SKETCHING IN DESIGN:
FORMALISING A TRANSFORMATIONAL PROCESS

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Abstract. The process of sketching can support the sort of transformational thinking that is seen as essential for the interpretation and reinterpretation of ideas in innovative design (Suwa 2003). In this paper, the initial outputs and findings of an ongoing project called Design Synthesis and Shape Generation are described based on experimental investigations of the mechanics of sketching from practicing architects and industrial designers as they responded to a series of conceptual design tasks. Preliminary analyses of the experimental data suggest that the interactions of designers with their sketches can be formalised according to a finite number of generalised shape rules. These rules formalise the transformations and reinterpretation of shapes for example through deformation or restructuring.

Keywords. Sketching; Exploration; Computer supported design; Shape rule

1. Introduction

Creative design is an activity that involves exploration of design alternatives (Cross 1997), but the nature of the exploration can vary. For example, designers interested in the visual composition of objects may explore designs according to guiding principles of composition (Stiny 2006). Pictorial representations of designs, particularly sketches, offer relevant support to design exploration through their impulsive generation and visual feedback (Goel 1995). Knowledge of design exploration with sketching might inspire new types of computer support which is not available in conventional CAD systems (Woodbury and Burrow 2006).

The research described in this paper results from the project 'Design Synthesis and Shape Generation (DSSG)'. The project explores how designers generate shapes and how shape computation systems might support the creativity of designers. If successful, a new computation of shapes consistent with observations of design practice will stimulate new ways of design thinking and provide mechanisms to enable shape exploration. This paper reports on experimental investigations of the sketching of practicing architects and industrial designers. It reveals how the making of sketches assists the process of shape transformation and reinterpretation, and thus informs future computer based design systems. In addition, this paper briefly discusses future research regarding a customisable selection of design outcomes from shape grammar systems.

2. Formal Shape Generation

Understanding exploration in design can be achieved via an examination of shape transformation in sketches and the perception of designers. Exploration, interpretation, and transformation of shape can be represented by shape rules (Stiny and Gips 1972) in a grammar which provides a connection between cognitive processes and formal exploration of designs. Shape grammars (Stiny 1980b) are production systems that generate designs according to sets of shape rules. Since their conception more than thirty years ago, shape grammar research has revealed many applications in a wide range of fields. For example, in the 1970s, shape grammars were used to analyse paintings and decorative arts (Stiny and Gips 1972), and more recently they have been applied in design as a tool for analysing and capturing the essence of existing designs as well as synthesising new ones. Moreover, the potential for applying shape grammars to generate designs in a particular style has been explored in areas such as architecture (Koning and Eizenberg 1981), and the advantages of having an explicit generative representation of designs in a particular car brand using shape grammars (McCormack, Cagan *et al.* 2004) has been discussed.

While the concept of shape grammars provides a technical focus for our research, shape rules offer an ideal foundation for capturing shape transformations in design. They may very well inform future generations of shape computation systems for design exploration. In this paper, shape rules are used to formalise the shape transformations commonly used by designers during sketching. A number of professional designers were observed whilst sketching a series of conceptual designs, and their manipulations of the sketches were encoded via shape rules.

3. Sketch Observation

Previous studies into the sketching process of designers have been concerned with design reasoning (Goldschmidt 1994) via interviews (Cross 2003) and case studies (Candy and Edmonds 1996). Observation and recording of designers while conducting design tasks (Goel 1995; Suwa and Tversky 1997), focusing on ‘seeing’ rather than ‘moving’ (Stiny 2006), has become popular. Thus, our approach focuses on exploring the mechanics of sketching based on observation and recording during set tasks.

