Supporting design through the strategic use of shape grammars

M. Smyth \textsuperscript{a,*}, E. Edmonds \textsuperscript{b,1}

\textsuperscript{a}School of Computing, Napier University, 219 Colinton Road, Edinburgh EH14 1DJ, UK
\textsuperscript{b}LUTCHI Research Centre, Department of Computer Science, Loughborough University, Loughborough LE11 3TU, UK

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Abstract

This paper is concerned with the early processes of design, particularly in the context of spatial arrangements. We are interested in the strategies that a designer uses in order to achieve success and with the opportunities that might exist for computer support. The technical device that provides the focus for the work is the concept of a shape grammar. The investigation that has taken place has looked at certain opportunities that might exist for building support systems employing shape grammars and the implications that they might have for the strategic level of design. From the exploration we conclude that the use of shape grammars to expand the strategies available to a designer and to provide computational support for exploring the implications of employing given sets of design rules is promising. Moreover, we have already identified a number of directions in which the research should be taken further.

Keywords: Strategic knowledge; Shape grammars; Support systems; Design

1. Introduction

This paper is concerned with the early processes of design, particularly in the context of spatial arrangements. We are interested in the strategies that a designer uses in order to achieve success and with the opportunities that might exist for computer support. The technical device that provides the focus for the work is the concept of a shape grammar [1]. The investigation that has taken place has looked at certain opportunities that might exist for building support systems employing shape grammars and the implications that they might have for the strategic level of design.

One important strategy in early design is the generation of alternatives. Two aspects of this are particularly important. Firstly, the alternatives should include unexpected solutions and, secondly, they should be reasonably likely to be evaluated as good solutions. The joint requirements for something to be both unexpected and good (by whatever definition) do not sit well together. However, the notion of a search space defined by a grammar offers an interesting possibility. A generative grammar can represent an infinite set of entities by finite means. Thus it is quite capable of generating something that is unexpected. On the other hand, the set of all possible results that can be generated is restricted to those that conform to the rules of the grammar. In that sense, it is possible to constrain what is generated to entities that might be judged ‘good’, providing that the rules are appropriate. In fact, no guarantee of unexpectedness or goodness can be given to the results of applying a generative grammar. Our contention, however, is that the probability of generating such interesting entities might be relatively high. Thus we consider it worthwhile to look into the use of such grammars in early design support systems.

We argue that successful solution finding in design is often founded on the ability to generate and communicate alternatives. Within the design process the generation and selection of such alternatives plays a vital role both in articulating ideas and in facilitating a better understanding of the problem at hand. The conception of design as an active co-operative process raises important issues for technologists seeking to support its early phase. In particular, the generation and display of design alternatives is significant for design creativity. The explicit representation of design knowledge is central to this endeavour.

In this paper, we explore a development in the application of shape grammars to this problem. We take particular advantage of their generative nature in order to produce new design ideas. In the experimental system developed, a designer may interact, guide and select the spatial arrangements generated through interaction with the grammar.
Preliminary investigations with designers have led to some understandings about the design search strategies that they employ when using such a system. We speculate on the potential of strategic knowledge developments that are implied by this research.

2. Shape grammars

Increasingly, there have been moves away from the traditional case study within architecture where the concern was with descriptive examination, to the search for principles of design. The underlying objective being to make architectural knowledge and its teaching explicit and to facilitate the intellectual appropriation of formal precedents in design [2].

One such model for representing formal principles of design is that of shape grammars [1]. The analogy between language and architecture is long established. Whereas semiotics deals with meaning, generative grammars are concerned with mechanisms for the construction of sentences, shape grammars follow this model and are applied to the generation of shapes. A shape grammar is a set of precise generating rules, which in turn, can be used to produce a language of shapes. Just as linguistics is primarily concerned with analysis, rather than the invention of new languages, the initial application of shape grammars have been in analysis or criticism. Typically, a given building or style has been taken and the shape rules induced that can re-generate the given shapes. Rather than the generation of new languages of design, work with shape grammars has focused on the definition and articulation of designs in known styles. Examples from architectural design include, Palladian Villas [3] and Frank Lloyd Wright’s Prairie-style houses [4], from furniture design, Hepplewhite-style chair backs [5] and from painting the work of de Stijl [6]. Such work on the characterisation of similarities is distinguished by the following:

- clarifying the underlying structure and appearance of known instances of style;
- supplying the conventions and criteria necessary to recognise whether any other design is an instance of the style;
- providing the compositional machinery needed to generate new instances of the style.

