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Visual Calculation through Shape Grammar in Architecture

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ABSTRACT: Design is often perceived to be subjective, an inventive flash based entirely on one's intuition and free creative expression. To develop such intuition is often considered a big hurdle for an architecture student during initial years of graduation. Shape grammar which is a system of rewriting shape rules through mathematical computations can be considered as solution, as well as aid to design students. In this research we have analyzed that Design process can be explained through a very objective approach rather than through subjective factors 'creative inspiration', the 'inventive flash', or 'individual genius' Shape grammars equip user with algebraic and graphic methods which are explanatory and/ or generative in use. Shape grammars allows intervention at multiple steps which helps in bringing subjectivity in the design process and helps in achieving a design which is truly unique and not a standardized module. Shape grammars allow us to overcome the organic nature of creativity and give design students and educators a way to make learning visible and concrete.

Keywords: shape grammar, visual calculation in design, formal methods, nonstandard shape algebras,

I. INTRODUCTION

Although design education has been discussed widely as the traditional studio method, in which Students develop their design projects under the advice of an experienced architect-instructor, is still the prevalent system. The studio method has been described as a reflective conversation between a student and his coach. Computer-aided design in architectural courses has also had an influence on teaching and most schools are still searching for appropriate ways of balancing design activities between paper and computer. The traditional studio method does not provide the novice student with the tools and methods he or she needs to develop a design that is based not only on functional issues, but also on formal ones. On the other hand architectural education introduced as pure art, without regard to users and their needs, is also criticized.

This research introduces the shape grammar formalism as a generative system for the development of designs. Shape grammar one of the earliest algorithmic systems for creating and understanding designs directly through computations with shapes, rather than indirectly through computations with text or symbols.

II. SHAPE GRAMMAR

Shape grammars were introduced by Stiny and Gips in 1972. It is a set of shape rules applied in a step-by-step way to generate a set, or language, of designs. It gives designer the ability to show their design process and design rules by shapes rather than text. Shape grammar is spatial, rather than textual or symbolic, algorithmic. Shape grammar is a set of rules applied on initial shape to generate designs. The rules are designed to transform the initial shapes, so the user may decide which rule can be used to achieve the desired outcome. Since the designed shape may consist of different shapes, and there could be different rules for different shapes.

Fig. 1. Stages in shape grammar design.

Steps showed in Figure 1. are generally followed in the given temporal order, but the user has full control over each step and can make adjustment at any time as desired.

A shape is composed of a finite collection of labeled or unlabeled points, lines, planes, areas, or solids. A rule in shape grammars can be written in the form A→B, where A and B are shapes. When this rule A→ B is applied, an instance of shape A is replaced with shape B.

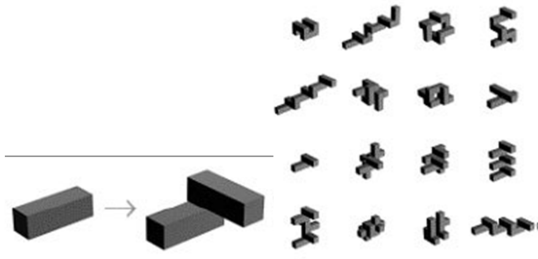


Fig. 2. With the use of addition rule different possible designs created by the grammar.

Figure 2 exemplifies a shape grammar based on a vocabulary (composed of a single oblong) and one simple addition rule. Despite the simplicity of this grammar it can generate a number of different designs within a language.
Shape grammar generates designs on an orthogonal grid. The initial shape is a square (I). The rule (R) specifies a possible shape replacement operation, joining two shapes: a pattern, a square, and its replacement, the same square with the addition of a translated copy arranged.

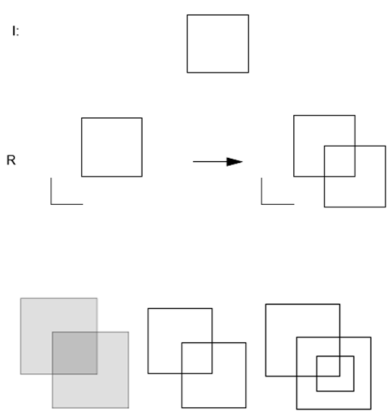


Fig. 3. Transformation in shapes by using simple shape grammar.

