

How designers perceive sketches

Alexandre Menezes, Escola de Arquitetura, Universidade Federal de Minas Gerais UFMG, Rua Paraiba 697 Funcionarios, 30130.140, Belo Horizonte/MG, Brazil

Bryan Lawson, School of Architecture, University of Sheffield, Arts Tower, Sheffield S10 2TN, UK

This research examines how novice and advanced design students perceive different things from conceptual sketches. This is chiefly explored through their descriptions of these sketches to a member of their peer group. It shows differences between the two groups in terms of their use of formal and symbolic references and explores what this might tell us about how designers think while sketching. It also investigates whether sketches from the designer's own domain are described differently to sketches from another domain, and discusses what this might tell us about the acquisition of design expertise.

© 2006 Elsevier Ltd. All rights reserved.

Keywords: conceptual design, design cognition, drawings, perception, protocol analysis

While developing their ideas, designers commonly use a number of forms of graphic representation. Chief amongst these are the ubiquitous conceptual sketches and abstract diagrams that, even after the advent of computer-aided design, seem more than any other medium to characterise the process of designing. These graphical devices are different from any other type of drawings employed by designers (Herbert, 1993; Fraser and Hemni, 1994) in that designers create them not just to record an idea, but to help generate it. This process has been beautifully and famously described as ‘the designer having a conversation with the drawing’ (Schon, 1983). This is the kind of sketching this work refers to as conceptual sketching.

Many others (Schon and Wiggins, 1992; Herbert, 1993; Goldschmidt, 1994; McGown et al., 1998; Verstijnen et al., 1998; Suwa et al., 2000; Dorst and Cross, 2001) have suggested that designers are able to see more information in such sketches than was invested in their making. Thus, designers appear to see visual clues in their sketches that trigger mental images which in turn may suggest ideas for the current design

Corresponding author:
Alexandre Menezes
ammenezes@terra.com.br



www.elsevier.com/locate/destud

0142-694X \$ - see front matter *Design Studies* 27 (2006) 571–585

doi:10.1016/j.destud.2006.02.001

© 2006 Elsevier Ltd. All rights reserved. Printed in Great Britain

situation. Evidence suggests that designers dynamically associate sketch features with such meanings when the association is needed, rather than intending to convey the meaning when making the sketch (Goldschmidt, 1994).

Conceptual sketches are thus central to the phenomena of emergence and reinterpretation during early design activity. Emergence refers to new thoughts and ideas that could not be anticipated or planned before sketching. Reinterpretation refers to the ability to transform, develop and generate new images in the mind while sketching. There is considerable evidence (Goldschmidt, 1991; Lawson, 1994; Robbins, 1994; Suwa and Tversky, 1997; Suwa et al., 2000; Kavakli and Gero, 2001; Tovey et al., 2003) to suggest that the production of design ideas appears to depend heavily on this interaction with conceptual sketches.

Investigating this interaction in real-time design is thus particularly full of methodological challenges since it is both implicit and central and thus easily disturbed by any obtrusive experimental techniques and not visible to unobtrusive techniques. In this paper therefore we examine the process of interpreting sketches by designers outside the design process itself. We see this as imperfect and as only a first step in trying better to understand this most delicate and yet crucial part of design thinking. This study then depends on the simple device of asking designers to describe a drawing to another designer. The description task is made purposeful by requiring the second designer to reproduce the drawing purely from this description. Both the describer (A) and the reproducer (B) are drawn from the same design domain and stage of development, so the describers are able to describe as if to themselves.

1 Designers and precedent

The currently growing literature on the nature of design expertise suggests that experts access different types and amounts of knowledge during the process of reinterpretation (Suwa and Tversky, 1997; Casakin and Goldschmidt, 1999; Kokotovich and Purcell, 2000; Kavakli and Gero, 2001, 2002). In particular, it appears that sketching may not be as helpful for novices as it is for expert designers in the development of new ideas (Goldschmidt, 1991; Lawson, 1994; Goel, 1995; Suwa and Tversky, 1997; Verstijnen et al., 1998; Casakin and Goldschmidt, 1999). This is probably so for several reasons. At least one important reason is the dependence of designers on episodic knowledge rather than theoretical knowledge to create design solutions (Visser, 1995; Lawson, 2004). We use the term precedent here to describe this since it is commonly used by designers, however, we also acknowledge the

