INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 18 - 21, 2004.

DESIGN 2004

IMPROVING PRODUCT DESIGN VIA A SHAPE GRAMMAR TOOL

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Keywords: shape grammars, product design

1. Introduction

Product design is a creative discipline where design teams have the goal of developing successful products that fit consumer requirements. These requirements are not only functional but also psychological. Products communicate to consumers a particular style, feeling and understanding through their texture, colour and material, but mainly through their form. Designers use a limited range of styling features in order to communicate a particular style through form [Podehl 2002]. It is difficult, however, to harmonize all the features in a unique design because a small change in the composition of the form can lead to an alteration in the perception of the product.

It is a current trend for consumers to be constantly update and change their possessions. Therefore, in order to keep up with their customers companies need to continually produce new products or redesign their current products. As a consequence of this development it has become necessary to reduce the length of the production process, including the design stage. This pressure to speedily generate new or revised products along with other pressures such as accelerating developments in technology which mean that new specialists are required to be incorporated into the design process. This in turn has resulted in the need for designers to work in wider design teams. In order for these design teams to be successful, it is essential that there is clear communication of ideas between different members of the team. This means that it is important for individual designers to be able to reveal the intentions behind their proposals as well as the form itself.

During the early design stages of developing a product such as a motor vehicle, the roles of generation and perception are fundamental. The designers produce many ideas, moving from one to another very quickly without thinking in depth and only considering a few designs as potential concepts. Sketching using pen or pencil and paper is the most popular way to produce ideas since it is very flexible and no preparation is needed. Designers gain an understanding of proportions and forms through the drawings and use ambiguity in the sketches to gain new ideas for further designs. These drawings also give them a means of communicating their ideas to others; however, they do not provide any quantitative information about their designs, and they provide little insight regarding the designer's intention.

On the other hand, CAD techniques create accurate digital models of design concepts that can facilitate certain types of precise evaluation, for example finite element analysis, as well as judgement of overall form, colour and finish; however, they do not provide flexibility to allow designers freedom to thoroughly explore a design space.

Shape grammars [Stiny 1980] have the potential to bridge the gap between traditional sketching techniques and modern computational methods of design, allowing a designer the freedom to explore a design space, whilst also providing quantitative information about the designs produced [Brown et al. 1996].

This paper presents a new approach to how shape grammars could be developed into a useful tool for product design, assisting designers to explore and develop their ideas, whilst providing a means of communicating the intention of the designer as well as the form of products in a quantitative way. The particular focus for our studies has been car design.

2. Introduction to Shape Grammars

Shape grammars have the power to create designs through rules, offering variations on a theme and making the design process comprehensible. Since their conception more than thirty years ago, shape grammars have found applications in a wide range of fields. Initially they were used to analyse paintings and decorative arts [Stiny and Gips 1972]. Since then they have been most commonly applied in design where they have been used as a tool for analyzing and capturing the essence of existing designs as well as synthesizing new ones.

The potential for applying shape grammars to generate whole product designs has been explored in a few areas such as consumer products [Agarwal and Cagan 1998]. There has been little discussion of their role in design communication, although the advantages of having an explicit generative representation of designs in a particular style using a shape grammar has been discussed [McCormack et al. 2004].

Shape grammars are a production systems that generate designs according to sets of shape rules. These rules are of the form a → b, where a and b are both labelled shapes, and are applicable to a shape S if there is a transformation that imbeds a onto S. A shape rule is applied by replacing the transformed shape a in S with the similarly transformed shape b. Shape grammars provide a basis for new computer based generative tools that will allow designers to synthesize designs and explore design spaces.

A child playing with *Lego* plastic building blocks provides a simple example of how it is possible to construct complex two or three-dimensional forms merely from simple elements, and the smaller the size of the elements compared with the overall size of the constructed form, the more detailed the construction can be. Similarly, shape grammars have the ability to construct complex shapes from simple shape elements.