Applying the rule to the initial shape yields a shape containing three squares, two the same size as the initial shape and one half the size, emerging from the two. Applying the rule to the smallest square yields squares of three sizes: two the size as the initial square, two half that size, and one a quarter.
The fundamental unit of a basic shape grammar is a shape. In order to allow the reflection transformation in a basic shape grammar, we need to add a label to each shape object. The spatial relation between the labels of two shapes specifies the spatial relation between the two shapes unambiguously. These rules determine the geometric orientation of the newly generated shape objects.

III. SHAPES

The term shape is commonly used to refer to the form of an object or its external boundary (outline, external surface), as opposed to other properties such as color, texture, material composition. Shape is the arrangement of basic elements in space. Shapes have a position, orientation, size in a coordinate system.

basic elements

space	points	lines	planes	volumes
0D	√			
1D	√	√		
2D	√	√	√	
3D	√	√	√	√

Fig. 4. Arrangement of basic elements in the space.

IV. SHAPE RELATION

Spatial relations arise whenever there are two or more shapes in the space. With the advancement in the field of Geometry which involves spatial relationships (position, shape and size), substantial values can be derived helping man to think and find out the value of image produced and how to combine two or three-dimensional shapes to create new ones in the environment
Three kinds of shape relations are:
Overlapping - Those shapes that share a common part are said to overlap.
Embedding - If two shapes have common parts and at least one of these shapes has no part that is not a part of the other, then this shape is said to be embedded within the other.
Discrete shapes - Planes with no shared boundaries are discrete. However shapes that share a common boundary but have no part in common are also discrete.
Bullion operation on shapes:
Within the defined shape algebras, we can add and subtract shapes of the same kind of basic elements.

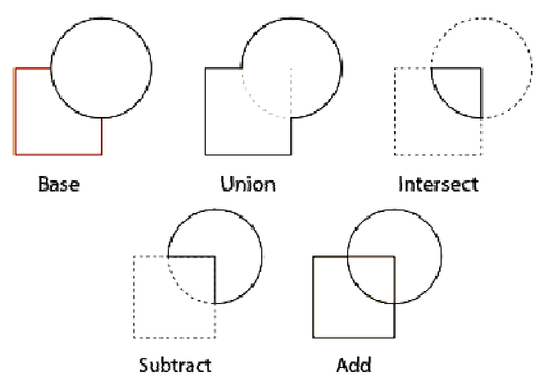


Fig. 5. Boolean operations on shapes.

Euclidean transformations on shapes:
Euclidean transformations that are used in shape grammars are translation, scaling, rotating and reflecting along with their combinations.

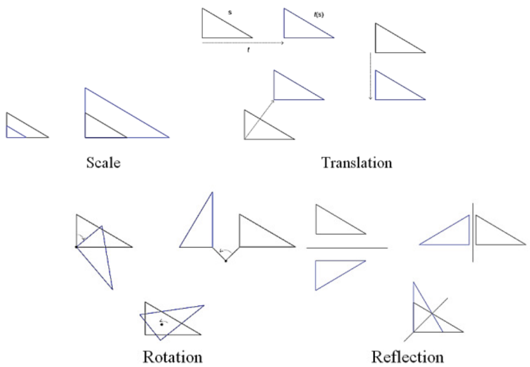


Fig. 6. 2D transformation of shapes.

