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Observations on ambiguity in design sketches

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Abstract
Physical and visual qualities of products, such as shape, colour, material and texture, are common outputs of an industrial designer's work. Among these, shape is perhaps the most influential characteristic in the user's perception of products. It is not surprising, therefore, that designers often focus on shape early in the process of product design. While various forms of 2D and 3D representations might be exploited, sketching forms a key technique in the generation and development of product shape. It allows ideas of shape to externalised and communicated. Perhaps more importantly, sketching can operate to assist individuals in the creative generation and development of shape. Central to this function is the capacity for sketches to display ambiguity. Design sketches of shape and form are a particularly interesting category of visual representations because perception and interpretation are bound together with creation and evaluation in the shape sketching process.

This paper reviews the exploitation of ambiguity in design sketches. It also outlines a recent study at the Open University of the sketches of industrial designers. It suggests ambiguity has a vital role to play in the transformation of ideas and reveals how sketches present an ideal form of representational technique that is well matched to the cognitive processes of creative designing.

1. Introduction

While there is clear evidence of inquiries into drawing since the Renaissance drawing research is a remarkably young domain. Even two decades ago the function and value of sketching in designing and the important role of ambiguity in drawing was largely a topic of speculation. In the intervening years we have seen illumination of the nature of graphic ambiguity, its relationship with structures and processes of the mind and its important value in the creative process. We have seen the application of a wide range of qualitative and quantitative research tools brought to bear on the subject and these have done much to consolidate understanding founded on more anecdotal evidence.

The 1990s marked a new rigour in drawing research. Authors such as Fish (1996) highlighted the existance of a relationship between sketch imagery and a primitive human

survival mechanism. He proposed that indeterminacy or vagueness in sketches exploits a capability of the human brain to make sense of incomplete information. This mental capacity, he argued, is a cultural adaptation of a visual mechanism which would have allowed our ancient ancestors to make sense of and respond to confusing or incomplete stimuli from immediately present objects and events. In his thesis he goes on to propose that sketches are cultural inventions which can mimic aspects of such stimuli in order to allow us (artists and designers) to exploit this mental capability for the different purpose of imagining objects which do not yet exist. Thus, he linked the physical mark-making act to cognitive mechanisms of the mind in his proposition that ambiguity may have a positive and deliberate function in some types of drawings - particularly sketches. Sketching not only facilitates a recording or reporting of the maker's perception but that it is also intrinsically bound up with qualitative concerns of perception itself. That is to say, sketching may be viewed as having a direct relationship with both a quality of seeing and a process of 'selecting'. For those involved in a visually creative subject such as design this is significant. In 1997 Bruce Archer noted that:

> All acts of drawing, and especially all acts of sketch drawing, entail a great deal of selection of features for inclusion and features for omission, and of features for direct representation or features for transmutation. All of this is achieved through rapid and sustained mental cycling between external reality (or imagined reality), cognitive model and external representation. (Archer 1997 p40)

This paper is concerned with an examination of this seeing and selecting process - and particularly the role of sketch images in design.

2. Shape creation in design

Designers need to devise innovative products if they are to succeed in competitive markets. More than ever before they need to be creative. Creativity is not only concerned with the introduction of something new, but something valuable and unexpected (Gero 1996, Boden 1995). For designers, creativity includes the generation of ideas, alternatives and possibilities. The search for improved design methodologies has been motivated by the increasing complexity of design projects involving teams of great diversity and a growing pressure for computer based working. However, most models of the design process acknowledge the iterative nature of design thinking and appear to value the symbiotic relationship between formulating a problem and finding a resolution.

The creation of new shapes is central to the work of many industrial designers. Research on emergence has taken place in various fields and it has informed our understanding of shape generation in design. It has become a key theme in design research, particularly where computer based representations are involved. Some researchers have attempted to classify different types of emergence. For example, Soufi and Edmonds (1996) identify

emergent shapes associated with *interpretative* and *transformational* processes. Fig. 1 shows some examples of both processes. Fig. 1a shows a simple design. Fig. 1b shows two examples of emergent shapes, in thick lines, obtained by interpretative processes where the emergent shape is embedded in the design. Fig.1c shows two examples of emergent shapes obtained by transformational processes, where the emergent shape is visually suggested by the boundaries of the design but it is not graphically represented.

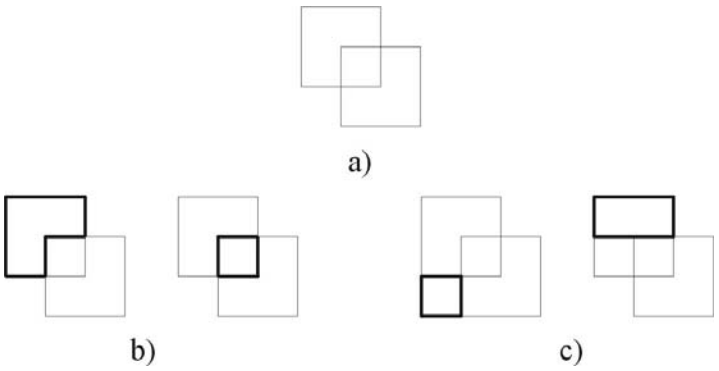


Figure 1

Similar distinctions of emergent shapes have been suggested by Tan (1990) and Gero and Yan (1994). More recently, Gross (2001) described three types of visual emergence, two of which are based on the interpretative and transformational processes. His third type of emergence, which is similar to the interpretative process, occurs when two or more designs are regrouped in a new configuration. This is illustrated in Fig. 2 which shows two different visual configurations of two neighbouring designs. The first figure shows, in think lines, the intended grouping, whereas the second figure shows an emergent grouping provoked by the proximity of both designs.

