APPLICATIONS IN ARCHITECTURAL DESIGN, AND EDUCATION AND PRACTICE

Report for the NSF/MIT Workshop on Shape Computation

by

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Shortly after shape grammars were invented by Stiny and Gips, a two part project for shape grammars was outlined by Stiny. In a 1976 paper,[1] Stiny described "two exercises in formal composition". These simple exercises became the foundation for the many applications of shape grammars that followed, and suggested the potential of such applications in education and practice. The first exercise showed how shape grammars could be used in original composition, that is, the creation of new design languages or styles from scratch. The second exercise showed how shape grammars could be used to analyze known or existing design languages. Both exercises illustrated the unique characteristics of the shape grammar formalism that helped motivate a quarter century (almost!) of shape grammar work. General but simple, formal yet intuitive: qualities that continue to make shape grammar disciples and confound skeptics.

The **history of shape grammar applications** in architecture and the arts for the two complementary purposes of synthesis and analysis, as well as for a third, joint purpose is sketched in the first section of this report. These three categories of applications do not have rigid boundaries. They are used in this report mostly as a framework for discussion. An overview of the **roles of shape grammar applications in education and practice** is given in the second section. **New and ongoing issues** concerning shape grammars in education and practice are discussed in the last section.

HISTORY OF APPLICATIONS IN ARCHITECTURE AND THE ARTS

Original design

Interestingly, the earliest applications of shape grammars were in an area and for a purpose quickly dropped and not taken up again for a number of years. The first published paper on shape grammars by Stiny and Gips in 1972[2] illustrates shape grammars for original languages of paintings. The published theses of Gips and Stiny both from 1975[3], and the joint Stiny and Gips book *Algorithmic Aesthetics* from 1978[4], also illustrate the shape grammar formalism with original grammars for paintings. The shape grammars in these works are embedded in aesthetic systems for interpreting and evaluating works of art.

Stiny and Gips do not explore or explain the genesis of the original grammars they give in their early works. A specific approach for creating original grammars from scratch was first proposed in 1980 by Stiny in his paper, "Kindergarten grammars: designing with Froebel's building gifts"[5]. Stiny examines the kindergarten method of Frederick Froebel and its analogy in the studio method of designing, and then proposes a constructive alternative to these mostly intuitive methods. A five stage programme is given for creating new design languages: a vocabulary of shapes, spatial relations, shape rules, initial shape, shape grammars. Stiny uses Froebel's building blocks in the many simple and elegant shape grammars and designs created with this approach. These shape grammars are the first defined in a three-dimensional space, laying the groundwork for three-dimensional architectural grammars to come.

Stiny's kindergarten programme for creating original grammars lay dormant for several years while analytic applications of shape grammars grew quickly (see below). In papers beginning in 1992[6], Knight took up Stiny's programme in an expanded approach for creating shape grammars as well as color grammars[7] 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 programme into practice in graduate architecture courses taught at UCLA and MIT. Some student projects from these courses are documented.[8] Computer programs implementing Knight's programme have been developed and used by students at MIT in recent years.[9]

Concurrent with Knight's work was work by Radford, Woodbury, and others with simple, user defined and computer-implemented grammars.[10]

Analysis

The first two decades of shape grammar applications focused almost exclusively on analysis. Through this work, shape grammars became an established paradigm 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".[11] The grammar laid out in this paper sets the standards for shape grammars that followed. With five simple rules, the grammar captures the compositional conventions of lattice designs, generates existing lattice designs and an infinite number of new, hypothetical designs in the same style.

The second analytic application of shape grammars, the Palladian grammar by Stiny and Mitchell from 1978[12], 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[13], Frank Lloyd Wright[14], Glenn Murcutt[15], Christopher Wren[16], and Irving Gill[17], for the vernacular styles of Japanese tearooms[18], bungalows of Buffalo[19], Queen Anne houses[20], and Taiwanese traditional houses[21], and for the landscape architecture of Mughul gardens[22]. 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. Shape grammars for styles in the arts more generally include ones for the paintings of Richard Diebenkorn[23], Georges Vantongerloo[24], and Fritz Glarner[25], the chair designs of Hepplewhite[26], the window designs of Frank Lloyd Wright[27], and ornamental designs on ancient Greek pottery[28]. The stylistic range of this work, from formal and geometric to more amorphous and organic, is evidence of the generosity of the shape grammar formalism.

Analysis/original design

Original shape grammars and languages can be created from scratch in theory (in the classroom). In practice, original languages are not created from scratch, but from past or existing ones. This latter approach to original design lies behind work combining analytic and synthetic approaches.