3.1. EXPERIMENTAL METHOD

The aim of this experiment, which involved six architects and eight industrial designers, was to identify shape rules used in shape transformation. Five of the industrial designers had been practicing for more than six years and the other three had between two and four years of professional experience. Of the architects, two participants had more than four years of professional experience, two participants had between two and four years of professional experience, and the other two participants were architectural researchers. The participants responded to a series of conceptual design tasks and produced an output of nearly 300 sketches. This data was supplemented by retrospective interview where the designers were questioned concerning their interpretation and transformation of shapes. During the sketching process participants’ activities were recorded via (i) a video camera for voice and hand gestures, (ii) a device called DigiMemo, a digital tablet which provides a native pencil-and-paper environment and (iii) software for video screen capture which facilitated the recording of sketch stroke sequences. These two video clips – from video camera and video screen capture – were synchronised in order to accurately interpret participants’ movements whilst sketching (Figure 1).

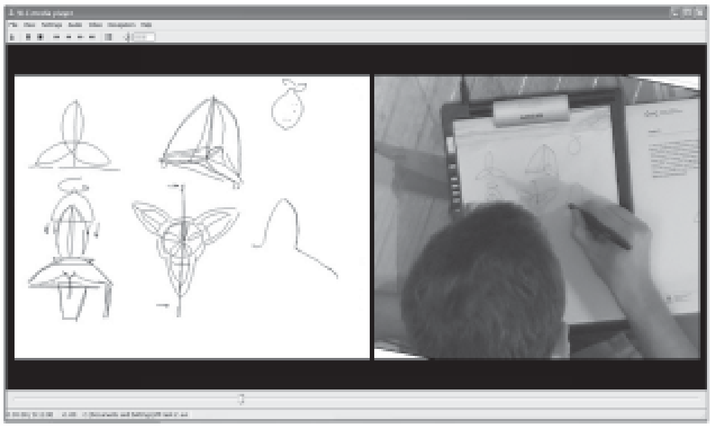


Figure 1. Synchronised videos. Left: Video screen capture of sketch stroke sequences via DigiMemo. Right: Video of hand gestures via a camera plus audio of voices.

In this experiment, shape transformations were analysed using three criteria – Decomposition, Reinterpretation, and Design family – which were applied to three tasks consisting of short design briefs and initial design stimuli.

1. Decomposition: This is a strategy applied in shape analysis and exploration (Krstic 2005) and exploits cognitive perceptual mechanisms. (Singh, Seyranian *et al*. 1999).
2. Reinterpretation: Studies have revealed that interpretations of drawing can lead to different strategies in their reproduction (van Sommers 1984). Suwa and Tversky (1997) indicate that new design ideas are often a consequence of reorganising and reinterpreting parts or elements in design representations.
3. Design family: Previous studies (e.g. Goldschmidt 1994) have suggested that designers rarely produce single concepts in creative design; instead, they often generate sketches in successive spells creating close groupings of ideas or 'families' of design concepts. In this research a 'design family' is a 'group of vertically transformed shapes' (Prats and Garner 2006b).

The first task, corresponding to the criterion *decomposition*, used two abstract shapes (Figure 2) adopted from the work of van Sommers (1984). Two groups of subjects were asked to begin by copying the given shapes which were presented as logos and develop them according to a given design brief. The subjects in groups A and B were given different meanings of the logos depicted. The aim of this study was to see if the mechanisms used to transform shapes are related to interpretation and segmentation. Two task descriptions, based on two different interpretations of the designs, were used: (Figure 2a) crossed swords or two mice sniffing, and (Figure 2b) cocktail glass with cherry or person with telescope.

Figure 2. Two abstract logos.

The second task, concerning *reinterpretation*, provided another abstract shape – a triquetra (Figure 3). Subjects were introduced to this as a concept design for a lemon squeezer (to industrial designers), and as a conceptual building design (to architects). The analysis here sought to examine to what extent meaning and interpretation of an initial shape leads to different shape decompositions and shape transformations.

Figure 3. Triquetra as a lemon squeezer (industrial designers), and as a building (architects)

The third task, concerning *design family*, provided a more explicit shape (Figure 4). It intentionally offered less freedom in interpretation than the second task. The initial shapes were defined as a concept for a kettle design (for industrial designers) and as a reference to a new building (for architects).