argument (Goldschmidt, 1998) that this is slightly misleading and the term 'reference' might be better. Goldschmidt argues correctly in our view that designers are not looking for accurate precedents in the way lawyers are but rather looking for some reference that may be useful. Often the source of such precedent may be from a different domain to the design situation under consideration and therefore that designers commonly make use of analogical reasoning in drawing upon precedent (Goldschmidt, 1998; Casakin and Goldschmidt, 1999; Suwa et al., 2000; Kavakli and Gero, 2001; Lawson, 2001). The use of precedents and analogical reasoning are strategies on which skilled designers rely heavily. Much of this information comes through drawings and images rather than being experienced in reality. Certainly it is most frequently interpreted through sketching, and design students are invariably encouraged to keep sketchbooks for this very purpose. We believe therefore that a study of what designers pay attention to in looking at images is likely to be helpful to develop an understanding of how design cognition develops.

For this reason our study here includes two groups of designers one of which are relative novices and the others much more experienced. We also use two images for description one of which lies in the subjects' domain and one of which does not. We hypothesise that the more expert group will produce richer descriptions of the drawings and that this will be even more apparent when describing the drawing from their own domain.

2 Experimental design

A total of 60 students at The University of Sheffield School of Architecture were involved in this experiment. Half were from the first year (novices) and half from the sixth and final year of study (advanced). They were volunteers invited randomly in the studio and without warning so that their participation was as natural and unprepared as it is possible to achieve.

The experiment was divided into 30 sessions. Each session involves two students; a describer (subject A) and a reproducer (subject B). The whole session was comprehensively videotaped recording words, drawing actions and gestures.

There are four different tasks: two description tasks, one remembering task and one review task at the end of the session. During the description tasks subject A is shown the two different images separately (non-architectural and architectural sketches) and has to observe them for later

verbal description to subject B. Subject A can look at the image while describing. Subject B has to listen to the description and draw what he/she understood from that without any interrogation of subject A.

After these description tasks, subject A is asked to draw from memory the two sketches he/she described to subject B.

Finally, in the session there is a review task. Subjects A and B are asked to view all the images and drawings produced and comment on the experience. Specifically, they are asked to say which of the two drawings they found easier to describe or draw. The two subjects then looked at all the drawings and were asked to review the experience focusing on what was difficult or uncertain and what was in their minds at the time.

2.1 Apparatus and stimuli

The experiment was carried out in a specially prepared room divided into three parts. In one part, there is a table where subject A sees the two sketches. Camera 1 shows the drawing being described. Camera 2 records subject A examining and describing the sketch. A workspace (desk and chair) with drawing material (paper A4-size, black pen) was provided for the subject B's use in another part of the same room. There is also a workspace (desk, chair and control panel) for the experimenter's use. The experimenter controls the video and sound through monitors (Figure 1).

The sketch to be drawn is concealed from view in the workspace by a screen dividing the viewing and working areas. While subject B is sketching what he/she is hearing, two cameras are recording from different angles. Camera 3 focuses on the sketching area and subject B's hands while Camera 4 is placed in front of subject B to register his/her movements and gestures. All four camera images were combined onto a single screen for the experimenter to monitor the sessions and analyse later.

2.2 Images

In order to facilitate the interpretation of the data and allow comparisons between groups, we decided that all subjects must describe the same images. The sketches must be from other authors than the participants. The non-architectural image is a sketch from Paul Klee/1939 (Double Island) and the architectural one is a sketch done by Mies van der Rohe during the process for the Hubble House/1935. The two images were carefully selected to appear to have approximately the same level of graphical complexity and both were line drawings. From



Subject A describing to Subject B



Subject B listening the description and drawing



Both subjects talking about the experience



Four cameras recorded the experiment

Figure 1 The experiment. Image 1 – subject A describing to subject B. Image 2 – subject B listening the description and drawing. Image 3 – both subjects talking about the experience. Image 4 – four cameras recorded the experiment