In 1981, Knight proposed a method for developing new languages of designs on the basis of existing ones. Languages are created by transforming the spatial relations underlying grammars for existing languages. In other words, a known style is first analyzed by inferring a grammar for it, the rules of the grammar are transformed, and then the transformed rules become the basis for a new grammar and style. Knight's model had a dual purpose. It could be used to characterize the historical evolution of known styles into succeeding ones. It could also be used to innovate new styles on the basis of given ones. Knight developed her model in a series of papers, a doctoral dissertation, and a book[29]. In the book, the model is applied to analyze stylistic changes in the work of Frank Lloyd Wright, in De Stijl painting, and in ancient Greek ornamental designs.

In a 1990 paper, Flemming proposed a model similar to Knight's for teaching architectural composition.[30] General architectural languages based on vernacular or "high-style" traditions are introduced to students. These languages include wall architecture, mass architecture, panel architecture, layered architecture, structure/infill architecture, and skin architecture. Grammars underlying these architectures are also presented. Students use the grammars to learn about the languages, then modify them to generate their own new languages. Thus, Flemming's strategy is both analytic and synthetic or creative. Others have adopted similar teaching strategies. Julie Eizenberg, an award winning architect and coauthor of the Wright grammar, has introduced shape grammars in her studio teaching at UCLA, Harvard, MIT, Yale, and elsewhere in an analysis → transformation → synthesis process. Students analyze the buildings of an architect, extract rules, then play with these rules to formulate their own rules for buildings that satisfy a given program.

Current, very promising work by three doctoral students in the Design and Computation program at MIT is in the same spirit. Each student is working on a shape grammar for an existing style of architecture. Unlike earlier analytic grammars, these grammars are being developed with very specific practical or pedagogical goals in mind. They are not just meant to be "read". They are meant to be used. Each grammar will have some degree of flexibility built in so that potential users of the grammar will not only be able to understand and generate designs in the original style, they will be able to generate new designs in a broadening of the style. To achieve these goals, the grammars will incorporate new grammatical or other devices such as description grammars, parallel grammars, color grammars, or multiple algebras.[31]

Birgul Colakoglu is writing a grammar for a traditional housing type in Bosnia. The grammar is intended to be used by design students to teach them about this type. It is also intended to be used to generate "interpolations" of the type that can be built in a contemporary Bosnian context. Andew Li's shape grammar is for the Chinese building system documented in the 12th century building manual Yingzao Fashi.[32] The grammar is being structured in such a way that it can be used by students to generate and explore variations of the system. Jose Duarte is developing a grammar for a housing system designed by the Portuguese architect, Alvaro Siza.[33] This work is unique in that it encapsulates the work of a living architect as well as a "living style"--that is a style that continues to be built today. Duarte has the enthusiastic support of Siza in developing his grammar, and anticipates that Siza will test and may ultimately use a computer-implementation of the grammar to build new houses.

A common use of shape grammars by design students who have taken shape grammar courses is an informal version of the applications above where the author of designs and of grammars are the same. With a project in progress in a traditional studio course, a student analyzes her own design or some part of it, extract rules, and then plays with these rules to generate new design possibilities. One or more possibilities may then be selected for further development in the project.

THE ROLES OF APPLICATIONS IN EDUCATION AND PRACTICE

The value of the applications above and the new opportunities they bring to education and practice are summarized below. These opportunities raise new, diverse, provocative issues that are discussed in the concluding section.

Original design

Applications in this area have obvious implications for both education and practice. In his early work, Stiny is unreserved in his ambitions for shape grammars, setting his approach in opposition to traditional, "romantic" approaches to design. Shape grammars provide the foundation for a "science of design"[34] and for a "theory of architectural composition".[35] Moreover, his constructive approach "is proposed in the belief that something like it will ultimately replace the kindergarten method both in the studio and in practice . . . Using rules instead of intuition, the designer need no longer rely on 'creative inspiration', the 'inventive flash', or 'individual genius'. Once these barriers to clear thinking in design have been removed, we can begin to answer that persistent query: 'Where do designs come from?'"[36]

Many of Stiny's early goals have yet to be realized. Certainly, shape grammars are well-suited for teaching composition and visual correlates such as proportion[37] and symmetry. To the author's knowledge, no comprehensive pedagogy using shape grammars in this way, with the exception of Flemming's course, has been instituted in a design curriculum. Behind the polemics of Stiny's comments, are important questions about the relationship between shape grammars and traditional design practice. With a shape grammar approach, one may begin to answer the question "Where do designs come from?" by pointing to rules that generate them. However, this question is then replaced with an equivalent, equally difficult question "Where do rules come from?". It is precisely this question that students ask, often indirectly, when attempting to write a grammar for a design project.

