



# Constructing and Understanding Visuo-Spatial Representations in Design Thinking

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## Background

This is a position paper for the workshop on *Constructing and Understanding Visuo-Spatial Representations in Design Thinking*, to be held in conjunction with the *Design Computing and Cognition 2006* conference. It is the aim of this paper to present a small set of hopefully controversial core hypotheses around which the workshop will be constructed. We cordially invite participants to come forward and submit a one-page abstract in reaction to the statements presented here.

Submissions will be reviewed by the workshop's program committee. Based on the review process and in order to provide for vivid and productive discussions, selected authors will be asked to actively contribute to the workshop program. More details on the workshop as well as information on how to submit can be found online at:

[www.sfbtr8.uni-bremen.de/vsdesign06](http://www.sfbtr8.uni-bremen.de/vsdesign06)

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## Introduction

Designing is a cognitive process which, among other activities, involves visuo-spatial thinking, sketching, and modelling. All three activities involve visuo-spatial representations. On the one hand, constructing visuo-spatial representations refers to the making of visual and spatial models of the necessary elements to be used. These models may be constructed either internally (i.e., mentally) or externally (i.e., physically). Visuo-spatial thinking, sketching and modelling often involve both internal and external models; and are frequently dynamically interrelated by perception, reasoning, and actions of the designer. On the other hand, understanding visuo-spatial representations in design thinking refers to revealing what meaning internal or external representations convey. This also includes how internal and external representations differ in structure, style, and use; how different representations interact in design activities; how such interaction eventually brings about design solutions; and what such representations may reflect about design thinking and designing in general. Tracing the internal (or mental) and external construction of visuo-spatial representations may inform design research about how conceptions are formed, developed, represented, and re-interpreted.

To provide for a vivid but focused discussion, we take the following perspectives on designing:

## Program committee:

Uday Athavankar, *IIT Bombay*  
B. Chandrasekaran, *Ohio State University*  
Ellen Do, *Carnegie Mellon University*  
Christian Freksa, *Universität Bremen*  
John Gero, *University of Sydney*  
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- #1. designing is problem solving
- #2. problem solving in design is equal to problem redefinition
- #3. designing requires problem redefinition in terms of both mental and external visuo-spatial models
- #4. designs are products of bootstrapping processes driven by the repeated mental and external redefinition of a design problem

In the following, we will clarify and discuss our statements.

### Designing is Problem Solving (#1)

Designing is commonly described as a problem solving process, and it certainly is if one focuses on the engineering aspects in designing: given a design task  $T$ , three properties can be established: (1) a satisfactory design  $D_{sat}$  is characterized by the requirements expressed in  $T$ 's design brief, with  $D_{sat}$  consisting of one or multiple visuo-spatial design representations  $VS_{sat}$  and a corresponding design concept  $C_{sat}$ ; (2) different given designs  $D_k, D_l$  may instantiate the requirements of  $T$  to varying degrees; (3) design actions lead to transforming a design  $D_m$  into another design  $D_n$  (i.e. to redefining  $D_m$  as  $D_n$ ), thereby potentially changing the degree of instantiation of the requirements. We can thus describe successful (i.e., overall goal-directed) designing as a sequence of design actions that take in design  $D_{init}$  as initial argument and, after finitely many steps, produce  $D_{sat}$  as a result.

Naturally, such clear-cut description is overly idealized and, with respect to classic problem solving approaches in the spirit of Newell & Simon's (1972), design problems have in fact often been diagnosed as ill-defined (Goel, 1995). In terms of problem solving attributes, this means that (a) the initial problem representation  $D_{init}$ , (b) the description of the design goal  $D_{sat}$ , or (c) the methods and procedures to reach the latter from the former are at least partially unknown (cf. Simon, 1973). These practical difficulties do not preclude the general argument that much of the design process can be adequately described as a problem solving activity, in particular as one that is driven by alternating and interlocked mental and external visuo-spatial reasoning processes. However, there exists a rather fundamental shortage of knowledge about the individual design process, notably, before and while designing. Much of this shortage is being caused by information remaining implicit in the process. One reason for implicit information lies in design aspects that cannot be (easily) formalized as they relate to 'soft constraints' which involve human emotions, preferences, or style (Schlieder &

Hagen, 2000). Explorative methods utilised during the design process are aimed at increasing available knowledge and involve completely or partially defining and often re-defining a given design problem, i.e., formulating and reformulating the design space. For example, a problem definition may be based initially upon qualitative mental models arising from experiential knowledge, design team knowledge, or available data (Parmee 2005). Another approach to problem definition relates to the integration of knowledge from other sources, through for example, analogical reasoning or metaphorical transfer from other problem domains (Gero and Shi 1999). We expect that utilising such and other approaches will then play a significant role in defining the direction of further investigations and result in radical changes in problem representation.