Figure 2

Clearly personal interpretations and perceptions play a part in seeing and making sense of such shapes. Boden (1996, in Knight 2003a), proposed a line of demarcation for researchers between *intelligible emergence*, which can be formalized and therefore understood, and *unintelligible emergence*, which probably cannot be understood, even with formalizations.

Many factors guide the way people perceive shapes. The Gestalt psychologists considered perceptual grouping into whole structures to be the basis of perception. They defined a number of principles and went on to demonstrate how these governed people's preferences when grouping of elements was tested. The law of good continuity, the law of similarity and the law of proximity are some of the perceptual laws proposed by these early psychologists. Nonetheless, there are other factors which may explain the individual differences in perception such as intentions, goals and motivations. More recent researchers have suggested that visual perception involves the decomposition of shapes into elements (or parts). There is evidence from psychological studies that the human visual system uses part-based representations for tasks such as object recognition. Hoffman and Richards (1984) argue that parts are useful because one never sees an entire shape in one glance. Furthermore, parts are also useful to interpret incomplete known shapes and non-rigid objects, for example, representations of the human hand. Bloch (1995) suggests that shapes may first be perceived as wholes, and if these shapes require further processing, then individual elements may become salient. Biederman (1987) argues that in order to describe objects, people tend to decompose perceived shapes into simple volumetric elements. Decomposition of complex shapes serves as a method to analyse and recognize them since the elements may be simpler than the whole. Recognizable shapes tend to be decomposed similarly, mostly guided by their functions. Well known objects such as kettles are usually decomposed into similar elements, for example, body, spout, lid and handle. Abstract shapes, such as the inkblots on Rorschach cards, give rise to much more personal and ideosyncratic decomposition elements and here there is much more variety in interpretations.

3. Thinking, sketching and shape creation

Many researchers have investigated the role of visual representations in the thinking processes of design. Schon and Wiggins (1992), for example, have suggested that the design process is a reflective conversation with representations whose basic structure of 'seeing-moving-seeing' is an interaction of designing and discovering. 'Moving' here refers to the decisions made by designers about their interpretations of the visual representations. Sketches provide an excellent basis for reflective conversation since they enable emergence of unexpected shapes. The use of sketching and sketches can be found across different design disciplines and while the style of sketches may differ the aims and objectives of using sketching are surprisingly similar (Garner, 1990). However, some studies of cognitive processes in design (Akin, 2001), and shape cognition (Wang, 1998) have identified differences between design disciplines. Wang's studies, for example, found that shape perception tendencies between architects, industrial designers and graphic designers are different. Here architects revealed an ability for identifying emergent shapes associated with transformational processes, whereas industrial designers had a superior ability for interpreting volumetric sub-shapes from two dimensional

representations. Akin (2001) suggests that some designers (in this case architects) continue to search for alternatives solutions even when they have already developed satisfactory ones.

Why do designers use imagery to explore new designs? Kosslyn (1990) argues that one of the purposes of imagery is anticipating changes or transformations to physical objects. Finke & Shepard's work suggests that there is a cognitive mechanism that integrates mental processes with the physical and graphic exploration of design conjecture. They suggest that designers use imagery to provoke and stimulate perception during design exploration (Finke and Shepard, 1986) and some images made for this purpose might consist of very few graphic actions (Garner 2001). In the design process different types of sketches can be identified. Ferguson (1992) outlines three types of sketches: (i) thinking sketches, which are produced to focus and guide non-verbal thinking, (ii) prescriptive sketches, which are produced to direct others in subsequent work and (iii) talking sketches, which are produced spontaneously during discussions with others involved in the task.

The previous section proposed that design was a process of decomposing shapes into elements but how might designers achieve this? In the early stages of a design process, visual representations, particularly sketches, tend to be ambiguous and vague and this promotes alternatives in the options for decomposition. How the elements are perceptually grouped and how unintended shapes emerge during the design process appears to be crucial in understanding the thinking process of design. One of the factors that appears to guide perceptual decomposition of shape is the influence of past experiences (Arnheim, 1974). Goldschmidt (1994) proposes that certain features can be found in graphic representations which she terms 'clues'. These act to relate present perceptions to past experiences. She says '*clues… trigger some relevant information that is stored in the memory but that is otherwise difficult or impossible to tap'*. Arnheim provides a useful example, shown as Fig. 3.

The image may be spontaneously interpreted as a triangle attached to a line.

Figure 3

But if the shape is presented in the sequence shown in figure 4, it will probably be interpreted as a corner of a square about to disappear behind a horizontal line. Thus the final shape in Fig. 4 may be perceived differently to the shape in Fig. 3. Arnheim points out that the influence of memory increases when strong personal factors are involved (Arnheim 1974).

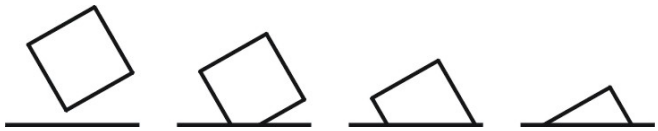


Figure 4

Far from being a limiting factor in design this link between memory and the interpretation of graphic images may actually assist creative thinking. Goel (1995) suggests that two types of transformations can be identified in design problem solving: *lateral* transformations and *vertical* transformations. Lateral transformations concern the manipulation of one idea into a different idea while vertical transformations clarify or add detail to an idea which remains broadly the same. Lateral transformations are generated as a consequence of new interpretations or the integration of new elements. Vertical transformations generate a range of similar ideas. They are developmental and occur mainly when designers see an idea as a potential candidate. Goel suggests that freehand sketches provide a good foundation for lateral transformations since sketches can exploit the ambiguity necessary for multiple interpretations.