The value of using rules to design was detailed in Stiny's kindergarten paper.[38] Stiny's seven points can be condensed to two important ones for design education. First, rules make explicit or externalize a student's design ideas so that they can be examined, changed, communicated more readily. Second, rules make possible multiple design solutions rather than a single solution. It is not the multiple solutions themselves that are important. Rather, it is the possibility of *choosing* between different solutions that is important. The process of evaluating and selecting among different designs again brings into focus a student's design intentions.

Knight's work using (from scratch) grammars in studio-like projects has raised many questions concerning the relationship between shape grammars and traditional design approaches. These are discussed in the concluding section.

Original shape grammars have yet to be applied in practice, that is, outside of an academic setting.

Analysis

Applications in analysis have much educational potential. There is no better way to learn about styles or languages of designs (at least compositionally) than by either studying shape grammars already written for languages or by writing grammars oneself. Good analytic grammars are both parsimonious and descriptive. They are eye-openers, revealing simplicity or regularities behind designs seemingly complex or random. They reveal the thoughtfulness, the "individual genius", behind designs that students might otherwise take as unfathomable.

Grammars also reveal general design strategies that students can learn from and use in their own work. Different grammars for very different languages (temporally, culturally, geographically) often use common design strategies. For example, in a number of shape grammars, designs are based on an abstract grid or parti. Spaces are delineated within the grid, and then finer details are added within these spaces. The Palladian grammar, the Japanese tearoom grammar, and Li's Yingzao Fashi grammar all work in this fashion. A number of grammars use subdivision as the basis for designs. This strategy is useful when designs in a language have the same, regular boundary. The ice-ray grammar, the Hepplewhite chairback grammar, the Siza grammar, all of the painting grammars (Vantongerloo, Glarner, and Diebenkorn), and to some degree, the bungalows of Buffalo grammar, work in this way. Other grammars use an additive process for generating designs. This strategy is useful when designs in a language have irregular boundaries or when different designs have different boundaries. With this approach, designs are generated beginning with one part (the core) of a design to which other parts are successively added. The Wright grammar, the Queen Anne grammar, and Colakoglu's Bosnian house grammar follow. Three-dimensional architectural grammars describe strategies for vertical connections between spaces. For example, in the Wright grammar, the Queen Anne grammar, the Siza grammar, and the Gill grammar, the spatial organizations of first and second floor are strongly connected: the organization of the second floor mimics that of the first and is derived from it.

The general design strategies that cut across different grammars and the more specific ones embodied in particular grammars are theories of composition and may not correspond to historical fact. That is, a grammar may have nothing to do with the way designs were conceived or created by the original designer. In this sense, a grammar may be unbelievable. Yet, there is no way of verifying whether a grammar is historically accurate, even with the testimony of a living designer. Thus, shape grammars are not, to use AI terminology, strong theories of styles, but weak theories of styles. The more compelling a grammar is, though, the more it may seem to correspond to historical reality. Stiny's ice-ray grammar is a good case in point. Stiny suggests in his paper that it is easy to imagine that Chinese artisans constructed ice-ray window grilles using exactly the process encoded by his grammar: "Indeed, the steps in the ice-ray lattice generation . . . could well comprise the frames in a motion picture of the artisan creating his design!".[39] The grammar for Greek ornamental designs is believable in the same way.

Most shape grammar authors, though, do not view historical truth as a goal for their grammars. The creative strategies and ideas suggested by a well-crafted grammar, believable or not, can be very valuable. A well-crafted grammar may be used to classify designs and 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.[40]

Analytic grammars have yet to be used in design practice. In architecture and the arts, fields with a heavy emphasis on originality and novelty, it seems unlikely that a designer would implement any grammar but his or her own (an original grammar). In engineering and product design, implementations of grammars for known languages seem more likely. Agarwal and Cagan's grammar for coffeemaker designs is a good example of a grammar that could be put into practice.[41]

Analysis/original design

For architectural design education, combined analytic/synthetic applications may be more useful than either analysis or synthesis alone simply because they teach multiple skills in a coordinated way. Students learn about the work of accomplished designers or their own work in progress, about ways of designing, and about ways of developing their own work.

Analytic/synthetic grammars have not been used in practice. However, the applications being worked on by researchers in architecture (for example, Duarte's and Colakoglu's grammars) and in engineering may take these types of shape grammars out of the classroom very shortly. These applications are most promising for practice.

NEW AND ONGOING ISSUES IN EDUCATION AND PRACTICE

Shape grammars are more than twenty-five years old, but their potential in education and practice is still far from being realized. Shape grammar theory is now far in advance of practical applications. Why? What can be done to narrow this gap?