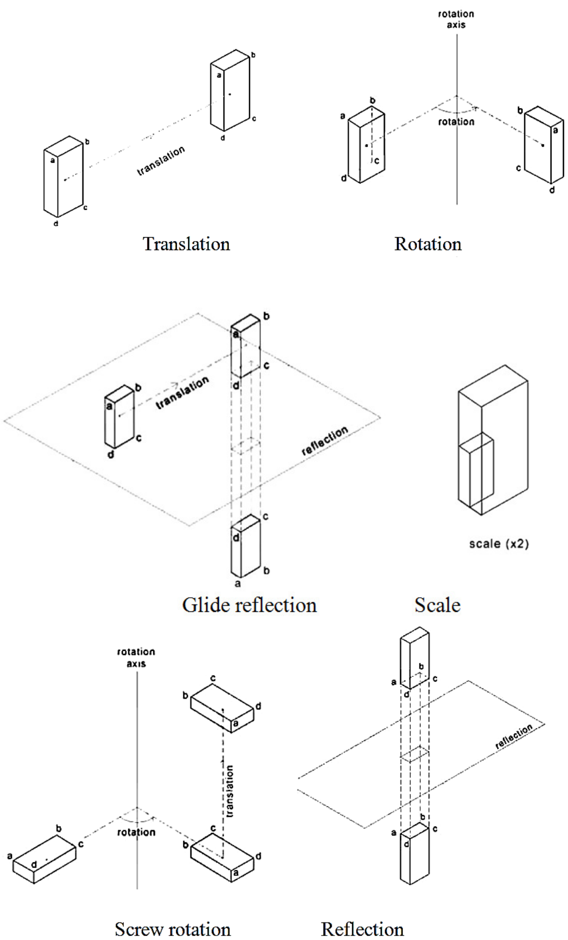


Fig. 7. 3D transformation of shapes.

V. SHAPES RULES

A rule in shape grammars can be written in the form A→B where A and B are shapes. When this rule A→B is applied, an instance of shape A is replaced with shape B. Creativity in rule-based design lies in the creation of the rules. Rules can be modified and expanded at every stage of a design process allowing the designer to make explicit his/her design knowledge in a structured framework. The designer controls form-generation by explicitly defining the criteria for new designs that fit a given context.
A rule applies to a Design whenever there is a transformation t that makes the left-side A, a part of the Design.
To apply the rule first subtract the transformation t of the left-side A from the Design and then add the same transformation t of the right-side B to the Design.
The result of applying the rule is a New Design:
New Design = [Design - t (A)] + t (B)

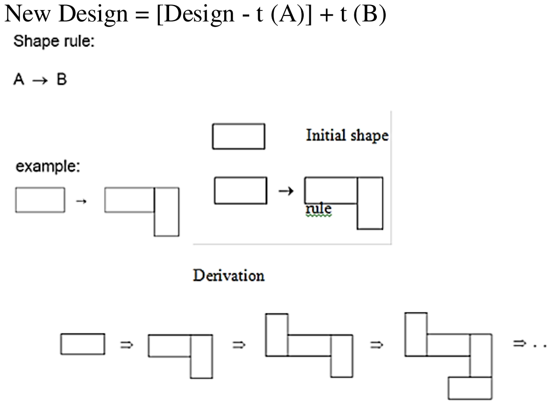
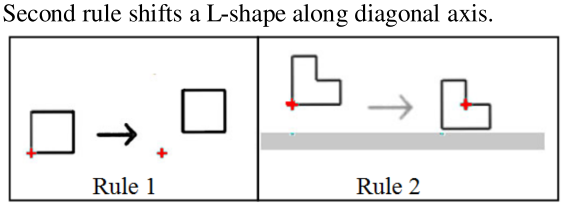
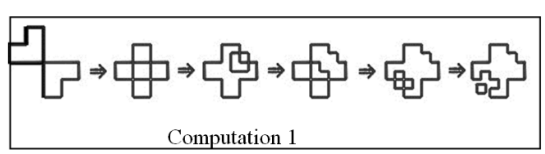


Fig. 8. Applying shape rules.

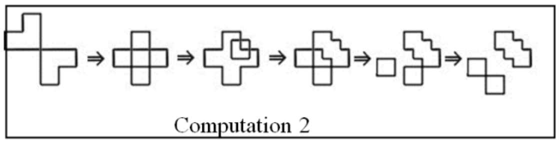
Final shape will depend on what rules are used, and when and how. This can vary for different rules and in fact it changes every time any rule is tried.
For example, if we consider two rule
First rule shifts a square halfway along diagonal axis of square
Second rule shifts a L-shape along diagonal axis.



Using above grammar we can do the design computation. From second step on, rules can be applied either to emergent L-shape or square. So the user has the opportunity to use these rules at any stage and in any order on the hence produced shapes during the process.