Van Sommers (1984) collected a large number of drawings recorded on videotape with the aim of finding common features. His studies reveal that drawings are often segmented into elements. Van Sommers argues that drawing is organized in a layered system in which any action can be simultaneously structured or constrained at different levels. One of his studies, concerning the perceptual segmentation based on meaning, was accomplished by having two groups of subjects copying designs to which different meanings were attributed. The design shown in Fig. 5a, was presented to one group of subjects with the title ‘crossed swords’ and to the other group with the title ‘two mice sniffing’. The results were that the two groups copied the same design in different stroke sequences. All the people in the first group represented the design by two crossing lines, as shown in the left of Fig. 5b. In the second group, the majority of people represented the design by two rotated Vs meeting at their vertices, as shown in the right of Fig. 5b.

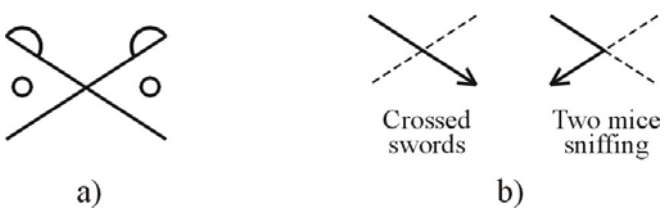


Figure 5

The study carried out by Van Sommers leads us to believe that strokes produced in a drawing are related to the perception of its elements. However, what about the preferred stroke sequence in shapes without meaning? In another study carried out by Van Sommers, subjects were asked to copy different designs from memory. The subjects drew a number of designs after a five-second inspection. Fig. 6a shows one of the designs used in the study, referred to here as a *triquetra*. In this particular example, it is interesting to see how a shape without a given meaning is interpreted differently between subjects. As a result several spontaneous stroke sequences were obtained. The subjects drew the triquetra using continuous lines, by a composition of arcs, or by a composition of petals among other drawing sequences. In this particular example, since the design does not have a given meaning, the decomposition of the shape, and its re-creation as part of the study, is driven by geometric factors rather than semantic factors.

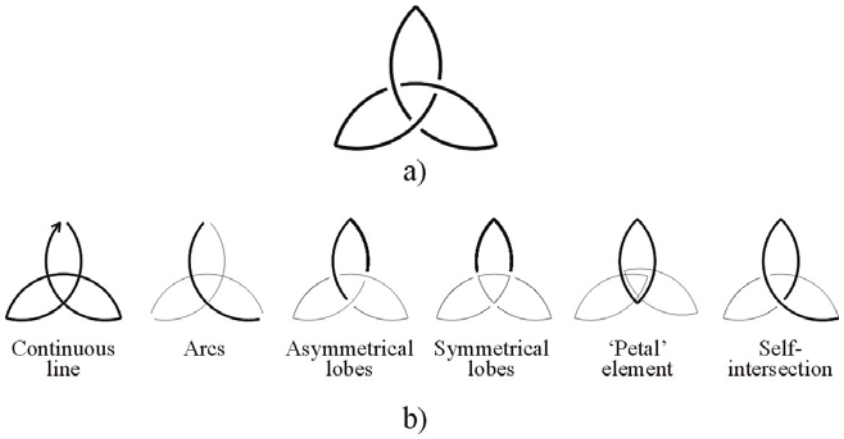


Figure 6

The study of the segments of sketches and the order of drawing elements gives insight into the mental organization underlying the design. Tversky (1999) argues that often designs are too large to be imagined at once, and therefore, design ideas are organized hierarchically and are normally structured in a natural way, by appearance, by function, and by significance. Thus interpretation of shapes depends upon several factors, which originate from different perceptual preferences across different people. Certainly, people can attain more than one interpretation, but, as Suwa, Tversky *et al*, (2001) point out, often once a particular interpretation has been reached, even if it has been achieved with great effort, it is difficult to see alternatives.

4. A study of shape creation through design sketches

Many studies in this research field have attempted to understand designers' reasoning. Sketches have been used as external representations of design thinking and some findings from protocol analyses are relevant to this study. However, few studies have focused on

the investigation of shape relations among sketches. To put it in Schon's terms, most studies have focused on the 'seeing' of designers rather than the 'moving'. The purpose of this study is to explore kinds of moving involved in creative stages of industrial design.

The study was concerned with what Ferguson (1992) termed 'thinking sketches' and sought to understand the creative, transformational processes of industrial design. The study set out to investigate how industrial designers generate and explore design concepts, and to analyse the relationships among the constructed representations, particularly where these dealt with product shape. Two questions shaped the inquiry:

(i) How do industrial designers graphically deal with shape at the conceptual design stage and can similarities between designers be observed?
(ii) What relationships exist between representations when lateral transformations are made?

In this study participants undertook a set task in their normal work or home environment, without being observed or forced to think-aloud, and they had a four week period to complete the task. The instructions for the task were sent by post and the completed work was returned by post. They were provided with an introductory letter, an A3 drawing sheet with an explanation of the task, and a questionnaire which participants had to open and complete after the task. Participants, therefore, had the possibility of breaking up the task if they wished. Although participants were provided with an 'official' sheet on which to sketch their designs the explanatory letter requested that all sketches and sheets produced during the design process be submitted.