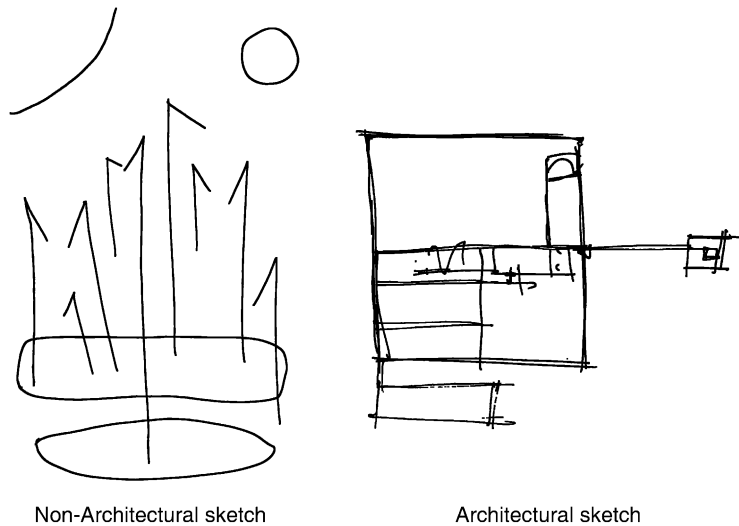
a pilot study we found that two descriptions was the longest session that was reasonable to ask a subject to attend and concentrate on.

Figure 2 shows examples of the two stimuli drawings as remembered by a subject (A). Figure 3 shows examples of the two drawings reproduced by a subject (B) from the description produced by a subject (A).

3 Analysis of the protocols

The verbal data were the main target of this analysis. They were collected from videotapes of the experiment and are composed of 30 sessions and 60 descriptions. All sessions and descriptions were analysed separately. Many systems for describing and analysing design protocols have been developed over recent years (Dorst and Dijkhuis, 1995; Suwa and Tversky, 1997; Gero and McNeill, 1998; Suwa et al., 1998; Bilda and Demirkan, 2003). The method developed in this study was adapted from the analysis methods proposed by Suwa and Tversky (1997).

Figure 2 Examples of drawings from the remembering task. Image 1 – non-architectural sketch. Image 2 – architectural sketch



The description protocols are divided into segments based on verbalization events such as pauses, intonations as well as syntactic markers for complete phrases and sentences. Therefore, pauses or syntactic markers flag the start of a new segment. Thus sentences or phrases or even

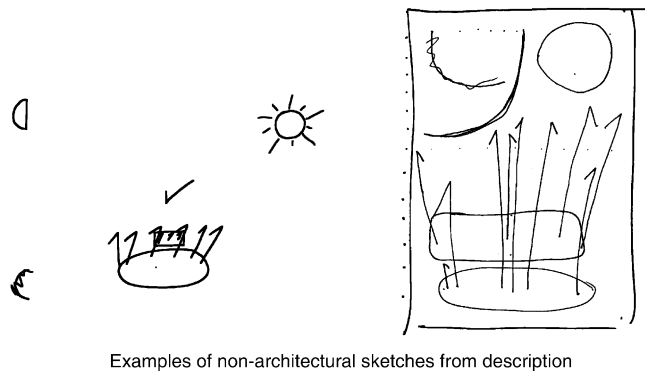
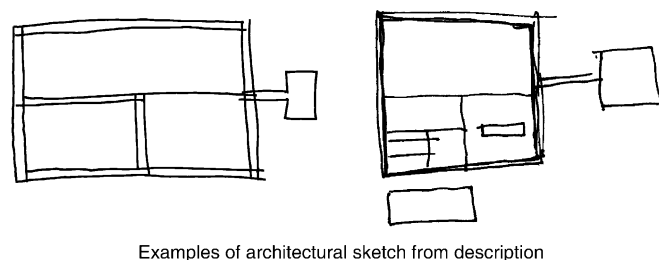


Figure 3 Examples of drawings from the description task. Images 1 and 2 – examples of non-architectural sketches from description. Images 3 and 4 – Examples of architectural sketch from description



fragments of phrases will become segments (Ericsson and Simon, 1983). Table 1 shows an example of this model of segmentation. Each segment was analysed for one or more cognitive actions.