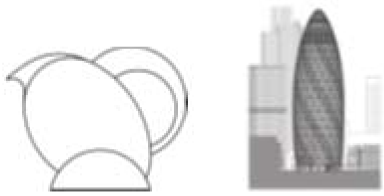
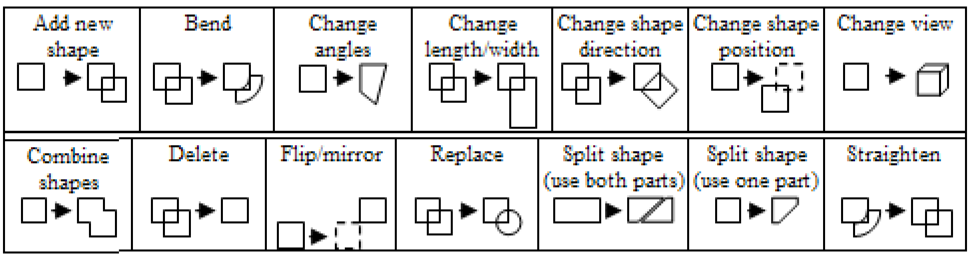


Figure 4. Left: Kettle for industrial designers. Right: St Mary Axe Building for architects.

3.2. SHAPE RULES FROM IDENTIFIED SHAPE TRANSFORMATIONS

The series of sketches for each task per participant are here summarised and analysed based on the above three criteria. The examination of how designers decompose and reinterpret designs and generate design families assisted us to better understand the kind of shape transformations which designers use in shape exploration. As a result, 14 shape rules were identified (TABLE 1). For example, the *bend* rule denotes 'giving curvature to a shape' while the *straighten* rule indicates the opposite meaning; the *change angles* rule indicates 'changing an interior angle of a shape'; and the *combine shapes* rule means 'adding and merging a new shape to an existing shape' while the *add* rule adds a new shape without merging them. This list of rules is not by any means complete; however, these rules were sufficient to capture participants' shape transformations.

TABLE 1. Shape rules identified



Note that these rules express shape transformations in an abstract way and they are not meant to represent the exact transformation of a shape. Indeed these shape rules can be modified into more specific shape rules, for example, the *bend* rule can produce different types of curvature to a shape captured in shape rules (e.g. soft radius, sharp radius, a curve with rising curvature and so on).

4. Classification of the Identified Shape Rules

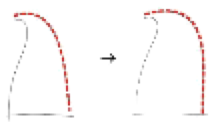
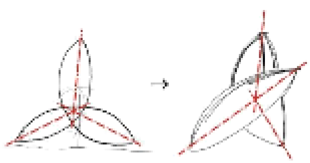
The results suggest that certain shape rules in TABLE 1 operate on various levels – perhaps due to the similarities among shape rules. A more general set of shape rules is shown in TABLE 2. Note that the *outline transformation* rule denotes 'changing outline shape including stretching and contour manipulation' while the *structure transformation* rule indicates 'changing shape position including rotation, translation and symmetry'.

TABLE 2. More general shape rules identified

Add	Cut	Change view	Delete	Outline transformation	Replace	Structure transformation

Shape rules at the higher (general) level could contain a number of lower-order rules. For example, the *outline transformation* rule could comprise a number of similar shape rules, i.e. *Bend*, *Straighten*, *Change length/width* and *Change angles*, while the *structure transformation* rule could include *flip/mirror*, *change shape direction*, *split shape (use both parts)*, and *change shape position* rules. TABLE 3 shows the possible multi-level of shape rules with respective sketch examples.

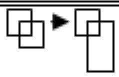
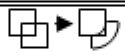
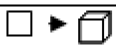
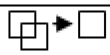
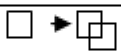
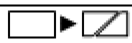
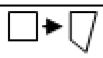
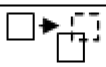
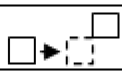
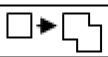
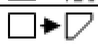
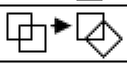
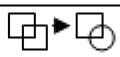
TABLE 3. Identified shape rules. Bolded (red) parts are criteria for the identification.

