسها تركيب جمل نحوية صحيحة بالانتقاء من قاموس ضخم من الكلمات، فإنه توجد أيضاً أجرومية فى التصميم المعمارى تستخدم قواعد معينة لتأليف تكوينات معمارية بالانتقاء من قاموس ضخم للأشكال والخواص وعناصر أخرى. وتهتم قواعد الشكل بتكوين وتوليد الأشكال من خلال تطبيق مجموعة من القواعد التى تحكم علاقة الأشكال ببعضها البعض لتحقيق طراز معين. وتتعرض هذه الورقة البحثية لفكرة أن قواعد الشكل – باعتبارها إحدى أدوات التكوين باستخدام الحاسب الآلى فى التصميم المعمارى – فإنه يمكن استخدامها فى المراحل الأولى من العملية التصميمية (مرحلة توليد الفكرة) لتوليد وتقييم أشكالاً معمارية تتفق وطراز معين. وتقدم الورقة البحثية أجرومية معمارية تتفق وطراز المعمارى اليابانى كيشو كوروكاوا فى تصميم مبانى المتاحف من خلال شرح وتحليل لعدد خمس مشروعات من مشروعاته المعروفة. وتستخلص أجرومية لغته المعمارية، ثم تستعرض الورقة التطبيق المقترح من خلال مجموعة من قواعد الشكل التى تحكم طراز كوروكاوا فى تصميم المتاحف، والتى تم وضعها فى مصفوفة من الأشكال يتم من خلالها توليد وتقييم تصميمات جديدة ومتنوعة تتفق وطراز كوروكاوا المعمارى، هذا بالإضافة لفتح آفاق وأبواب جديدة للبحث فى نفس المجال.

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