3.1 Cognitive actions

Because the sessions were videotaped we have a wide range of data available to us. However, in this paper we concentrate only on the analysis of verbal protocols created by the participants during the description tasks. We analyse the verbal protocols by dividing them every time the describer moves from one topic to another. This analysis leaves us with a series of cognitive actions. These actions are further broken down into three sub-categories which are general references, references to feature and reflective descriptions. General references are related to information about the medium of reproduction (A4, portrait or landscape), to size (big, small, cm, mm), to spatial relations (left, right, above, below), to general view (quantity or grouping) and to conclusive comments ('that's all'; 'that's the best I can'). Feature references are divided in two groups: Formal and Symbolic. Formal references are related to physical and geometrical characteristics. They include descriptions such as square, oval or line. Symbolic references are related to analogies and elements that are not represented in the drawings. They include descriptions such as box, sausage or wall. Reflective references involve judgement such as difficult, easy, hard or simple. They also

Table 1 Segmentation of the protocol

Segments
1. Draw a sheet of A4, 2. Rectangular paper portrait format. 3. Towards the bottom 4. Are two sausages, 5. Longs ovals. 6. One on top of each other 7. With a gap between them. 8. Top right corner 9. Is a circle 10. Top left corner 11. A sort of a quarter of the circle, 12. Cutting the corner of the page. 13. That's all. 14. With the left hand side of the arrows. 15. It looks likes a face, 16. Two eyes, two lips. 17. I think, I hope. 18. Like a flag or something, 19. Golf flag.

involve remembering ('that I told earlier', 'remember that', or 'you just drew'), reflecting ('I think', 'I hope', 'is that making sense', 'if you know what I mean') and recapitulating ('I'll try again', 'you should have' or 'it's basically composed').

4 Results and discussion

The most noticeable feature of the results is the enormous variety in responses, which is hardly surprising. Bartlett's famous work on perception and memory suggests that uniformity and simplicity of stimuli are no guarantee of uniformity and simplicity in response particularly at the human level (Bartlett, 1950).

There are some important statistically significant differences between the subject groups related to the number of segments per minute, the number of verbal cognitive actions per minute and the use of formal and symbolic references while describing the same images. The statistically significant differences found enabled further analysis on the interaction of description, the image described and the drawing produced between the two subject groups.

4.1 Expertise and type of image

Both the novice and advanced subject groups spent more time describing and drawing from memory when working on the architectural sketch as opposed to the non-architectural one, though overall these differences were not statistically significant. However, in both cases these differences were greater for the advanced than for the novices. However, the length of time taken to describe the images does not seem to us as important as the richness of the description which we measure by the number of segments and cognitive actions used per minute.

The advanced group used more segments per minute and more verbal cognitive actions per minute on average for both descriptions than the novices (Figure 4). Where their expertise was greater, that is, with the architectural sketch, this effect was significantly more pronounced. In fact the majority of the advanced group used more segments per minute (53%) and more verbal cognitive actions per minute (60%) for the architectural sketch (Figure 5). By contrast a significant majority of the novice group used more segments per minute (87%) and more verbal cognitive actions per minute (67%) for the non-architectural sketch.

Thus we see a combination here of slightly, though not significantly increased overall description times for the experts and significantly increased rates of cognitive actions. Taking these results together then

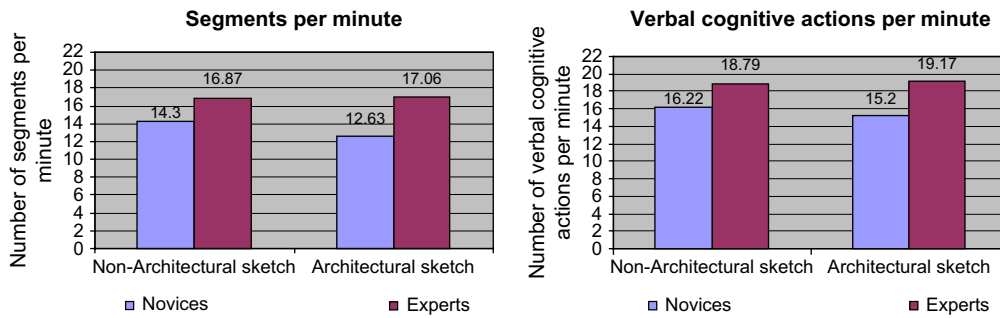


Figure 4 Number of segments per minute and number of verbal cognitive actions per minute

the advanced group produced richer descriptions of the architectural sketch compared with the non-architectural one and this was not so for the novices. Thus, all these results suggest that the architectural sketch was capable of yielding more interpretations and that more ideas emerged from looking at it when the subjects were more expert in the domain. This seems to support the results of previous studies of what