	Shape Rules	Example (general shape rules)	Example (detailed shape rules)
Outline Transformation	*Bend*		
	Straighten		
	Change length/width		
	Change angles		
Structure Transformation	*Flip/Mirror*		
	Change shape direction		
	Split shape (use both parts)		
	Change shape position		

In these studies some rules were used significantly more than others, e.g. *change shape length/width*, *view*, *add new shape*, and *straighten* (TABLE 4) were used 2 to 10 times more than others. However, the result indicates that the preferences for shape rules by designers are generally similar and it may be possible to identify consistent priorities in shape rule use. An analysis of the combination and/or sequence of the identified shape rules, which has not been done in our experiment, could provide further identifications of priorities. This result, however, may only be applicable to conceptual designs due to the nature of the sketches collected.

A combination of the above two results, i.e. a hierarchical classification and the use of shape rules offers the possibility of a customisable selection of design outcomes that are not available in conventional shape grammars. For example, consider that shapes S_1 and S_2 are composed of a number of shape rules $\{S_1 \mid R_a, R_b, R_a, R_d\}$ and $\{S_2 \mid R_a, R_c, R_b\}$ with respective sequences. If a designer considers that the shape rule R_a is most important to cluster an object, then the shape S_1 and S_2 could be classified in the same cluster. In all other cases, they would be classified in a different cluster. This can frequently happen when a designer and user are different. The customisable selection via different criteria might not only improve shape grammar system performance but could also provide more meaningful outcomes to designers. It is suggested that this can be done by parameterisation of shape rules adapted from a vagueness representation method (Lim, Lee *et al.* 2001) which parameterises vague geometric information to provide a fully customisable selection of geometric information.

TABLE 4. The use of the shape rules in architectural design. The numbers in each task indicate the number of uses and the number of participants who used (in parentheses).

Shape Rules[Rank]	Task 1	Task 2	Task 3	Shape Rules(Rank)	Task 1	Task 2	Task 3
[1] 	35 (6)	9 (4)	11 (3)	[8] 	9 (2)	0 (0)	2 (2)
[2] 	0 (0)	22 (6)	21 (5)	[9] 	10 (2)	1 (1)	0 (0)
[3] 	18 (4)	8 (3)	7 (3)	[10] 	0 (0)	0 (0)	8 (2)
[4] 	22 (6)	0 (0)	2 (2)	[11] 	5 (2)	1 (1)	0 (0)
[5] 	13 (5)	0 (0)	1 (1)	[12] 	3 (2)	2 (1)	0 (0)
[6] 	5 (3)	4 (3)	0 (0)	[13] 	0 (0)	0 (0)	1(1)
[7] 	10 (5)	0 (0)	0 (0)	[14] 	0 (0)	0 (0)	0 (0)

5. Conclusion

Preliminary analyses of the experimental data produced a number of general/detailed shape rules. Although the rules express shape transformations in an abstract way without representing the exact transformation of a shape, the analysis suggests that the interactions of designers with their sketches can be represented by a finite number of generalised shape rules, which formalise the transformations and reinterpretation of shapes, e.g. through deformation or restructuring. These results reflect the work of Stiny (2006) who categorised shape transformations using generalised schema within the framework of shape grammars. On the other hand, the analysis reveals a possibility of a customisable selection of design outcomes which might not only improve shape grammar system performance but could also provide more meaningful outcomes to designers. Future work is concerned with exploring (1) how the defined shape rules can be further detailed in a hierarchical manner, (2) how Stiny's theoretical developments regarding shape representation and manipulation reflects practice, (3) how the idea of customisable selection of design outcomes can be further developed and formalised, and also (4) how these results can inform the development of computational tools for conceptual design.

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