The number of design (architecture, arts, engineering) schools that include shape computation or shape grammars as part of their curriculum has grown steadily as graduates of shape grammar programs find teaching positions worldwide and establish their own shape grammar courses. Shape grammars now have a much wider reach than they have ever had, but practical accomplishments have grown slowly. Some issues and questions need to be addressed for continued and more rapid progress.

There are questions of **pedagogy**--how to teach shape grammars. Shape grammars, like their Turing equivalent, can do (compute) almost anything. To understand and deploy the full capabilities of shape grammars, a unique combination of technical, spatial, and intellectual abilities and interests is required. A number of graduate students and researchers with these abilities and interests continue to push the boundaries of shape grammar theory. However, there is a wider population that can enjoy, learn from, or use shape grammars very profitably that needs to be reached. Introducing shape grammars to this population with different levels and kinds of experience and abilities may require different teaching strategies. The spatial abilities needed to grasp shape grammars, especially in three dimensions, require practice even for experienced designers. In this author's experience, the best way for students to understand how grammars work is through concrete and collaborative exercises. Hands-on implementations of grammars with physical 2D or 3D shapes, that are manipulated manually in space, or with 2D drawings of shapes (on trace) is essential. Because shape grammars are unlike anything most students have ever seen before, students call on a wide range of skills to understand what they are doing. Collaborative work allows students to share their different learning strategies.

Should the shape grammars first introduced to students be abstract ones like the kindergarten grammars or interpreted ones in which shapes have definite meanings or functions? An advantage to abstract grammars is that they demonstrate easily the mechanics of shape grammars. Also, they do not limit possible interpretations of the designs they generate. Designs can be read in multiple ways leading to multiple applications. For beginning design students, though, abstract grammars can have disadvantages. Students with limited or no design experience may not be able to see beyond, or generalize from, what they physically have in hand (a 2 x 1 x 1/2 wooden block, for example), thus limiting their understanding of what grammars can be used for. Interpreted shape grammars, such as the wall, panel, and so on grammars of Flemming, may be more instructive or motivational for beginning students.

Strongly tied to pedagogical questions, are questions of **computer implementation**. When and how are computer implementations of shape grammars useful for students or practitioners? What should these implementations look like?

For teaching purposes, computer implementations may not be as effective as by-hand applications of grammars. Slow, by-hand applications of rules require careful thinking about how rules work. In the long term, this results in a better understanding of grammars and better quality design work. Computer implementations of grammars can encourage mindless defining and testing of rules. Interesting or useful designs may be arrived at, but by chance and with no understanding of how the designs were generated or how to generate other results. Also, computer implementations provide only two-dimensional representations of generated designs. Three-dimensional grammars can generate complex designs that are difficult to comprehend without a physical, 3D model. A two-dimensional representation of a three-dimensional object, no matter how sophisticated, cannot compete with the object itself. Linking rapid prototyping technologies to computer implementations may be a solution to this problem.

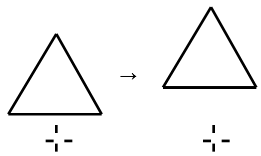
There are, of course, overwhelmingly strong reasons for having computer implementations. Computer implementations are good demonstration tools for showing novices the range and power of shape grammars. They can allow students and designers who do not wish to deal with the technicalities of grammars, to develop or use shape grammars with success. For advanced shape grammarians, who understand how shape grammars work, they allow for rapid explorations of rules and design possibilities. Shape grammars are powerful devices and the power of computers is needed to explore their limits.

Currently though, there are few computer implementations that are practicable for students or practitioners. Most do not have interfaces that make them easy for nonprogrammers to use. More efforts have gone to computational problems than to interface ones. Implementations of simple, restricted grammars that are visual and require only graphic, nonsymbolic, nonnumerical input are needed. Successively more general and powerful implementations can be built from these. Tapia's program for two-dimensional, nonparametric shape grammars is a great start.[42] Still simpler programs for three-dimensional set grammars developed by Duarte and Simondetti and by Wang at MIT have done much to promote the use of shape grammars among graduate design students at MIT.[43]

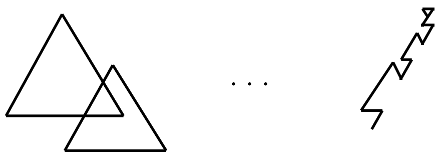
As more students and researchers explore possibilities of putting shape grammars into practice, questions of **authoring a shape grammar** for practical applications are emerging. These questions are different for different applications: original design (from scratch or from known designs), analysis, or some combination of the two.