The shape grammar method outline below assists designers by allowing them to experiment quickly with new forms and features for products. This method uses line elements to construct segments of curve or straight line, which are then joined together to represent the form of a product. Shape rules are fundamental to establish the relationship between segments as well as between line elements. The rules are addition rules where a new line is attached, at an angle, to a previously existing labelled line of the same length, Figure 1. The rules are applicable if a labelled line is found in the design, and it is applied a predetermined number of times.

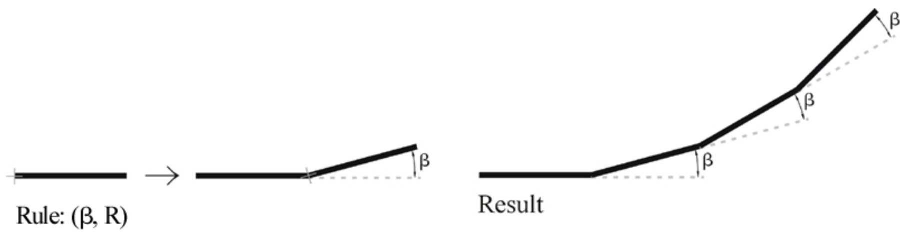

Figure 1. A shape rule repeated four times

The lines to which rules are applied are considered to be of unit length. Generally, the rules are stipulated by two parametric values - the angle of rotation, β, and the number of rule repetitions, R. Repeated application of a single rule results in a circle but designers require convex and concave curves with different rising curvatures and lengths in order to obtain a form through which to communicate a specific style and a desirable appearance. To generate more varied curves it is necessary to apply more than one rule. For example in Figure 2, three curves are constructed by applying two different rules. The second rule follows on immediately from the first and there is no distinction between the segments of curve created by them. In order to create a distinction the curve segments are labelled by colour according to the rule that created them. Each curve is associated with a list of parameters that define the segments that compose it, for example in Figure 2a) the curve is composed of a curve segment with parameters $\beta = 6^o$, R = 10 and in Figure 3b) the curve is composed of a curve segment with parameters $\beta = 2^o$, R = 20. In Figure 2c) an additional parameter, Pd, is introduced in order to create a tangential discontinuity between the two segments. The higher the value of Pd, the larger the discontinuity.

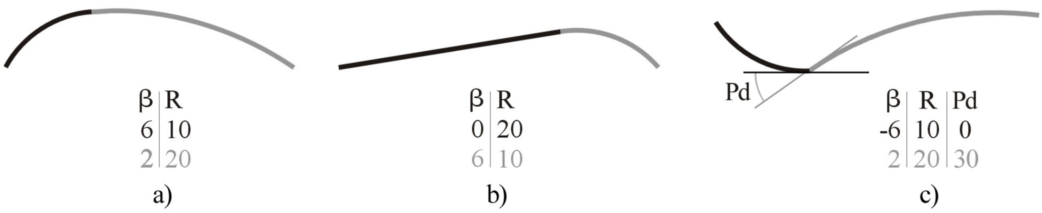

Figure 2. Generation of curves via application of two rules

By applying a variety of rules in sequence, it is possible to generate contours of different products. For example in Figure 3, a sequence of up to five rules is used to define the contours of a wide range of drinking glasses. An additional rule is used to reflect the resultant contour to form the shape of a glass.

Figure 3. Some glass designs generated via atomic rules

Designs generated via the shape grammar method outlined above are associated with a list of parameters that define the curves that constitute the design. Modification of parameters results in corresponding modifications in the design. Designers can systematically explore a design space by systematically modifying parameters. This is effective both for exploring the full range of possible designs, e.g. Figure 3a), as well as small local modifications, e.g. Figure 3b). In the former parameters are allowed wide variation while in the later parameters are highly constrained.