The same rules can then be used to generate new shapes in the language of the original. Just as linguistic grammars provide a finite set of rules capable of generating an infinite set of linguistic constructions [7], so shape grammars consist of sets of rules that can be used to generate infinitely many instances of shape arrangements that conform to the specified rules. The rules are replacement rules, so typically state that if a spatial configuration contains a given sub-element then that element may be replaced by a new, specified, shape. The application of the rules begins with a given seed shape and can proceed in a non-deterministic manner. Furthermore, by making alterations to a given shape grammar the language of shapes can be modified in either subtle or radical ways. In this way it could be possible to model an incremental development of style. Knight [8] has demonstrated how a shape grammar for a known style can be systematically transformed by the application of ‘change rules’ to produce new shape grammars defining new styles.

Shape grammars thus offer the potential to formally represent rules and objects associated with a particular design style and, critically, the opportunity to apply these rules thereby generating new shape arrangements in the language of the original. This paper presents a prototype system, implemented in Prolog and based on a simple shape grammar. The system incorporates the concept of ‘change rules’ in the form of labels. The purpose of the system is to enable the exploration of how such a representation could provide a designer with a ‘meta-grammar’ by which to manipulate a shape grammar and thereby explore a wider range of possible solutions. Through such manipulation novel ideas may be released to spark the creative iterative process vital in design. In short, shape grammars consist of a set of rules that can be used to generate infinitely many instances of shape arrangements. This can be considered as a ‘state-space’ from which alternative configurations might be found.

3. An experimental system

An experimental system was developed in order to investigate the utility of a shape grammar as a mechanism for the generation of alternative solutions. In particular, the production of spatial relationships associated with the combination of simple abstract shapes. Furthermore, the ‘outline prototype’ enabled the authors to hold discussions with a number of design practitioners concerning the utility of the approach. A basic shape grammar, as defined by Knight [9], was implemented using LPA MacProlog32 [10]. It comprised rules, which described the spatial relationships between a square and a rectangle. The rules were both additive and recursive as the shapes added coincide with those on the left hand side of other rules in the grammar. This provided the potential for the rules to be re-applied any number of times.

The system incorporated the concept of spatial labels [11]. These labels have the effect of reducing the symmetries of shapes to order one. For example, the application of a label to the bottom left hand corner of a square, usually represented as a dot, would destroy the object’s symmetry. In the context of a basic shape grammar the effect of introducing labels was to restrict to one, the number of alternative spatial configurations associated with a given label combination (Fig. 1). Thus by allowing the designer to interactively alter these combinations the result was to generate a range of spatial configurations associated with the grammar.
In short, the labels act as a ‘meta-grammar’ through which a designer can explore the solution potential of a shape grammar.

The system consisted of three windows, a control window, a rule window and a shape window. The control window provided the functionality for both starting and stopping the system and for setting up the labels associated with the rules that comprise the grammar. The application of the labels provided the designer with a special form of ‘meta-grammar’ through which they were able to instigate strategic action on the problem. The rules were displayed in the rule window. Initially these were presented without labels, but if the radio button in the control window was activated the effect was to annotate the rule shapes with a series of small circles located in the corners of each shape. At this point the designer was able to select any combination of labels using the mouse. Selection was indicated by the label turning into a black dot. Once the labels have been set to the satisfaction of the designer the grammar can be started from the control window. As labels destroy the symmetry associated with the rule shapes, this necessitated the use of certain transformations, in particular combinations of rotation and reflection, in order that the appropriate rule might first be identified and then applied to the spatial configuration under development. In effect the designer is selecting the strategies offered by the rules from which to have alternatives generated. The resulting spatial configuration was displayed in the shape window.