A total number of 8 designers took part in this study. 5 participants were based in different industrial design consultancies. Also there was one university lecturer, one web designer and one design researcher. All participants had between three and five years experience of professional design practice, including the design and development of various consumer products, packaging and urban furniture. Because of their education and professional experience all participants had proficient drawing skills.

Participants were asked to devise a concept design for a new electric jug kettle. The brief stated that the new design should be composed of organic forms and that it should include a separate base to which the power cord was attached, a water level indicator, an on/off button and a power indicator light. Participants were encouraged to produce at least 10 sketches and to come up with a single and preferred proposal. In order to analyse progression in designing, participants were asked to number the sketches as they created them and they were requested not to erase anything.

The kettle theme was chosen for various reasons. Firstly, kettles are well-known products. Technologically they are relatively straightforward and participants are unlikely to need to engage in research or investigations in order to generate concept designs. Secondly, kettles are mature products that offer few opportunities for functional innovations. Designers usually rely on aesthetic issues in order to differentiate their product from other kettles in the market. Thirdly, kettles permits designers to pursue new shape opportunities using graphic strategies. For example, some designers may concentrate on the generation of complex curves that outline the external appearance of the kettle, while others may pursue new compositions and relationships between elements.

The first part of the post-task questionnaire concerned the design process, and the second part gathered personal details. One of the questions in the first part, perhaps the most relevant within this study, asked participants to reflect on their generated sketches and, if possible, to place their designs into distinct groupings.

5. Observations from the study

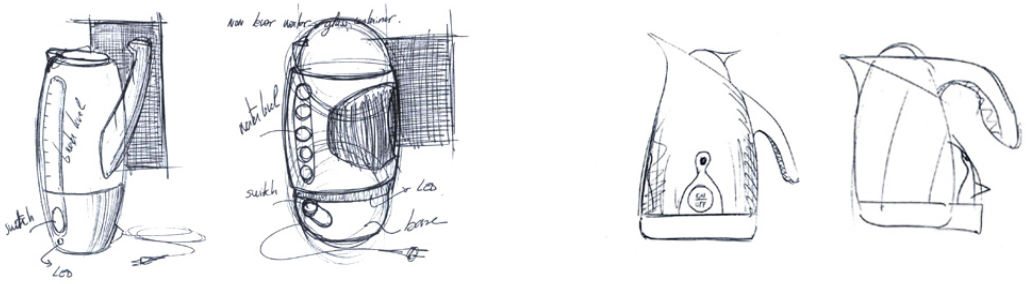
Each designer produced on average 20 sketches. The least productive participant generated 12 sketches and the most productive generated 71. Where design concepts were represented by two or more views, e.g. plan view and side view, these were considered as one sketch. All participants produced their sketches in monochrome and used ball pens, fine-line pens or pencils.

Many sketches produced in this experiment exploited redrawing, where the participant repeated a particular shape or area of a sketch. According to Do and Gross (1996), who refer to this as ‘overtracing’, it can serve several functions including assisting the selection of, or drawing attention to, an element; the recognition or confirmation of shape emergence by reinforcing particular shape interpretations; and assisting shape refinement, the adding of detail to a basic or roughed out shape.

The complexity of sketches varied enormously, both between participants and within the submissions of individual participants. All participants produced sketches of two dimensional (2D) and three dimensional (3D) views but 2D representations predominated. This might be due to a difficulty of visualising or constructing perspective images of organic forms. Some concept designs were sketched with few lines and no details, others were produced with more detail including annotations, shading or hidden lines. Many participants used brief annotations to their sketches. This was used to indicate, for example, the position of buttons, the material of a specific part of the kettle and also to name parts or concepts, e.g. water drop, bamboo or gourd, thus assisting specific interpretations to the sketches. The annotations of participants were particularly useful in the analysis of concept designs.

5.1 Reinterpretation

The sketches of most participants reveal variety in the types of strokes used to graphically represent concept designs. Van Sommers (1984) experiments suggest that there is a strong relationship between design interpretation and the production of graphic strokes and this study provided an opportunity to examine this. For example, consider the sketches produced in this study by two industrial designers shown in Fig 7a and Fig 7b. The sketches are presented in the sequence they were produced, that is, the sketches illustrated on the right of each figure were produced immediately after the sketches on their left.



a) b)

Figure 7

Fig. 7a reveals that, initially, the participant produced an outline that encompasses the body and the base of the kettle in one continuous stroke. In the following sketch, the participant drew the base and body by separate strokes. This decomposition between body and base appears to give rise to new creative opportunities for example, the base becomes more spherical. In the pair of drawings shown in Fig. 7b, the participant initially appears to have constructed the spout and body in one stroke, but in the following sketch, the spout was produced independently from the body. This is taken to indicate a change to the designer's initial interpretation. In the sketches produced after Fig. 7a and Fig. 7b (not illustrated here), the body/base and spout/body were repeatedly produced by separate strokes. Similar examples can be observed in the sketches produced by other participants. Generally, although not always, changes in the production of strokes occurs at intersection points, for example, between the spout and body, handle and body, spout and lid. The decomposition or grouping of elements appears to be influential in the way further ideas are developed. Once participants had visually decomposed their concepts into a particular set of elements, these decompositions were retained while vertical transformations were performed. Generally, changes to interpretation have led to lateral transformations where a design is reframed, potentially giving rise to a new range of alternatives.