Below is another example of the shape grammar. The steps are identical for first three stagesand then a deviation is seen resulting in a different design altogether.



These rules can be used to articulate different results from the very same inception point. This gives the user a fluidity of thoughts as his decisions and comprehension of shapes largely decides the end design while keeping him in the bounds of certain rules. The technique varies from general algebraic calculation, but essentially establishes the idea of visual calculation.

VI. SHAPE GRAMMAR APPLICATION IN ARCHITECTURE AND ARTS

Since the idea of shape grammar was conceived back in 1972, it has high applications of synthesis and analysis in architecture and art.

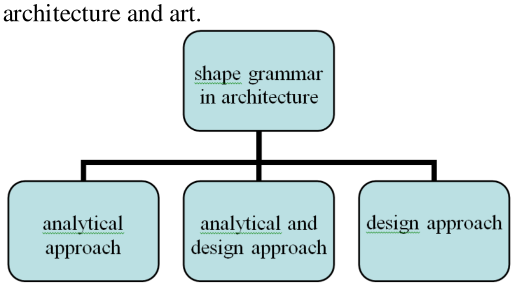


Fig. 9. Shape grammar in Architecture and Art.

Original design

The earlyideas by Stiny and Gips failed to elaborate upon the vast applications the original grammars could offer in design synthesis. This was first proposed only in 1980 by Stiny'spaper, "Kindergarten grammars: designing with Froebel's building gifts. In this Stiny examined the original idea of kindergarten method by Frederick Froebel and its similarities to general studio design. Through his analysis he proposed an alternate calculative approach rather than intuitive. The five stages of this approach to design are: a vocabulary of shapes, spatial relations, shape rules, initial shape, and shape grammars. Stiny himself used Froebel's basic building blocks to create original grammars and designs in three-dimensional space, laying the foundation for three-dimensional architectural grammars to come.

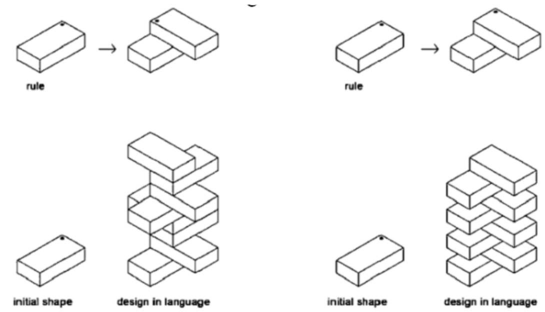


Fig. 10. Kindergarten grammars, Stiny (1980).

Stiny's kindergarten methodology for creating original grammars didn't come in practice for several years while analytic applications of shape grammars grew quickly. It was only in 1992, Knight wrote papers reviving Stiny's program and adding upon the approach of creating shape grammar as well as color grammars in three-dimensions. Colors in a color grammar are used as indices for attributes of shapes such as material, function, functional elements, or colors themselves. Knight put this program into practice in graduate architecture courses taught at UCLA and MIT. Computer programs on the basis of Knight's work have been developed and are being used by students at MIT. Radford, Woodbury, and others worked on similar lines as knight on simple, user defined and computer-implemented grammars.

Analysis

Analysis was the exclusive focus of early shape grammar works. Through this work, shape grammars became an integral part in design theory, CAD, and related fields. The first analytic exercise with shape grammars was given by Stiny in his 1977 paper, "Ice-ray: a note on the generation of Chinese lattice designs"Guided by just five simple rules the grammar encapsulates the essence of conventional compositions of lattice designs and generates existing lattice designs and an infinite number of new, hypothetical designs in the same style.

The one of analytic application of shape grammars, the Palladian grammar by Stiny and Mitchell from 1978, initiated work on more ambitious and complex shape grammars for architectural styles that continues today. Included in this work are shape grammars for the architecture of Giuseppe Terragni, Frank Lloyd Wright, Glenn Murcutt, Christopher Wren, and Irving Gill, for the vernacular styles of Japanese tearooms, bungalows of Buffalo, Queen Anne houses, and Taiwanese traditional houses, and for the landscape architecture of Mughal gardens.

The Wright grammar is notable for being the first three-dimensional architectural grammar--motivated in part by Stiny's earlier work on kindergarten grammars and the alleged influence of Froebel on Wright's architecture.