The action of the grammar was as follows: an initial shape was generated, in this case the shape on the left hand side of the first rule of the grammar. Each rule was then applied in turn until a match was found with the shape added by the previous rule. An example of such a sequence using unlabelled rules is provided in Fig. 2. Owing to the potentially infinite recursive nature of the rules used in the system each of the sequences was stopped at a particular point, in practice at a depth of seven. If the designer wished to use labels then the process could be

![Fig. 1. Example application of Rule1 (a) without labels and (b) with labels, in both cases the seed shape is a square.](image1)

![Fig. 2. Spatial configuration generated by unlabelled rules.](image2)
repeated for different combinations of labels, thereby enabling the exploration of a range of spatial relationships. Examples of possible design alternatives produced in this way are provided in Fig. 3a and b.

4. Empirical evidence

The prototype system was used to initiate discussions with three experienced designers. This process of demonstration was partly driven by their responses and was used as a trigger for a discussion about the potential of the approach in design and the strategies that would be employed in using it. Interestingly, it transpired that the discussions were mostly about the strategic thinking of the designers during concept formation. Below, we present summaries of the discussions with each designer.

4.1. Designer A

The designer was positive concerning the possibility of technology, which offered the opportunity to aid lateral thinking. Indeed, it was described as an ideal scenario. This was particularly the case when the approach provided the chance of something unexpected to happen. The designer commented that he could not decide whether the prototype was aimed particularly at the early conceptual phase of the design process, where ideas are ‘thrown around’, or if it could also offer a diagrammatic representation of an already thought through idea. If the latter was true, the plan drawings could then be viewed in projection. One of the points that the designer stressed was the issue of breaking the set way of design working. He talked of the intuitive process of design where influences can be numerous, for example shape, material and texture. The support prototype only considered one of these.

In terms of how technology such as this might contribute to the design process, the designer saw it as offering routes...
through, and in effect speeding, the process of route selec-
tion through a problem space. This process was viewed as
assisting with judgements or possible design alternatives.
Finally the idea of the organic generation of spatial rela-
tionships was raised as a possible direction in which software
designed to support design might explore.

4.2. Designer B

During the course of the interview the designer com-
mented that she felt that shape and space were inextricably
linked. The designer commented that during the process
of working with shape she was continually thinking about
the possibility of space within the shape. This position
would appear to support the linkage between shape (2D)
and space (3D) an issue, which was raised in the first inter-
view. The designer considered that the prototype and the
ideas underpinning it would be relevant to both architecture
and interior design.

Later in the conversation the topic of emergence arose
and how shape grammars might be applied to shapes that
emerge out of the evolving spatial relationships. At this
point the issue of and relationships between shape, colour
and space arose. In particular the designer commented that
in many cases colour could be more visually stimulating
than shape and she asked whether grammars of colour, as
well as those of shape, could be generated. She continued to
argue that such grammars could be used in conjunction with
the notion of 3D space, thereby providing a direct linkage of
shape, colour and space. In turn this might lead to the forma-
tion of a model, which reflected the various formats of
shapes. This she felt would be very interesting as a concep-
tual tool with which to think about problems.

4.3. Designer C

An initial comment made by the designer after seeing the
shape grammar prototype and in particular the idea of
labels, was to ask if it were possible to activate two labels
in the one shape which comprised a given rule. He felt this
would be particularly interesting, as it would introduce a
decision point during the application of the grammar. He
considered that such points act as a focus of creative thought
on the part of the designer even though the decisions made
sometimes only exhibited a benefit later in the design
process. The designer commented on the similarity to the simi-
larity to the situation when an extra constraint is added to a problem in
order to overcome the ‘blank page’ and in some way facil-
itate the design process.