3. Design Generation via a Shape Grammar Tool

We will now turn to an examination of the shape grammar tool in defining basic car body profiles. Initially concepts are generated randomly by computer, through random selection of parameter values although some constraints are applied by the designer in order to ensure that the curves generated are within the design space for car profiles. The parameters used are angle of rotation, number of repetitions, and tangential discontinuity, denoted by β, R and Pd respectively. In Figure 4 three initial concepts are shown that were randomly generated by the shape grammar program. In the first, the segments of curve that compose the car profile are labelled with respect to the number of the rule that generated them. The graph shows how the parameters of these rules are constrained. Note that for some rules Pd is highly constrained. This is to ensure that the initial concepts have discontinuities in places that are common in car profiles. These constraints can be altered according to the designer's intention.

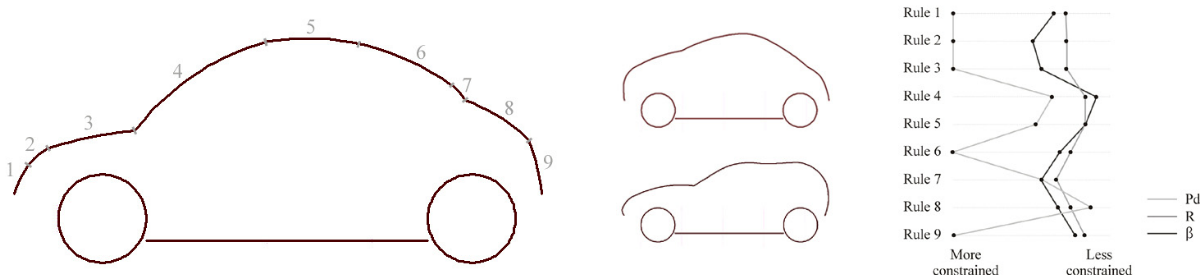

Figure 4. Initial stage of car profile generation

Random generation of concepts by computer allows the fast generation of a large range of design concepts for the design team to explore, some of which may otherwise have been overlooked. When a feature is generated that captures the intention of the designer that feature can be preserved by restricting the freedom of the parameters of the curves that define it. If required, the feature can also be modified systematically by applying incremental changes to the parameter values. In Figure 5 the designer is preserving two features that have been randomly generated by the computer, these are the front and rear ends of the car. In order to ensure that the intentions of these features are kept in subsequent designs the designer restricts the freedom of the parameters of the rules that define these features. Comparison of graphs reveals that the parameters of rules 1-3 and 7-9 in Figure 5 are more constrained than those in Figure 4. As a result of this, the features of the front and rear of the car remain intact in subsequent designs generated by the computer.

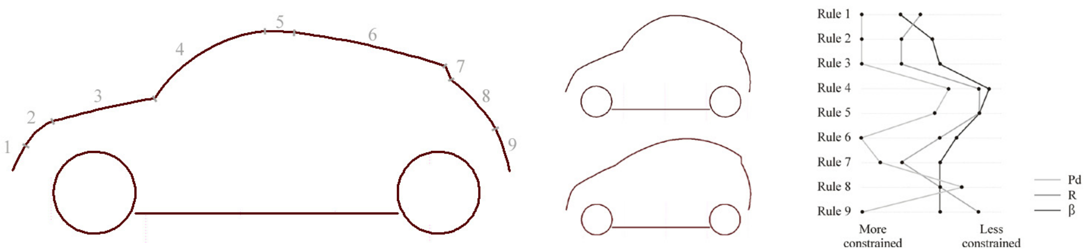

Figure 5. An intermediate stage of car profile generation

The process of random generation continues, but with added constraint on specific features. As more features are decided upon, constraints are added to more rules, until all concepts generated are within the intentions of the design team, as seen in Figure 6. The less freedom allowed to the parameters, the more defined the concept is. Notice the increasing levels of constraint between figures 4, 5 and 6.