In original design applications, the author and user of a grammar are the same: a designer. Are some kinds of shape grammars more suitable than others for designers to work with? Like computer implementation issues, consideration must be given to the power and generality of a grammar on the one hand, and ease of use on the other. Knight has proposed that simple, restricted types of grammars with a minimum of shape grammar paraphernalia (parameters, labels, etc.) may be best suited for the early conceptual stages of design.[44] Restricted grammars are easy to design, easy to understand, and they can generate a multitude of innovative design possibilities. Generated designs can be elaborated either by elaborating the grammar or by traditional means.

One critical problem in authoring an original grammar is how to develop a grammar that meets the goals and constraints of a particular project. A commonly asked question by design students writing grammars for a project is "How should I start?". At some point in the process of developing a grammar--if not at the start--a connection must be made between rules that describe spatial form, and the goals of a project that may describe anything from function to meaning to aesthetics and so on. Making this connection is not an easy task because shape grammars are in general unpredictable. Seemingly simple rules can produce surprisingly complex results. See, for example, the rule below which shifts a triangle, and the result of applying the rule recursively to two triangles (taken from Lionel March[45]).

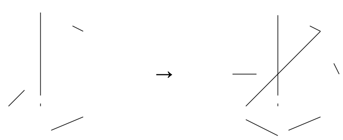


rule



recursive application of rule

Seemingly complex rules can produce surprisingly simple results. See, for example, the rule below and the result of applying the rule recursively to the shape on the left side of the rule.



rule

recursive application of rule

Different approaches to connecting grammars and goals have been suggested. One approach is direct. It involves writing rules with the foreknowledge that the generated designs will meet, or start to meet, given goals. In order to do this, the behaviors and outcomes of rules must be predictable in some way. In a 1987 paper, Flemming recognized the problem of predictability, writing "There is, at the present time, no body of theory available that would allow us to predict the properties of shapes generated by a grammar solely from an inspection of its rules."[46] Recently though, Knight has attempted to establish just such a theory.[47] Knight has proposed a classification of types of grammars from unrestricted, standard shape grammars to simpler, restricted ones, showing the increasing predictabilities of each type. Assuming a lack of theory, Flemming suggested: "In order to assure that a grammar is properly constructed, we often have to enumerate a substantial number, if not all of the shapes it generates. This process is tedious and error-prone if done manually and could clearly gain from automation."[48] This implies an alternate, indirect approach to connecting grammars and goals that has also been researched in recent years. With this alternate approach, grammars are developed without a clear idea of their outcomes. An automated search and test strategy is then used to explore the space of designs generated, sampling designs and testing them to see if they meet given goals. Cagan's shape annealing technique is a successful example of this approach.[49]

Authoring an original shape grammar inevitably raises questions of creativity. For beginners, writing a shape grammar requires "a willing suspension of disbelief"[50], a commitment to an unfamiliar enterprise, and a consequent feeling of a loss of control over the design process. Also, because shape grammars are spatial rather than symbolic or textual (like computer programs), they have an immediacy and directness that seems to challenge the authority of some designers. With increased experience and control over writing grammars, issues of creativity tend to disappear. Creativity is simply transferred from the designing of a single design to the design of rules. The same intelligence, imagination, guesswork, and intuition that goes into the former is required for the latter.

In analytic applications of shape grammars, the author and the users of a grammar are different. Traditional analytic shape grammars were intended for a diverse audience from historians to designers who use the grammars for educational purposes--to understand a particular style. Criteria for authoring a successful analytic grammar for a style were spelled out early by Stiny and Mitchell. Requirements of a grammar are that: "(1) it should clarify the underlying commonality of structure and appearance manifest for the buildings in the corpus; (2) it should supply the conventions and criteria necessary to determine whether any other building not in the original corpus is an instance of the style; and (3) it should provide the compositional machinery needed to design new buildings that are instances of the style."[51]

In newer, combined analytic/synthetic applications of grammars, the author and the users of a grammar are also different. However, unlike analytic grammars, these grammars are intended for an audience who use the grammars for practical design purposes as well as educational ones. New criteria for authoring these new grammars are called for.

Like traditional analytic grammars, new analytic/synthetic grammars describe styles of designs that are diverse and complex. In order to generate such designs in a comprehensible way, virtually all analytic shape grammars have been nondeterministic and parametric.[52] Thus, the users of these grammars have choices of ways to execute rules. In each step of the generation of a design, these choices may include (1) a rule to apply, (2) where to apply a rule, (3) what transformation to apply a rule under, and (4) an assignment of values to parameters in a rule. These choices are structured in a sequence determined by the author of the grammar. The sequence may or may not reflect the process by which a designer might create the same designs.