The designer was asked how he thought about space
during the early part of a project and in particular whether
the shape grammar system struck any chords with that
process. He replied that he thought of space in the context
of function and also its interaction with other spaces, both
internal and external. He felt that the prototype would be particularly usefully for massing, which was described as a wilful division of space within a structure. In particular, the ability of the designer to set up relationships, sequences and orders and then to observe what this creates and the possible ideas that could then be hung on the resulting configurations. The system was likened to a style of Scandinavian architecture which was based around 'loose fit' rules. These rules produced a geometric sequence that acted as a spine or core which gives an order and a legibility. The building functions can then be slotted into the basic structure. In the context of shape grammars, the designer suggested the following possible loose fit rule: a rule such that the placement of the adjacent shape must have a common boundary of at least a certain length. The designer described this as a desire to introduce a sense of irregularity as he considered the highly regular nature of the prototype grammar to be slightly disconcerting. This also produced the tendency to view the output of the grammar as a building plan. For example, by masking off parts of a given spatial configuration produced by the grammar (Fig. 4) the designer felt that the output was reminiscent of Mies van der Rohe’s Barcelona Pavilion (Fig. 5) — a building that focused on the overlap between highly structured spatial relationships.

The designer was asked to comment on the previous suggestions to include a 3D quality in terms of how the configurations produced by the grammar were presented. The designer felt that this would be unnecessary as it could make the system more prescriptive in terms of its description of space and deflect the designer away from the more fundamental interaction with the grammar (i.e. the manipulation of the rules). Thus, creativity might be hindered by this addition.

At a personal level the designer expressed a preference for buildings comprising more irregular shapes than those produced by the particular grammar employed. He considered that people’s perceptions of such spaces is more enduring as such buildings are more provocative and the individual’s views are ever changing when interacting with such spaces. The designer suggested that it would be interesting to use the system to explore the nature of just one or two shapes by changing and bending them. The idea was discussed of enabling the designer to deform the rules in some way, then observe and interact with the evolving spatial configuration and thereby learn more about the fundamental nature of the relationship between the shapes.

The designer returned to his concern about the lack of variety in the produced configurations and the fact that repetition may not be enduring. He suggested the need for regularity with a chance element. The designer was then presented with a more irregular spatial configuration produced by the prototype grammar (Fig. 6). Immediately the designer saw this he was reminded of the buildings of the architect Richard Meier (Figs. 7 and 8).

The designer considered that the idea of introducing a degree of change in the application of a rule would produce more irregular and therefore interesting shapes. For example, a geometric shift could be incorporated in the relationship after each successive application of the rule. The designer considered that an interesting feature of the prototype was the way in which it made a designer consider the process of evaluating a space. Indeed, the designer commented that it would appear to

Fig. 4. Example output from shape grammar.

Fig. 5. Plan of the Barcelona Pavilion by Mies van der Rohe.

Fig. 6. Output from shape grammar system.
be the sole purpose of some architects to produce repetitive progression of a shape. For example, the way certain housing projects interconnected and follow the contours of the land — the designer considered these to be an imposed order rather than a natural one. Continuing the housing theme the designer commented that again some of the patterns produced by the grammar were reminiscent of 1970s local authority housing plans, in particular courtyard housing, (see Fig. 4).

In the view of the designer the major benefit of such a shape grammar system as the prototype would be to enable the exploration of a small number of shapes with a small number of rules. Rather than pure repetition of shape this would enable the designer to exercise a great deal of issues in terms of the relationships between the shapes. If the rules were chosen with a balance in mind then it could be expected that the resulting configurations would also exhibit a similar degree of balance. Indeed the progressions that might be generated would express so much more about the initial spatial relationship. This would be the same for both regular and irregular shapes. In short, if the rules are ‘right’, then the subsequent combinations will also be ‘right’.

The conversation moved on to the idea of emergence and the way that shapes can appear through the combinations of others. The designer questioned the merit of such an approach from a spatial point of view and commented that emergence appeared to run contrary to the fundamental structure of shape grammars. He suggested that it would be more logical to apply something that you think would be useful in the first place rather than waiting for something to fall out by chance.

The notion of loose fit rules came up again and, in particular, the progressions that might be generated — spines and cores. The designer commented on architects’ designs in which clusters of objects, say houses or rooms, were broken by other objects. The designer said that he suspected that the architect was using implicit ‘rules’ to create these structures. The idea of a repeated mutated shape reminded the designer of Reima Pietila’s library building in the shape of a fan (Fig. 9). The introduction of such rules would contribute to the production of more organic configurations. The designer commented that maybe designers are always using rules in some way. For example, maybe these take the form of having a tendency to behave in a particular way to the extreme of something that they would never do. Classical architecture consisted of a series of rules and the buildings that were produced are highly thought of.