Lateral transformations and vertical transformations may not always be identified by merely observing shape modifications; sometimes it is necessary to involve the participant's own interpretation. For example, Fig 8a illustrates a pair of concept designs -

the original is on the left and its modification is on the right. Is this a lateral transformation or a vertical transformation? The answer is that both transformations can be considered. In Fig. 8b we see that a small line has been added to the original concept design and therefore we might view this is a vertical transformation because it is an insertion of detail to an original idea. However, if we interpret the added line as an extension of the kettle body's contour, converting it into a symmetrical shape as shown in Fig. 8c, then this is a lateral transformation because this movement leads to a broadly different idea compared to the original version. The spout becomes a detached element from the body.

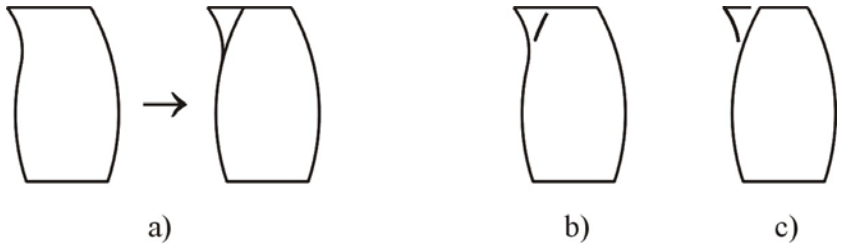


Figure 8

Both designs, shown in Fig. 8b and Fig. 8c, are interpreted as the composition of the same parts; body and spout. However, reinterpretation of shapes often leads to the discovering of unintended parts from emergent shapes.

5.2 Emergence

Designers often perceive features in their sketches that may not have been initially intended. This phenomenon can be found in different types of processes, for example, interpretative processes, transformational processes and regrouping processes. In this experiment five instances of emergence due to transformational processes were identified and three instances arose out of broadly interpretative processes. No instance of regrouping emergence was found. Only instances that are clear and therefore can be identified by simple observation have been counted. However several questionable instances of emergence were also observed, which suggest that participants recognized more emergent shapes than reported here.

The most frequent type of emergence employed by participants was based on transformational processes. Here emergent shapes were visually suggested by outlines. Consider, for example, the top row of Fig. 9 which shows some kettle concept sketches generated by one of the participants. The second row shows schematic representations of the sketches used as explanatory illustrations. As the participant revealed in the questionnaire, the underlying concept shown in Fig. 9 was inspired by the shape of a coffee bean and, at this stage, the participant focused mainly on the external appearance of the kettle. This concept may be perceived as a composition of two elements, as illustrated in the schematic representation.

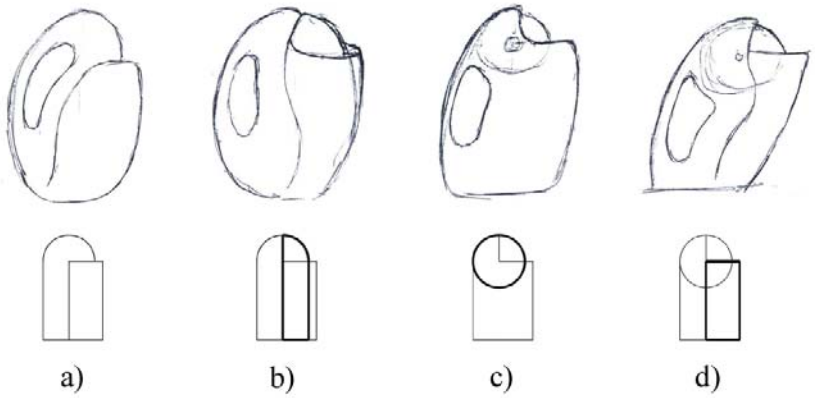


Figure 9

Here, perhaps because the designer focused on functional aspects such as the introduction of a lid to the kettle, a new element emerged from a transformational process. Fig. 9b shows the central line of the initial concept extended in order to reveal an emergent interpretation. The thick outline in the schematic representation outlines the emergent shape. The sketch in Fig. 9c is the result of an alternative interpretation where a new element emerged by a transformational process. The semi-circular shape on the top of the kettle is now interpreted as a cylinder or sphere, and as a consequence part of the previous shape is replaced by this. In the final sketch, Fig. 9d, the designer reinterprets an element that was initially present, but which disappeared during the process. Fig. 9d shows, in thick line, the re-instated element.

This example suggests how designers take advantage of emergent shapes obtained from transformational processes. Furthermore, it illustrates that the creative process is not a linear process, and that designers explore several alternatives in order to make an improvement. Comparing the schematic representations in Fig. 9a and 9d, it can be observed that the transformations from one to another are understandable but quite complex steps in the progression of the design.

Another type of emergence employed by designers is based on interpretative processes, where emergent shapes are embedded in the outlines of the design. In this study, interpretative emergence occurred mainly in sketches of low complexity. Some participants initiated the design task by generating several primitives such as circles, ellipses and lens shapes among others. In some cases concept designs were represented with two or more primitives overlapped and intersected. In such cases some participants overtraced the outer boundaries defined by the primitives in order to stimulate emergent shapes.

It was also found that instances of emergent shapes occur from dimensional transformations. This type of emergence has been investigated by Wang (1998), who suggests that because industrial designers deal with certain types of volumetric shape more frequently than architects and graphic designers a different perception operates. Wang's experiments show, for example, that industrial designers have a strong ability to see the illusion of a three dimensional cube when shown a line drawing of a hexagon. In the study presented here, one industrial designer began the sketching task by exploring different type of vessels or jugs using perspective views. Initially, the designer considered only revolved volumes, and due to the effects of perspective the circular top section of each vessel was represented as an ellipse. After several sketches, a new concept of kettle emerged based on the repeatedly drawn form of the ellipse. Consider the sketches shown in Fig.10 which present the original layout.