New analytic/synthetic grammars must be structured in some designerly way in order to be practicable. Most traditional analytic grammars are not structured in this way and thus are not practicable. In other words, the way in which choices are presented to users may not be sensible from some design point of view. This is particularly true for choices relating to parameters. With some architectural grammars, for example, a user must decide the dimensions of individual spaces in a plan before the arrangement of all the spaces is decided. In the first stage of the Palladian grammar, for instance, spaces are generated one or two at a time to define the underlying grid of a plan. As each space is added, it must also be dimensioned. Thus, a user must decide the dimensions and proportions of individual spaces before knowing (generating) the size and proportions of the overall grid. In the Wright grammar, the dimensions and proportions of some spaces in the core unit of a house are decided before the functions of these spaces are assigned. Problems such as these arise because shape grammars do not easily allow for the separation of dimensioning from other choices. Currently, Li is exploring a solution to this problem in his Yingzao Fashi grammar with the use of parallel grammars.[53] Different grammars are used to generate different stages of a design. One grammar generates generic layouts of buildings. Layouts are then passed to a parallel grammar in which layouts are dimensioned. Dimensioned layouts are then passed to a parallel grammar in which dimensioned layouts are extruded into three dimensions, and so on. The output of the parallel derivations is a set of different representations of a design. Duarte and Colakoglu are also exploring the use of parallel grammars in their work, not only as a solution to the parameter problem but as a way of generating multiple representations of designs.

Another question that arises from practical uses of grammars is how to find or generate subsets of a language that satisfy particular criteria. (This issue is similar to the problem of connecting original grammars with goals discussed above.) For example, Duarte's grammar for Siza houses is intended to be used by Siza or his clients. For clients with particular requirements (a number of bedrooms, for example), a mechanism is needed to find / generate just those houses in the language that satisfy the requirements. Duarte is exploring a number of automated mechanisms either embedded within the grammar or external to it that will perform this task. One solution to the general problem of searching through languages to find particular designs involves the use of description grammars.[54] A shape grammar can be linked with a parallel description grammar so that a design and a description of the design are generated in parallel. Every design generated by the shape grammar thus has a description (including number of bedrooms, for example). Given some requirements, the rules for generating a description that includes the requirements can be used as input to run the shape grammar. This input specifies which shape rules to apply to generate a design with that description.

These are just a few of the issues that have come up in education and practice. They can serve as the basis for further discussion at the Workshop.

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1 G. Stiny, "Two exercises in formal composition," *Environment and Planning B* 3 (1976): 187-210.

2 G. Stiny and J. Gips, "Shape Grammars and the Generative Specification of Painting and Sculpture," in C. V. Freiman, ed., *Information Processing 71* (North Holland, Amsterdam, 1972), pp. 1460-1465.

3 J. Gips, *Shape Grammars and their Uses* (Birkhauser, Basel, 1975); G. Stiny, *Pictorial and Formal Aspects of Shape and Shape Grammars* (Birkhauser, Basel, 1975).

4 G. Stiny and J. Gips, *Algorithmic Aesthetics* (University of California Press, Berkeley, CA, 1978)

5 G. Stiny, "Kindergarten grammars: designing with Froebel's building gifts," *Environment and Planning B* 3 (1980): 409-462.

6 T. W. Knight, "Designing with Grammars," in G. N. Schmitt, ed., *Computer-Aided Architectural Design* (Verlag Viewag, Weisbaden, 1992), pp.33-48; T. W. Knight, "Color Grammars: the Representation of Form and Color in Design," *Leonardo* 26 (1993): 117-124; T. W. Knight, "Shape grammars and color grammars in design," *Environment and Planning B: Planning and Design* 21 (1994): 705-735.

7 Color grammars are an extension of the shape grammar formalism (T. W. Knight, "Color grammars: designing with lines and colors," *Environment and Planning B: Planning and Design* 16 (1989): 417-449). They allow computations with shapes made up of lines, planes, or volumes and attributes of shapes such as color. "Colors" in a color grammar are equivalent to Stiny's later "weights".

8 R. Brown, "Continual Motion: Ocean Observatory and Educational Facility," *Crit* 30 (1993): 42-43; [8] T. W. Knight, "Designing with Grammars," in G. N. Schmitt, ed., *Computer-Aided Architectural Design* (Verlag Viewag, Weisbaden, 1992; T. W. Knight, "Shape grammars and color grammars in design," *Environment and Planning B: Planning and Design* 21 (1994): 705-735.