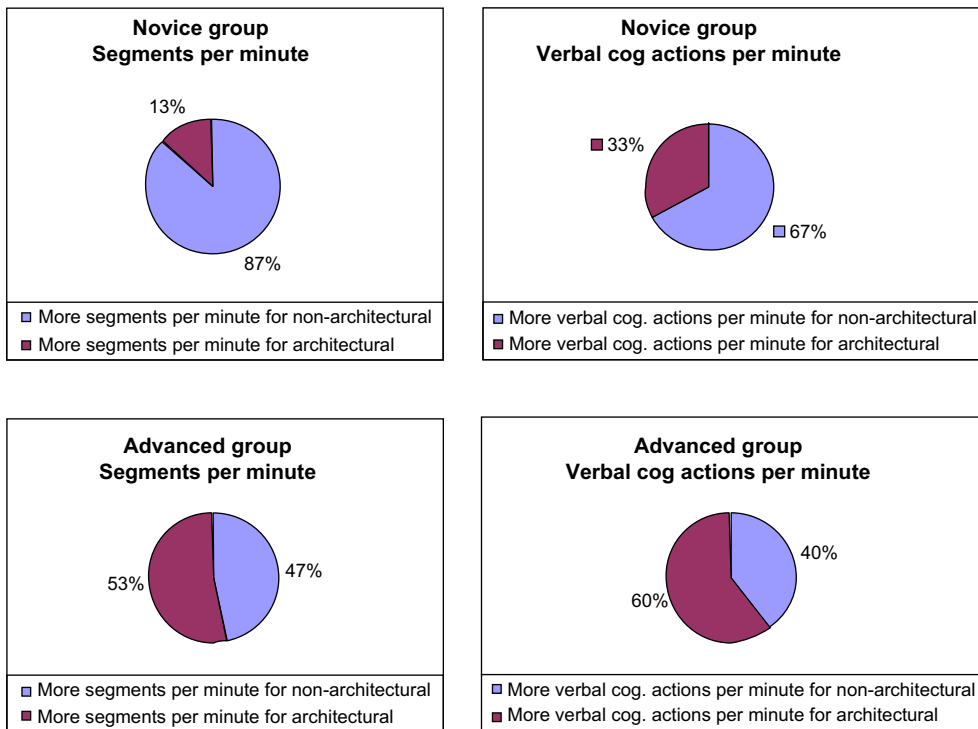


Figure 5 Segments per minute and verbal cognitive actions per minute for each sketch

novice and expert designers perceive in design sketches (Suwa and Tversky, 1997; Gero and McNeill, 1998; Suwa et al., 1998).

4.2 Formal and symbolic references

Next we examine the kinds of cognitive actions employed by both groups. The references were analysed as being either to formal or symbolic features. Both groups of students used more formal than symbolic references for both sketches. Some 80% of novices and 87% of advanced used more formal references for the architectural image than the non-architectural one. The results show that the non-architectural sketch was described with symbolic references by both groups to a much larger extent than the architectural one (Figure 6).

4.3 Subjects own assessment of difficulty

In the fourth and final experimental task (review), the subjects were asked to identify which of the two images they found the more difficult to describe. Both groups chose the non-architectural sketch as the easier to describe. We connect this with the previous finding and suggest that symbolic references are seen as easier to make than formal ones. This conclusion is supported by some comments made in the reflection phase of the experiment such as ‘easier to associate with pictures, pound, tick and sun’; ‘hard, no reference to me, no sense’; ‘easy to relate to some thing’; ‘hard, more abstract’; ‘easier, geometric things’. This preference for symbolic over formal material has many parallels in the literature of perception, not least again with Bartlett’s work on image reproduction from memory (Bartlett, 1950).