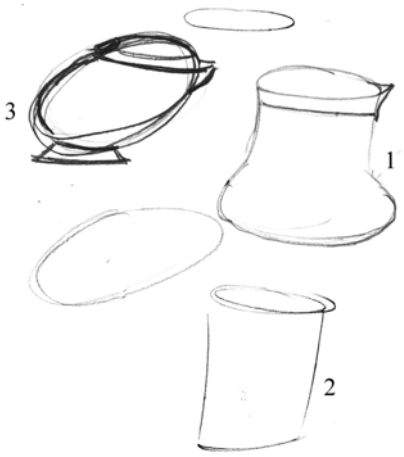


Figure 10

The numbers shown in the figure indicate the sequence in which the sketches were produced. It seems that the egg-like third design has emerged from a dimensional transformation of the spherical qualities of the first sketch idea and the cylindrical qualities of the second sketch idea.

5.3 Levels of abstraction

As discussed earlier, in the initial stages of design, designers need to keep options open and to explore broadly and speedily. For this reason initial sketches tend to be fast, loose and with little detail. This type of sketch is not restricted to conceptual design and it can be found throughout the process, for example in embodiment or detail design. This is particularly true where small but significant problems arise in an otherwise suitable design proposal. Also, once designers obtain a promising and detailed concept design, they often step back to a higher level of abstraction in order to explore and evaluate the idea from its essence, omitting irrelevant constraints. Liu *et al*. (2003) discuss three levels of

abstraction, namely topological solution, spatial configuration and physical embodiment levels. While in the first and second levels concept designs are often represented by diagrams such as ‘bubble’ charts, in the physical embodiment level, concept designs are mostly represented using shapes.

Through the design process designers generate sketches using different levels of complexity. Generally, there is a correlation between the level of abstraction and the complexity of sketches. The lower the level of complexity in a sketch, the higher the level of abstraction, and vice versa. Here, the complexity of sketches is not measured in terms of shapes but in terms of types of information provided by the sketch. McGown and Green *et al*. (1998) developed what they termed a ‘complexity scale’ to measure a sketch’s degree of transformation, based on qualitative judgements. The most simple of sketches is rated ‘one’ and the most complex is rated ‘five’. For example, complexity level one involves sketches represented in monochrome line drawing, using no shading to suggest 3D form and no text annotations. Complexity level three involves sketches also represented in monochrome, but with rough shading used to give suggestion of form. Annotations may be used to describe certain aspects of the idea.

Using this scale, the sketches in this study ranged from complexity level one to complexity level three. Most participants progressed with an oscillating search approach, where the complexity of the sketches fluctuated according to the priorities at each particular moment. Consider, for example, Fig. 11 which shows a sequence of sketches generated by one participant. The sketches here are presented in the order they were produced, that is, the sketch on the left is the earliest concept and the sketch on the right is the later concept. Note that the participant generated more sketches than those illustrated in Fig. 11, which are not considered here. Using McGown and Green’s scale, the sketches illustrated in Fig. 11a and 11d are rated as complexity level 2 because they have annotations and shadings. The sketches in Fig. 11b and 11c are rated as complexity level 1. The sequence of these sketches suggests an oscillating exploration process.

Figure 11

The sketch in Fig. 11b suggests that the participant, at that point, was focused on the exploration of bases or supports for their kettle design. The sketch in Fig. 11c was perhaps

an exploration of the position and types of handles. These explorations were then further developed in more detail in the sketch shown in Fig. 11d. In this study, while some low complexity level sketches do not appear to be related to previous sketches, other sketches present similarities with previous concept designs represented at a higher complexity level. In this study it appears that designers proceeded by moving backwards and forwards across different levels of abstractions.

6. Design families

The reinterpretation of sketches and the exploitation of levels of abstraction appear to be crucial in design generation and all participants in this study made use of them to different degrees. Goldschmidt (1994) argues that designers rarely produce single and isolated sketches, and that more often, they generate sketches in successive spells. While reinterpretation can give rise to new spells, the use of levels of abstraction is probably more suited to assisting the exploration of spells. Where this works to generate a series of closely related proposals it is possible to refer to these as a design 'family'. This section attempts to identify boundaries of design families and relationships across concept designs that belong to the same design family.

To provide a clear definition of a design family is not an easy task. For the purpose of this study a family is 'a group of related designs'. Two concept designs may appear visually different but the participant may claim that they belong to the same group, and vice versa. This occurs because a design family can be constructed using different criteria. Imagine, for example, the shape of a kettle and a saucepan. Although they are visually different, they might be grouped in the same design family as both artefacts can be used for warming up water. Alternatively, a family might refer to a group of related shapes. But, what type of shape relations constitutes a design family? Using Goel's terms, the modification of one shape into another can be originated from the application of either a lateral transformation or a vertical transformation. While a lateral transformation is a movement creating slightly different ideas, a vertical transformation results in modifications to the same idea. A design family, therefore, is a group of vertically transformed shapes. Concept designs that emerge from lateral transformations, such as the designs illustrated in Fig. 9, are not considered a design family, rather each design offers a point of departure for a specific design family to be created and explored.

In practice, designers rarely apply one type of transformation at a time, but lateral and vertical transformations may be carried out concurrently in just one movement. Consider, for example, Fig. 12 which illustrates two design families. Note that the designs are presented in the sequence they were generated, but the original arrangement has been modified. The first design family, Fig. 12a, suggests that the participant was concerned with the curves that characterize the outline of the kettle, and with some of the details.