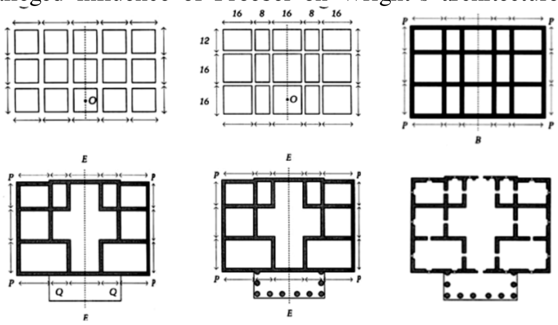


Fig. 11. The Palladian Grammar (Stiny& Mitchell 1978).

Analysis/original design

Knight worked further on shape grammars and in 1981 he devised a new method for development of new languages in design on the basis of existing ones. The approach was to study and identify the the spatial relationship of existing design styles and then transforming these relationships and rules to evolve new grammar and style. This model served both the purposes of analysis and synthesis as this would study and deeply analyze the existing styles and identify their shape rules and grammar. The tweak and transformation in the hence identified rules would let one evolve and synthesize styles and grammar.

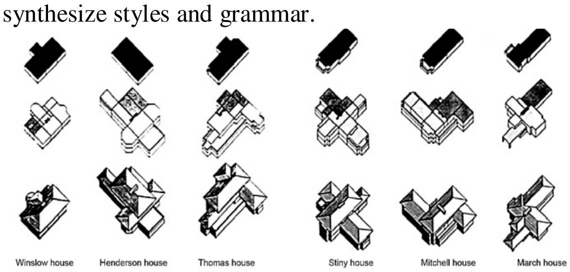


Fig. 12. F L Wright Prairie House Grammar (Konig & Eizenberg 1981).

Flemming, in his 1990 paper, proposed asimilar model as Knight's for teaching architectural composition. Architectural languages based on vernacular or traditional practices are taught to students. This includes wall architecture, mass architecture, panel architecture, layered architecture, structure/infill architecture, and skin architecture. Shape rules, relations and grammars of these styles are also discussed. Students, through this acquired knowledge, now modify grammars to generate their own new language. Thus, Flemming's strategy is both analytic and creative. Others have adopted similar teaching strategies. Julie Eizenberg, an award winning architect and co-author of the Wright grammar, also introduced shape grammars in studio teaching at UCLA, Harvard, MIT, Yale, and elsewhere.

VII. APPLICATION IN ARCHITECTURE EDUCATION AND PRACTICE

The concept is in use for a little over twenty five years, but still hasn't realized its complete potential in teaching and practice. Shape grammar theory is now far in advance of practical applications. Why? What can be done to narrow this gap?

Design schools that include shape computation or shape grammars as part of their curriculum has seen a steady growth. The graduates of shape grammar programs find teaching positions worldwide and establish their own shape grammar courses. This growth is unplanned and lacks strategy. "Should the teaching of shape grammars be theory-based or practically-based?" has to be addressed in a planned way. Should shape grammars be taught through their mathematical and philosophical foundations or should they be taught through concrete, practical applications or do we need a middle ground which seeks a balance between the two.

One of the major challenges that is faced while standardizing a shape grammar is how to develop a language that addresses all the challenges and goals of design and still be fluid in functioning. Also almost all the work till date has neglected the curves and organic forms while only sticking to straight lines and basic planar compositions. Introducing shape grammars to the students with different levels and kinds of experience and abilities may require different teaching strategies. Another question that needs answering is how to make the language adapt to dynamic nature of design evolution in practical day to day life and activities.

New analytic/synthetic grammars must be structured in some designed way in order to be practicable. Most traditional analytic grammars are not structured in this way and thus are not practicable.