4.4 The descriptions and the drawings produced

All the drawings made by the reproducers (subject B) were ranked by a series of seven judges who were architectural staff at the School of

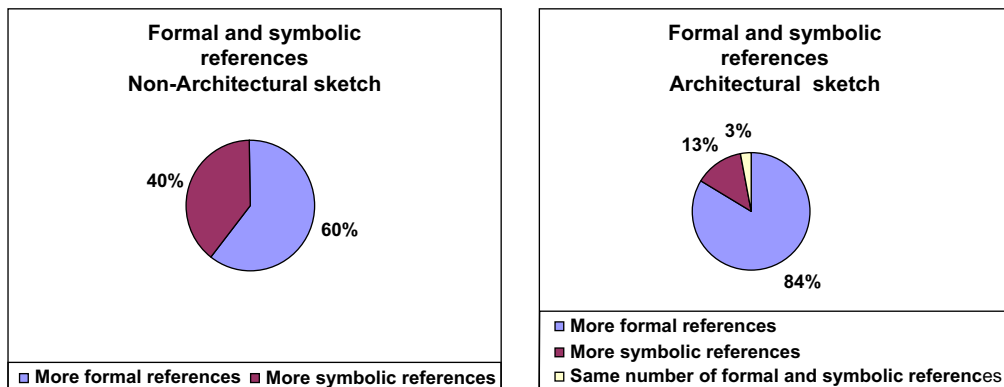


Figure 6 Formal and symbolic references

Architecture. They were asked to rank the drawings in terms of the extent to which they were accurate reproductions of the original. This task was done by sub-dividing the 30 drawings for each type of image into four piles and then ranking within each pile with a final overall check.

A statistically high level of concordance between judges was found (Kendall Coefficient of Concordance for non-architectural sketch $w = 0.80$ and architectural sketch $w = 0.74$). Therefore, all the subsequent analysis is based on the results of the average judges ranking. It was found that the advanced students achieved slightly better ranks for both drawings. We attribute this result to the greater number of cognitive actions employed by the advanced students thus giving more ways of indicating how the drawing should look.

4.5 Order of drawings

In each session each subject A described both the architectural and the non-architectural sketches. In half the cases the architectural sketch was first and in the other half the non-architectural sketch was first. Irrespective of this order, however, some 60% of each subject group got a better rank for the second than for the first description. We therefore analysed those cases where the subject improved his/her performance in the second description to see what had changed.

Some 78% of all students who got a better rank for the second description had increased the number of verbal cognitive actions. This difference was even greater for the advanced students (89% of them increased the number of verbal cognitive actions) than for novice students (67% of them increased the number of verbal cognitive actions). Again then we see more accurate reproductions associated with a greater number of cognitive actions in the description (Figure 7).

Next, the use of formal and symbolic references during the descriptions was contrasted. All students who got a better rank for the second description in turn also increased both the number of formal and symbolic references. It was found that 67% of all students increased the number formal references and 83% of them increased the number of symbolic references. It is interesting that all advanced students increased their use of symbolic references, whereas only two-thirds of novices did (Figure 8).

4.6 Most accurate and least accurate reproductions

Finally, we analysed the description protocols that gave rise to the drawings which were rated as the most accurate and least accurate

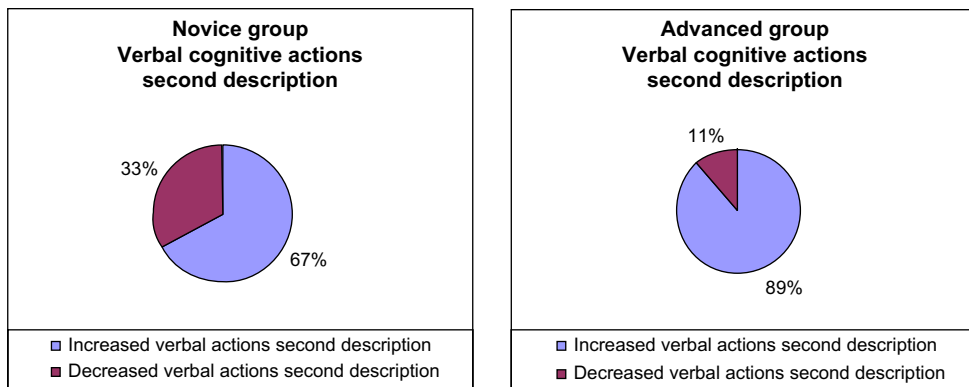


Figure 7 Verbal cognitive actions in the second description

reproductions of the originals. We took the top five and bottom five ranked reproductions of the two sketches and compared them. Overall, the descriptions of the top five showed an average increase in total cognitive actions of 98% compared with the bottom five. Formal references increased by 55% and symbolic references by 155%. It is interesting to see the much greater increase in the use of symbolic rather than formal descriptions being associated with the more accurate reproductions. These differences are further accentuated when we look at the two types of sketch separately. In the case of the non-architectural sketch, the number of symbolic descriptions increased by 55% whereas they increased by 255% for the architectural sketch. What this suggests is that when the drawing is in the describers' (subject A) domain of expertise they are able to use more symbolic references to concepts that are sufficiently well shared by the reproducers (subject B) for this to result