Consider now the sequence in which the base of the kettle has been explored. The upper part of the first base is represented with a convex curve, which is then replaced with a concave curve perhaps suggested by the intersection between the body and base. At this point, the emergent base was retained in the subsequent sketches. However, not all design families are created by manipulation of outlines. Sometimes designers combine strategies. Consider, for instance, the sequence in which the lid of the kettle is explored. Observe that, the first design does not have a lid, in the second sketch a lid with a lever has been added to the design, then, in the following design the lever has been removed, and in the last design only the lever has been considered.

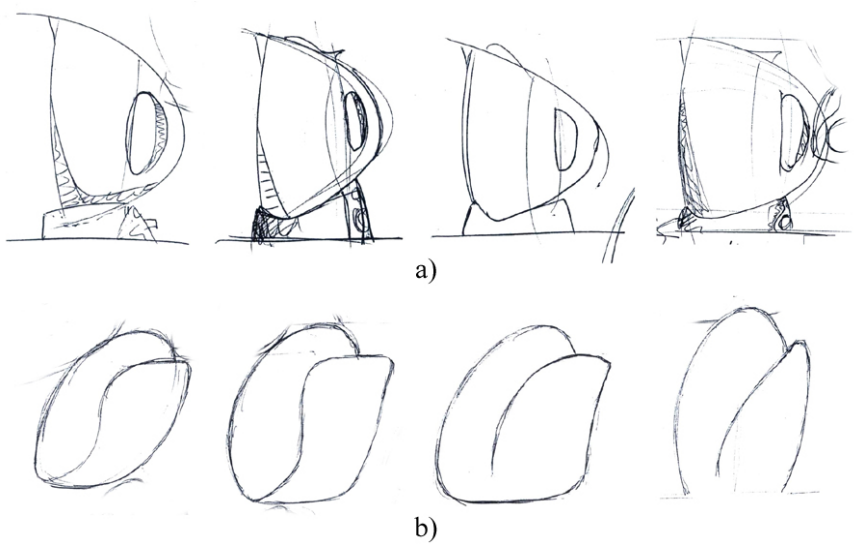


Figure 12

The design family shown in Fig. 12b has been generated using a greater level of abstraction. Observe that the sketches do not have any great detail which suggests that the participant, at this phase, was focused on the global appearance of the object, perhaps paying little attention to functional issues. In this design family the participant framed the problem of stability - of maintaining an upright equilibrium - by adopting the strategy of flattening the bottom part of the kettle. Also, as the exploration process advanced, the vertical axis of the object became more perpendicular to the base. These two design families reveal that minor variations to curves can produce a significant impact on the appearance of a design.

7. Discussion

One purpose of this study has been to explore shape relationships among concept designs generated in creative stages of industrial design. Previous studies (Cross 1994, Goldschmidt 1994, Goel 1995) have suggested that, in creative stages of design, designers spend much time exploring designs based on relatively few kernel ideas. Most concept

designs produced in creative stages are, in some sense, related and there is much evidence for the existence of close groupings of ideas or design ‘families’. In order to investigate shape relationships among designs this study analysed a series of sketches produced, largely, by professional industrial designers. Salient characteristics such as reinterpretation, emergence and levels of abstraction have been identified. While some of these characteristics assist the exploration of design families, others offer starting points for new design families to be explored.

The reinterpretation of sketches may involve subconscious elements that assist designers in the exploration of concept designs but there appears to be a significant consciousness of a process which at times seems systematic. Reinterpretations can be stimulated in many ways, for example, by analogy. In the experiment presented here some participants, after generating a design family, named their concept designs; e.g. water drop, bamboo or gourd. The progression of sketches suggests that participants did not have the associated name in mind before producing the sketch and that a reinterpretation of the sketch prompted the analogy. The sketches generated after naming the concept design display more similarities with the analogy than previous sketches, thus, the analogy perhaps served as a guide to participants in exploring further designs. This reinterpretation process has similarities with the idea of framing suggested by Schon (1988), where designers impose sets of descriptions on a situation that will guide subsequent moves. That is, when designers consider one particular interpretation they are consciously dismissing possible alternatives. How a particular design is interpreted determines whether a subsequent movement will be a vertical transformation or a lateral transformation, and therefore it determines whether a design family will be further explored or if will initiate a new design family.

In the experiment presented here three types of emergence have been observed; transformational, interpretative and dimensional. Emergence originated by transformational processes has been the most used among participants. Although this type of emergence might be more difficult to foresee, and the range of possible interpretations is much higher, than interpretative processes, it is no less logical and systematic than other types of emergence. Detection of emergent shapes provides points of departure for exploration of new design families.

The perception of sketches at different levels of abstraction appears to be common among designers. In this experiment participants produced sketches with different levels of complexity. Often participants produced sketches with low complexity levels after generation of more detailed sketches of the same concept design. This suggests that designers attend particular concept designs from both higher levels of abstraction and lower levels of abstraction in an iterative manner. On the one hand, exploration of local details may influence general structures of a design, but on the other hand, changes to the

structure may influence details. For this reason designers need to attend to both levels of abstraction in parallel. The perception of designs at higher levels of abstraction promotes changes of interpretation that may lead to new design families.

While the participants in this study appear to show no evidence of fixation, in the sense that they produced a varied number of concepts, it is observed that participants used several personal features in their sketches which are applied repeatedly during the process. For example, one participant drew a background to several concepts, or another participant highlighted the inner part of each kettle's handle. This suggests some degree of fixation on certain issues. While this may not constrain designers in exploring innovative concepts it does influence the appearance of the sketches. These fixations, which appear and recede across the sketching process, offer a starting point for exploration of style.