The interview concluded with the following comment from the designer: ‘one of the most important things that architects and designers have to learn is the ability to compensate for the way that they have to depict things… if you give modelling materials they never build it in the way that they would draw or design it because you have a feel for it, a sense of scale. Drawings are always going to kid you.’

5. Key issues

The benefits of a shape grammar based support systems were seen to come from various ways in which they could focus creative thought:

- Show the implications of specified relationships.
- Encourage the evaluation process.
- Force creative decision points.
- Encourage lateral thinking.

A number of proposals for further developments were put forward by the designers:

- The use of a 3D shape grammar (but not agreed by Designer C).
- The use of an additional grammar of colours.
- The use of ‘loose fit’ rules that can generate, for example, the spine of a building.
- The organic growth (e.g. geometric shift) of rules.

The process of using such an approach might include:

- Defining and exploring rule sets,
Exploring a small number of shapes in depth, Simply finding the unexpected.

6. The employment of the approach

Shape grammars provide a formalism in which rules about shape arrangements can be specified together with a mechanism with which it is possible to automatically generate new, conforming, arrangements. As the prototype system demonstrates, such a system can use graphical representations (based on the shapes themselves) for the user to see and manipulate. The rules of a shape grammar used in this way represent on aspect of design knowledge and the system prototyped is an example of one that allows the designer to interact with that knowledge in a domain specific way [13]. It seems that shape grammars do have a role here.

Amongst the proposals that came from the designers was the idea of ‘loose fit’ rules. This idea implies that the grammar might be specifically directed at core design structures, where perhaps the application of relatively well organised design rules make most sense. In this view, much elaboration is left outside the support system and can be dealt with more intuitively. The suggestions of ‘organic generation’ may have been made in much the same spirit. Here, diversity is added by what might be thought of as the application of mutants of the rules, such as a small geometric shift at each application. Such a mutation could, of course, come from the application of a meta-rule. If that was the case we might again allow for designers to experiment with the meta-rules in order to understand their impact on the generation of new ideas.

In all cases, a system such as that prototyped can be seen to act as a stimulus to the thinking of the designer. It might offer a range of alternatives that stimulates thinking about the criteria for evaluation. Interaction with it might demand other decisions that also stimulate creative thought. Thinking about the grammar being employed may itself stimulate ‘set breaking’ or lateral thinking and cause the designer to re-define the rules being employed.

7. Future directions and challenges

The four main proposals from the designers can be put forward as four directions for future research into the use of shape grammars to support creative design. We therefore briefly present them as four topics to challenge researchers working in the area of creative design support.

The use of a 3D shape grammar is not technically difficult. The issue, raised by designer C, is whether or not this would add creative stimulus. If the ‘loose fit’ rules idea is important, then perhaps a 3D version might be seen as regressive in that it defines more detail. However, a 3D shape grammar could still be defined to deal only with core issues.

The use of an additional grammar of colours could be most interesting. Colour grammars have been created before [14]. The new direction would be to experiment with them as an additional element in the support system. It was proposed that colour grammars and 3D grammars might be integrated. How would this integration work?

The use of ‘loose fit’ rules that can generate, for example, the spine of a building, do not implicate the support system itself. The implication is for the grammars defined and used. This needs to be investigated in the context of specific design tasks so that examples that differentiate the ‘core’ can be clearly defined.

The organic growth of rules is another question again. Two approaches seem most interesting. The first is to add meta-rules that modify the base shape grammar in geometric ways. This could be done using the approach of Ohsuga and Yamauchi [15]. The other approach could be to apply genetic algorithms [16] to the rules, rather than to the objects, of design.

The issue of the handling of emergence in the context of
shape grammars was discussed more than once but, at this point, no direction was identified from the thinking of the designers.

From our small exploration we conclude that the use of shape grammars to expand the strategies available to a designer and to provide computational support for exploring the implications of employing given sets of design rules is promising. Moreover, we have already identified a number of directions in which the research should be taken further.

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