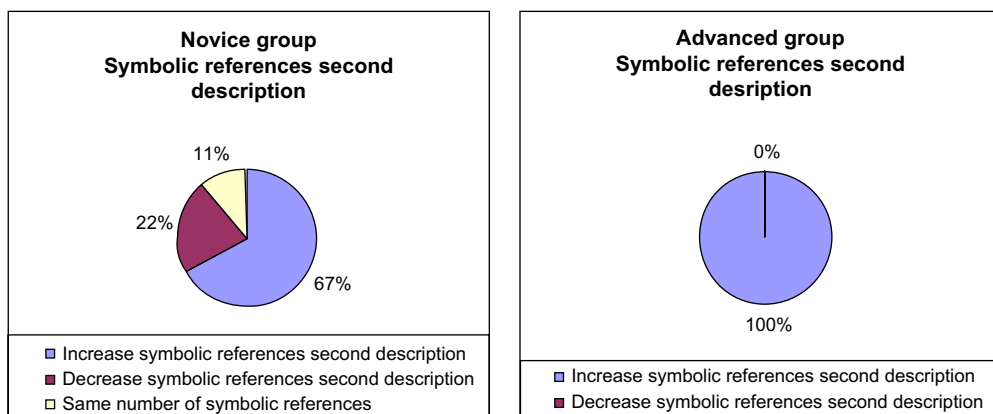


Figure 8 Symbolic references in the second description

in more accurate reproductions. This thus appears to show that designers are able to see more conceptual ideas in drawings from their own domain and that these concepts are shared by those with expertise in the domain.

5 Some experimental limitations

Our novices were already architecture students and even first year students might be seen to belong to the same culture. It would be interesting to repeat the experiment with students of other subjects. However, our experimental design is naturally conservative here. It seems reasonable to suggest that a much greater difference could be obtained between say very expert architects with many years of professional practice and novices from a population of say first year law students with little sketching experience.

The standard of students was not matched between groups. It is possible for example, that the novices were the top students of their group and the advanced were not. However, as it was difficult to find a clearly relevant way to identify the better students, they were randomly invited. However, this remains a limitation on direct comparisons between the groups.

The experiment focused exclusively on the mental process involved in the interpretation and verbal description of conceptual sketches. It did not deal directly with the actual sketching activity and certainly not the design process itself. However, the tasks clearly involved mental synthesis, as participants were asked to analyse the images and describe their thoughts. We see no reason not to expect to see a similar process occurring during design, but this remains to be proved.

6 Conclusions and implications

Evidence from both cognitive psychology and design literature supports the idea that architects, especially in the conceptual stages of the design process, have a strong interaction with their own sketches. This interaction with drawings seems to be more relevant to designers than the physical skill to draw.

This research showed that advanced architecture students used more verbal cognitive actions per minute than novices while describing the same images. Their performance was even better comparatively when dealing with a sketch from their own domain of expertise (architecture). This suggests that the way they describe and the way they use formal and symbolic verbal references might reflect the way they think and the way new thoughts might emerge during the interaction with sketches. In

particular we think it likely that these effects could be found during the conceptual phases of design when precedent is being interpreted through sketching and new ideas are being reflected upon.

6.1 Future work

Because of the objective of this research, it concentrates only on the analysis of verbal cognitive actions used by the participants while describing the images. However, in the videotapes it is possible to see a strong link between verbal descriptions and physical gestures, which suggests a very interesting field for new research. The question that might be asked is whether there are connections between the participants' mental activity and their body language while analysing and describing conceptual sketches. If yes, what might this suggest about mental synthesis, body language and sketching activity during the design process? Are there differences between the two groups and the two images?

During the experiment, the participants were required to remember and to draw by memory what they described. However, no analysis was conducted to investigate the relationship between remembered information and its previous description. Did the subjects remember the images in the same sequence as they described them? Is there any connection between the way we describe things and the way we remember them? If so, how can this help us to understand how designers' might remember relevant information while searching for a design solution? What are the differences between novice and expert designers related to this?