Alongside an illumination of sketch modelling of shape this study has highlighted the role of design families in industrial design. It has been proposed that generation and exploration of design families is often a systematic and logical process and it has been suggested that designer's moves are highly influenced by their interpretation of the design. Future computational tools that aim to assist generation and exploration of designs should take into account designer's interpretations and reinterpretations that may emerge through the designing process.

References

Akin, O. (2001). 'Variants in Design Cognition'. Design Knowing and Learning: Cognition in Design Education. C. M. Eastman, W. M. McCracken and W. C. Newstetter, Elsevier: 105-124.

Archer, L.B. (1997). 'Drawing as a tool for designers'. Proceedings of the Future of Drawing in Design conference (Ed. Moscovitch T), Huddersfield Univ., UK, 39-42.

Arnheim, R. (1974). Art and Visual Perception: A Psychology of the Creative Eye. Berkeley, University of California Press.

Biederman, I. (1987). 'Recognition-by-components: a theory of human image understanding.' Psychological Review 94(2): 115-147.

Bloch, P. H. (1995). 'Seeking the ideal form: product design and consumer response.' Journal of Marketing 59: 16-29.

Boden, M. A. (1995). 'Creativity and Unpredictability.' Constructions of the Mind: Artificial Intelligence and the Humanities 4.

Boden, M. A. (1996). The Philosophy of Artificial Life. Oxford, Oxford University Press.

Cross, N. (1994). Engineering design methods - Strategies for product design. Chichester, UK, John Wiley & Sons.

Do, E. Y. and M. D. Gross (1996). 'Drawing as a means to design reasoning'. Artificial Intelligence in Design (AID) '96 Workshop on Visual Representation, Reasoning and Interaction in Design, Palo Alto, CA.

Ferguson, E. S. (1992). Engineering and the Mind's Eye. Cambridge, Massachusetts, MIT Press.

Finke, R. A. and R. N. Shepard (1986). Visual functions of mental imagery. Handbook of perception and human performance. K. R. Boff, L. Kaufman and J. P. Thomas. New York, Wiley.

Fish, J. (1996) How sketches work: A cognitive theory for improved system design, PhD thesis, Loughborough Univ.

Garner, S. (1990) 'Drawing and designing: the case for reappraisal.' Journal of Art and Design Education, 9(1).

Garner, S. (2001). 'Comparing graphic actions between remote and proximal design teams.' Design Studies 22(4): 365-376.

Gero, J. S. (1996). 'Creativity, Emergence and Evolution in Design.' Knowledge-Based Systems 9(7): 435-444.

Gero, J. S. and Yan M. (1994). 'Shape emergence by symbolic reasoning.' Environment and Planning B: Planning and Design 21(2): 191-212.

Goel, V. (1995). Sketches of Thought. Cambridge, Massachusetts, MIT Press.

Goldschmidt, G. (1994). 'On visual design thinking: the vis kids of architecture.' Design Studies 15(2): 158-174.

Gross, M. D. (2001). Emergence in a recognition based drawing interface. Visual and Spatial Reasoning in Design II. J. S. Gero, B. Tversky and T. Purcell. Australia, Key Centre of Design Computing and Cognition, University of Sidney: 51-65.

Hoffman, D. D. and W. A. Richards (1984). 'Parts of Recognition.' Cognition 18: 65-96.

Knight, T. W. (2003a). 'Computing with emergence.' Environment and Planning B: Planning and Design 30: 125-155.

Knight, T. W. (2003b). 'Computing with ambiguity.' Environment and Planning B: Planning and Design 30: 165-180.

Kosslyn, S. M. (1990). Mental Imagery. Visual Cognition and Action. D. N. Osherson, S. M. Kosslyn and J. M. Hollerbach. London, England, The MIT Press. 2: 73-97.

Liu, Y. C., T. Bligh, et al. (2003). 'Towards and 'ideal' approach for concept generation.' Design Studies 24(4): 341-355.

McGown, A., G. Green, et al. (1998). 'Visible ideas: information patterns of conceptual sketch activity.' Design Studies 19(4): 431-453.

Schon, D. A. (1988). 'Designing: Rules, types and worlds.' Design Studies 9(3): 181-190.

Schon, D. A. and G. Wiggins (1992). 'Kinds of seeing and their functions in designing.' Design Studies 13(2): 135-156.

Soufi, B. and E. Edmonds (1996). 'The cognitive basis of emergence: implications for design support.' Design Studies 17(4): 451-463.

Suwa, M., B. Tversky, et al. (2001). Seeing into sketches: Regrouping parts encourages new interpretations. Visual and spatial reasoning in design. J. S. Gero, B. Tversky and T. Purcell. Sydney, Australia, Key Centre of Design Computing and Cognition: 207-219.

Tan, M. (1990). Saying what it is by what it is like - describing shapes using line relationships. The Electronic Design Studio. M. McCullough, W. J. Mitchell and P. Purcell. Cambridge, MIT Press: 210-214.

Tversky, B. (1999). What does drawing reveal about thinking? Visual and spatial reasoning in design. J. S. Gero and B. Tversky. Sydney, Australia, Key Centre of Design Computing and Cognition: 93-101.

Van Sommers, P. (1984). Drawing and cognition. Cambridge, Cambridge University Press.

Wang, C. J. (1998). Shape Cognition in Design. CAADRIA '98, Japan.