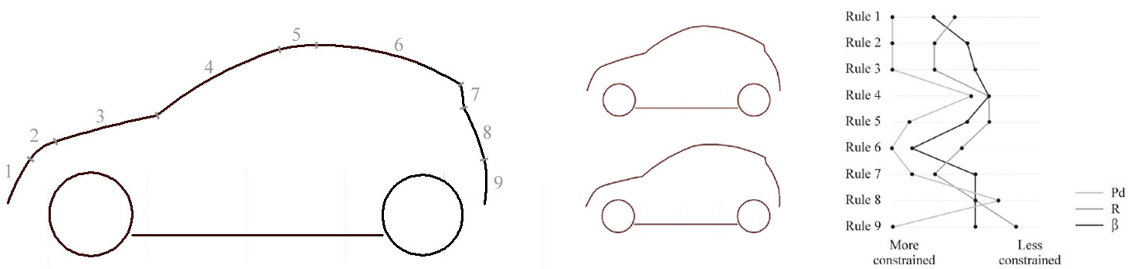

Figure 6. Concepts of a car profile

4. Design Communication via a Shape Grammar Tool

In the shape grammar method outlined above an individual designer starts by searching through random freeform curves. Via the opinions and suggestions of other participants the curves become more and more constrained, and as such reflect the designers intent, i.e. specific features that a designer considers a vital part of the design are more constrained whereas less important feature are allowed more freedom. The extent to which the curves are constrained is manifest in the constraint graph that accompany a design.

Designs generated in this manner can be communicated quantitatively within design teams in terms of the parameters that define the curves that the design is composed of, and an associated constraints graph. Because of the way the curves are constructed these parameters are related to their intrinsic properties and as such describe the shape of the curve regardless of its position in space.

If it is necessary to make modifications to a design for example in order to meet some functional or marketing requirements then these can be made so that none of the parameters of the design exceed their constraints - the design will remain consistent with the intention of the team.

For example, in Figure 7 a modification has been made to the larger concept from Figure 6 (the original concept is highlighted in grey). It was decided that the car would need additional storage space and so the length of the body and the angle of the back have been altered. The alterations made were within the constraints on the parameters of the design as such it is still considered to be consistent with the intention of the designer.

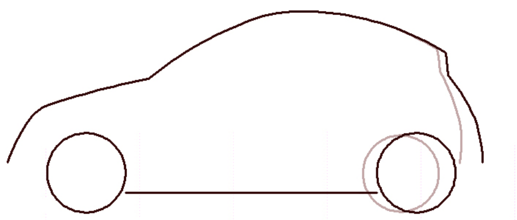

Figure 7. An example of a design modification

Similarly, if a range of concepts are to be designed in the same style, for example in order to preserve brand identity, then this method can be applied.

5. Conclusions

The shape grammar tool presented here is still in development, but early feedback suggests that it could make a valuable contribution to modern design practices. The tool assists creativity by generating variety within designer-imposed constraints and intentions. It has been shown that the tool can aid a design team in the process of exploring a design space by randomly generating a range of concepts. Specific features of concepts randomly generated by the program can be captured by applying constraints to the parameters of the curves that define those features. In the next stage of the generation process, features that are constrained remain intact. The tool allows the encoding of existing forms and the subsequent generation of new but related forms via the manipulation of parameters. Companies might use the tool, for example, to assist the generation of a family likeness across a product range and, where products are mature and stable, it enables a differentiation in form from those of their competitors. The tool has also been shown as a means of communicating a concept, not only the form of the concept but also the intention of the designer who created it. This offers the possibility of the tool being used to provide valuable support to modern collaborative design working in that it supports 'interdisciplinarity' [Garner and Mann 2002]. Manipulation of parameter constraints is straightforward thus facilitating the involvement in concept design of a variety of experts (e.g. marketing, production) and non-experts (e.g. users) potentially leading to reductions in lead time, improvements to product quality and/or enhanced consumer satisfaction. The examples discussed here use car design as a context but in principle, the shape grammar tool could be applied in a variety of product design fields.

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