9 J. P. Duarte, Jose and A. Simondetti, "Basic Gramars and Rapid Prototyping," *Proceedings of the 4th Workshop of the European Group for Structural Engineering Applications of Artificial Intelligence*, Lahti, Finland, (1997), pp. 117-119; Y. Wang and J. P. Duarte, "Synthesizing 3D forms: shape grammars and rapid prototyping," Workshop on Generative Design, *Artificial Intelligence in Design '98 Conference*, Lisbon, Portugal, (1998), pp. 7-18.

10 For example, R. F. Woodbury, A. D. Radford, P. N. Taplin, and S. A. Coppins, "Tartan worlds: A generative symbol grammar system" in D. Noble and K. Kensek, eds., *ACADIA 92*, p. 211.

11 G. Stiny, "Ice-ray: a note on Chinese lattice designs," *Environment and Planning B* 4 (1977): 89-98.

12 G. Stiny and W. J. Mitchell, "The Palladian grammar," *Environment and Planning B* 5 (1978): 5-18.

[13] U. Flemming, “The secret of the Casa Guiliani Frigerio,” *Environment and Planning B* 8(1981): 87-96.
[14] H. Koning and J. Eisenberg, “The language of the prairie: Frank Lloyd Wright’s prairie houses,” *Environment and Planning B* 8 (1981): 295-323.
[15] N. L. R. Hanson and A. D. Radford, “On Modelling the Work of the Architect Glenn Murcutt,” *Design Computing* (1986): 189-203.
[16] H. Buelinckx, “Wren’s language of City church designs: a formal generative classification,” *Environment and Planning B: Planning and Design* 20 (1993): 645-676.
[17] J. Gibbs, “Sincerity of Design: Irving J. Gill’s California Houses,” *Environment and Planning B: Planning and Design* (forthcoming).
[18] T. W. Knight, “The forty-one steps,” *Environment and Planning B* 8 (1981): 97-114.
[19] F. Downing and U. Flemming, “The bungalows of Buffalo,” *Environment and Planning B:* 8 (1981): 269-293.
[20] U. Flemming, “More than the sum of its parts: the grammar of Queen Anne houses,” *Environment and Planning B: Planning and Design* 14 (1987): 323-350.
[21] S-C Chiou and R. Krishnamurti, “The grammar of Taiwanese traditional vernacular dwellings,” *Environment and Planning B: Planning and Design* 22 (1995): 689-720.
[22] G. Stiny and W. J. Mitchell, “The grammar of paradise: on the generation of Mughul gardens,” *Environment and Planning B* 7 (1980): 209-226.
[23] J. L. Kirsch and R. A. Kirsch, “The structure of paintings: formal grammars and design,” *Environment and Planning B: Planning and Design* 13 (1986): 163-176.
[24] T. W. Knight, “Transformations of De Stijl art: the paintings of Georges Vantongerloo and Fritz Glarner,” *Environment and Planning B: Planning and Design* 16 (1989): 51-98.
[25] T. W. Knight, “Transformations of De Stijl art: the paintings of Georges Vantongerloo and Fritz Glarner,” *Environment and Planning B: Planning and Design* 16 (1989): 51-98.
[26] T. W. Knight, “The generation of Hepplewhite-style chair back designs,” *Environment and Planning B: Planning and Design* 7 (1980): 227-238.
[27] J. Rollo, “Triangle and t-square: the windows of Frank Lloyd Wright" *Environment and Planning B: Planning and Design* 22 (1995): 75-92.
[28] T. W. Knight, “Transformations of the Meander Motif on Greek Geometric Pottery,” *Design Computing* 1 (1986): 29-67.
[29] T. W. Knight, “Languages of designs: from known to new,” *Environment and Planning B* 8 (1981): 213-238; T. W. Knight, “Transformations of languages of designs,” *Environment and Planning B* 10 (1983): Part 1 125-128, Part 2: 129-154, Part 3:155-177; T. W. Knight, *Transformations in Design* (Cambridge University Press, Cambridge, 1994.
[30] U. Flemming, “Syntactic Structures in Architecture” in M. McCullough, W. J. Mitchell, and P. Purcell, eds., *The Electronic Design Studio* (The MIT Press, Cambridge, 1990), pp. 31-47.
[31] For description grammars and parallel grammars, see G. Stiny, “A note on the description of designs,” *Environment and Planning B* 8 (1981): 257-267; for multiple algebras, see G. Stiny, “What is a design?,” *Environment and Planning B: Planning and Design* 17 (1990): 97-103, and G. Stiny, “The Algebras of Design,” *Research in Engineering Design* 2 (3): 171-181.
[32] A. I-Kang Li, “Expressing Parametric Dependence in Shape Grammars, with an Example from Traditional Chinese Architecture,” *Proceedings of CAADRIA ‘99* (1999); A. I-Kang Li, “A 12th century Chinese building manual: descriptions and a shape grammar,” *Thresholds* 17 (1998): 25-30.
[33] J. Duarte, "Using Grammars to Customize Mass Housing: the Case of Siza's Houses at Malagueira," *IAHS World Congress on Housing*, Lisbon, Portugal, (1998); J. Duarte, "Order and Diversity within a Modular System for Housing," *Worldwide ECCE Symposium*, Lahti, Finland, (1997); J. P. Duarte, “Democratized Architecture: Grammars and Computers for Siza’s Mass Housing,” *Proceedings of the International Conference on Enhancement and Promotion of Computational Methods in Engineering*