VIII. TEACHING PROPOSAL FOR ARCHITECTURE STUDENTS

Shape grammar helps in exposing architectural students to a new evolved education system which will also influence their design process thinking. First year of architectural course for students serve as the initiation process where they are exposed to the various design ideologies and they get their first impression of design process. That impression leads to their own ideologies which they will follow in the years to come. Certain parameters need to be looked upon like using of computer and other digital means or manual process, thinking in three dimension or two. It is widely accepted among educational institutions that by hand application gives qualitatively long lasting result in terms of learning and understanding. Computer application can be later inducted to work on complex process and to meet the industry requirements. Moreover use of three dimensional models can ease the process of comprehending complex design rather than two Dimensional approaches.

A two-dimensional representation of a three-dimensional object, no matter how sophisticated, cannot compete with the object itself.

Students usually begin with abstract actions. They start at an early abstract experimentation stage with simple design assignments that are mostly about abstract or artistic explorations of shape composition, form generation, color and texture, etc. Goal driven composition at the Mid-Stage introduces some limitations to the design exercises in order to teach students to design in response to a defined purpose. More complex design requirements are introduced during the final stage of Experiencing architecture in a complete (yet simple) architectural project But the closer look at the novice student's thinking behavior and the expected learning outcomes reveals that the complexity plan in itself is not enough, there are other factors that should be altogether responsible for defining themes to control the selection of each stages' exercises. For example, the target thinking type at each stage should be defined, knowing that the architectural education aims to develop a bipolar thinking skill for students. Teaching them to control, combine and alternate between rational and imaginative thinking types in order to produce logical yet artistic designs.

One fact of the beginning studio is that novice students are more absorbent for new knowledge and experiences in their early design experimentation than other advanced students. Once they have seen something done in a certain way, or done it themselves, this experience tends to reinforce the idea in their fresh minds and may block other alternatives. Therefore, instead of teaching students to see things in a definite way, the proposed exercise intends to train their eyes on flexibility where there is no correct answer and all possibilities are open.

IX. THE WORKSHOP

The conducted experiment was organized on the basis of shape grammar experimentation through physical manipulation of building blocks. This design education proposal was tested with a group of students, who gained theoretical knowledge and practical design experience. Architectural theory was introduced through discussion and experimentation of the shape grammar exercises.

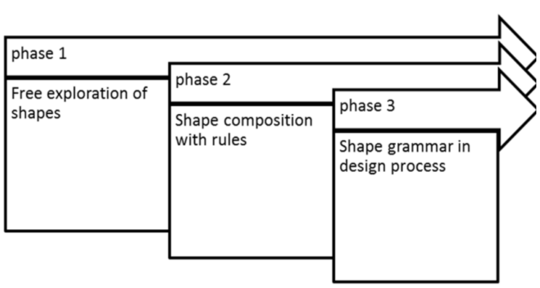


Fig. 13. Design studio exercises were organized in 3 different phases.

Phase 1: Free exploration of shapes

The experiment began with a quick lecture about shapes and how do we see it from a 1D to 3D perception, accompanied with examples from architectural masterpieces with basic geometric forms. started by identifying the composition's basic elements (vocabulary) then the way they all connect. Examples like "the ice-ray grammar were shown to demonstrate the simplicity of the vocabulary behind complex patterns like the Chinese Ice Lattice designs.

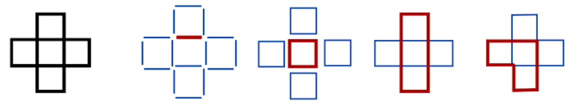


Fig. 14. An example on Ambiguity that shows how to perceive the basic elements of one shape in different way.

Afterward students were challenged with indirect and more complex ways of conceiving shapes as possible projections of multi-dimensional elements.

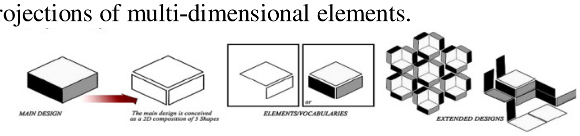


Fig. 15. Part of the tutorials example that shows the process of vocabulary extraction and design modification.

At this point, students became aware that something different lies behind every simple layout of a shape. Students were then given the experiment which is more like a creativity test. They were grouped in groups of three; each group was given one of the 2D shapes. They were then asked to draw at least 4 different readings for the shape and its basic elements with at least one 3D interpretation of which. To extend and modify the existing design they have to extract its basic elements and work with basic geometric operations to create their new designs.