Acknowledgements

We are grateful to the Brazilian Ministry of Education (CAPES) for funding this research.

References

- Bartlett, F** (1950) *Remembering — a study in experimental and social psychology* Cambridge University Press, London
- Bilda, Z and Demirkan, H** (2003) An insight on designer's sketching activities in traditional versus digital media *Design Studies* Vol 24 No 1 pp 27–50
- Casakin, H and Goldschmidt, G** (1999) Expertise and the use of visual analogy: implications for design education *Design Studies* Vol 20 No 2 pp 153–175
- Dorst, K and Cross, N** (2001) Creativity in the design process: co-evolution of problem–solution *Design Studies* Vol 22 No 5 pp 425–437
- Dorst, K and Dijkhuis, J** (1995) Comparing paradigms for describing design activity *Design Studies* Vol 16 No 2 pp 261–274

- Ericsson, K and Simon, H** (1983) *Protocol analysis: verbal reports as data* MIT Press, Cambridge
- Fraser, I and Hemni, R** (1994) *Envisioning architecture: an analysis of drawing* Van Nostrand Reinhold, New York
- Gero, J and McNeill, T** (1998) An approach to the analysis of design protocols *Design Studies* Vol 19 No 1 pp 21–61
- Goel, V** (1995) *Sketches of thought* MIT press, Cambridge
- Goldschmidt, G** (1991) The dialectics of sketching *Creativity Research Journal* Vol 4 No 2 pp 123–143
- Goldschmidt, G** (1994) On visual design thinking: the vis kids of architecture *Design Studies* Vol 15 No 2 pp 159–174
- Goldschmidt, G** (1998) Creative architectural design: reference versus precedence *Journal of Architectural and Planning Research* Vol 15 No 3 pp 258–270
- Herbert, D** (1993) *Architectural study drawings* Van Nostrand Reinhold, New York
- Kavakli, M and Gero, J** (2001) Sketching as mental imagery processing *Design Studies* Vol 22 No 4 pp 347–364
- Kavakli, M and Gero, J** (2002) The structure of concurrent cognitive actions: a case study on novice and expert designers *Design Studies* Vol 23 No 1 pp 25–40
- Kokotovich, V and Purcell, T** (2000) Mental synthesis and creativity in design: an experimental examination *Design Studies* Vol 21 No 5 pp 437–449
- Lawson, B** (1994) *Design in mind* Architectural Press, Oxford
- Lawson, B** (2001) *The context of mind* Designing in context DUP science, Delft
- Lawson, B** (2004) *What designers know* Architectural Press, Oxford
- McGown, A, Green, G and Rodgers, P** (1998) Visible ideas: information patterns of conceptual sketch activity *Design Studies* Vol 19 No 4 pp 431–453
- Robbins, E** (1994) *Why architects draw* The MIT Press, Massachusetts
- Schon, D** (1983) *The reflective practitioner: how professionals think in action* Temple Smith, London
- Schon, D and Wiggins, G** (1992) Kinds of seeing and their function in designing *Design Studies* Vol 13 No 2 pp 135–156
- Suwa, M, Gero, J and Purcell, T** (2000) Unexpected discoveries and S-invention of design requirements: important vehicles for a design process *Design Studies* Vol 21 No 6 pp 539–567
- Suwa, M, Purcell, T and Gero, J** (1998) Macroscopic analysis of design process based on a scheme for coding designers' cognitive actions *Design Studies* Vol 19 No 4 pp 455–483
- Suwa, M and Tversky, B** (1997) What do architects and students perceive in their design sketches? A protocol analysis *Design Studies* Vol 18 No 4 pp 385–403
- Tovey, M, Porter, S and Newman, R** (2003) Sketching, concept development and automotive design *Design Studies* Vol 24 No 2 pp 135–153
- Verstijnen, I, Hennessey, J, Leeuwen, C, Hamel and Goldschmidt, G** (1998) Sketching and creative discovery *Design Studies* Vol 19 No 4 pp 519–546
- Visser, W** (1995) Use of episodic knowledge and information in design problem solving *Design Studies* Vol 16 No 2 pp 171–187