and Science (EPCMES 99), Macau, China (Elsevier Press, forthcoming in 1999); J. P. Duarte, "Customized Mass Housing: A Grammar for Siza's Houses at Malagueira," (in progress).

[34] G. Stiny, "Kindergarten grammars: designing with Froebel's building gifts," *Environment and Planning B* 3 (1980): 461.

[35] G. Stiny, "Kindergarten grammars: designing with Froebel's building gifts," *Environment and Planning B* 3 (1980): 461

[36] G. Stiny, "Kindergarten grammars: designing with Froebel's building gifts," *Environment and Planning B* 3 (1980): 416.

[37] See, for example, L. March, "Architectonics of proportion: a shape grammatical depiction of classical theory," *Environment and Planning B: Planning and Design* 26 (1999): 91-100.

[38] G. Stiny, "Kindergarten grammars: designing with Froebel's building gifts," *Environment and Planning B* 3 (1980): 459-460.

[39] G. Stiny, "Ice-ray: a note on Chinese lattice designs," *Environment and Planning B* 4 (1977): 97.

[40] For example, the Irving Gill grammar was written by an historian to answer questions about the relationship of Gill to his contemporaries and mentors.

[41] M. Agarwal and J. Cagan, "A blend of different tastes: the language of coffeemakers," *Environment and Planning B: Planning and Design* 25 (1998): 205-226.

[42] M. Tapia, *From Shape to Style. Shape Grammars: Issues in Representation and Computation*, PhD Thesis, Department of Computer Science, University of Toronto, Toronto, Canada (1996); M. Tapia, "A visual implementation of a shape grammar system," *Environment and Planning B: Planning and Design* 26 (1999): 59-73.

[43] J. P. Duarte, Jose and A. Simondetti, "Basic Gramars and Rapid Prototyping," *Proceedings of the 4th Workshop of the European Group for Structural Engineering Applications of Artificial Intelligence,* Lahti, Finland, (1997), pp. 117-119; Y. Wang and J. P. Duarte, "Synthesizing 3D forms: shape grammarsand rapid prototyping," Workshop on Generative Design, *Artificial Intelligence in Design'98 Conference*, Lisbon, Portugal, (1998), pp. 7-18.

[44] T. Knight, "Designing a Shape Grammar" inJ. S. Gero and F. sudweeks, eds., *Artifical Intelligence in Design '98* (Kluwer Academic Publishers, 1998), p. 514.

[45] L. March, "Rulebound unruliness," *Environment and Planning B: Planning and Design* 23 (1996): 396.

[46] U. Flemming, "More than the sum of its parts: the grammar of Queen Anne houses," *Environment and Planning B: Planning and Design* 14 (1987): 349.

[47] T. W. Knight, "Shape grammars: six types," *Environment and Planning B: Planning and Design* 26 (1999): 15-31; T. W. Knight, "Shape grammars: five questions," *Environment and Planning B: Planning and Design* (forthcoming).

[48] U. Flemming, "More than the sum of its parts: the grammar of Queen Anne houses," *Environment and Planning B: Planning and Design* 14 (1987): 349.

[49] J. Cagan and W. J. Mitchell, "Optimally directed shape generation by shape annealing," *Environment and Planning B: Planning and Design* 20 (1993): 5-12.

[50] D. Schon, *Educating the Reflective Practitioner* (San Francisco and Oxford, 1987), p. 94.

[51] G. Stiny and W. J. Mitchell, "The Palladian grammar," *Environment and Planning B* 5 (1978): 17.

[52] Parameters and nondetermism do not add to the computational power of shape grammars. However, some languages can be characterized more simply or easily using parameters and nondeterminism.

[53] A. I-Kang Li, "Expressing Parametric Dependence in Shape Grammars, with an Example from Traditional Chinese Architecture," *Proceedings of CAADRIA '99* (1999).

[54] G. Stiny, "A note on the description of designs," *Environment and Planning B* 8 (1981): 257-267.