Fig. 16. Shapes given for the workshop.

After the exercise, each group was asked to present their final ideas, even though they were not consciously aware about their design quality.

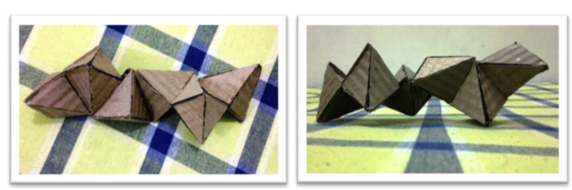


Fig. 17. Some of the design built on the basis of direct interpretation of basic elements.

Such process not only motivated the students' ability to see and make respectively, it also developed flexibility in design, an analytical awareness as well as confidence to take design decisions. This became a good start point for the next level workshop where students will be learning to design in response to shape rules. One question that arises out from these observations is whether the accomplishment of students is momentary- only for the time of the experiment- or will it last and affect their design behavior in future projects.

Phase 2: Shape composition with rules

After the first exercise of shape exploration students were now moved to next level where they will be learning to design with shape grammar. The exercise begins with the introduction of shape grammar theory. The students were guided, which rule to apply, where to apply the rule and how to apply. Grammars are experimented conceptually through the physical manipulation of thermocol blocks.

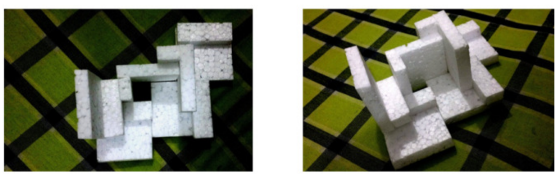


Fig. 18. Designbuilt by the group 1 by applying rules.

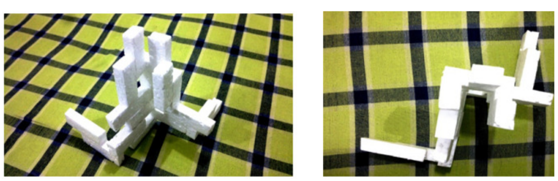


Fig. 19. Design built by group 2 by applying rules.

Fig. 20. Design built by group 3 by applying rules.

Phase 3: shape grammar applied in design process

After this conceptual rule exercise students were ready to design at their own. They were given building blocks and developed their own design solution for a house. The blocks were pre-cut and painted in different colors that defined their functions. A hypothetical location was given with definition of orientation (North Arrow) on the baseplate, which also had composition guidelines, allowing dynamic arrangements to be tested.

Fig. 21. Design made by the arrangement of building blocks.

Although students applied structured rules to their design compositions, the solutions were innovative and diverse. The results showed that the process produced interesting, viable and creative designs and the richness of the students' work demonstrated that the application of rigid rules does not interfere in the creative process. The student's learning curve was extremely fast. They assimilated the rules and enjoyed the design manipulation, which gave them more security in reaching viable solutions. The experiment showed that such innovative ways of developing a design project can give studio teachers new insights in architectural education. Care must be taken to avoid addictions to specific methods and treat design problems in isolation.

X. CONCLUSIONS

Shape grammars lays guiding rules for "science of design" and for a "theory of architectural composition". It can be developed into an innovative and scientific approach of understanding design process. Design process can be explained through a very objective approach rather than through subjective factors like 'creative inspiration', the 'inventive flash', or 'individual genius'. Questions like "Where do designs come from" or "how to design" can now be answered via this shape grammars approach. This approach is also relevant for teaching composition and visual correlations such as proportion and symmetry. Analysis and synthesis application of shape grammar

The concept of "Make Learning Visible", which states that teaching alone in isolation, is not enough for effective learning. If the learning can be quantified from time to time then steps can be taken by educator to increase the effectiveness of teachings.

Shape grammars allow us to overcome the organic nature of creativity and give design students and educators a way to make learning visible and concrete.

The focus of such approach was to help the students in understanding design as a systematic and structured process. "Perception of space" is another dimension of design which can be explored during such activity and can be analyzed keeping in mind the acumen of the students and the objective of the activity. Due to simplicity of the rules design process become easy but such approach should be treated in isolation for each project and should be worked out on project to project basis.

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