### Designing by Redefinition (#2)

By taking a problem-solving perspective on designing, we assume a computational stance and place an emphasis on design representations as well as on processes that redefine the design concept underlying one particular representation in terms of another representation. Designing thus becomes a sequence of such redefinitions, where successive small transformations gradually lead to the eventual result of the process. Given that the process is ill-defined, the choice of a successor to a given design  $D_m$  can be modelled as a heuristic procedure, based on the estimated decrease in distance to the (partially unknown) design goal. The significance of such chaining has, for example, been described for serial sketching as a mode of visual thinking in design where each subsequent sketch is generated based on an evaluation of the preceding one (Goldschmidt, 1992; or, Oxman, 1997, from a modelling perspective). One should consider, however, that the notion of a perfectly sequential process is somewhat unrealistic in non-routine design problems and that the structure of dependencies between different representations created in solving these types of problems is probably more complicated. For example, multiple representations can be developed by re-representing an initial representation.

A general mechanism for re-representing design concepts seems also advantageous if one considers that designing involves finding a solution to both routine and non-routine (and often complex) design problems. Designing becomes easier if the designer can focus on certain parts or aspects of the overall problem at a time (Bertel et al., in press) while other parts and aspects of the problem are implicitly preserved by external representations for use in later design stages. As design often involves creating objects that are

spatially structured and occupy physical space, visuo-spatial representations such as sketches or diagrams are particularly useful for this purpose.

### **Internal and External Visuo-Spatial Representations (#3)**

Visuo-spatial thinking during design problem solving involves constructing internal representations, many of which draw on mental visuo-spatial reasoning faculties. For example, it is likely that mental spatial models get constructed during positional or relational reasoning (Knauff & Johnson-Laird, 2000), where mental images play a role for problems that involve shape features or high degrees of visual detail (Kosslyn & Thompson, 2003).

Similarly, the ability to construct and inspect external visuo-spatial representations is crucial for many design tasks (e.g. Do & Gross, 2001). In particular, in the design literature, how designers think and solve design problems is typically identified as a reflection of how they interact with their sketches (Schön, 1983).

Mental visuo-spatial representations may be externalised by designers at different levels of abstractions (e.g., visual, spatial, or conceptual abstractions). In this way, such externalisations convey specific meaning to the person who generates them, and may convey different meaning to others.

How sketches, diagrams and models are externalised may be closely related to how they have been mentally constructed in the first place. Consequently, efforts to understand the use of mental representations may make a significant contribution to understanding design activity and the design output itself. Of central importance to the construction of internal and external representations is the interplay between different types of knowledge, such as abstract, conceptual knowledge and perceptual knowledge.

From a cognitive point of view, mental faculties involved in reasoning with external diagrams and those involved in mental visuo-spatial reasoning overlap to some degree (e.g. Kosslyn & Sussman, 1995). On the other hand, both sides show some complementary functionality, such as with respect to structural reconfiguration and reinterpretation of contents: while the purely mental reinterpretation of a mental image is hard, reinterpreting a sketch that is drawn after the image is easier (Verstijnen et al., 1998). In short: mental and external representations complement one another as representational and procedural limitations of one form are often compensated for by the other. For example, external representations are durable and stable, internal representations are volatile and flexible.

We can therefore postulate that purely mental visuo-spatial representations and reasoning methods alone would generally not lead to successful designs, nor would purely external ones, for that matter. Rather, it is usually the interplay of the mental and external worlds that lead to success. In that respect, designing is a prime example of integrated mental and external cognition (cf. Scaife & Rogers, 1998). On the other hand, it has also been shown that expert architects, when encouraged to use their imagery only, are able to construct and maintain a design of a building for extended periods of time and eventually come up with satisfying design solutions (Bilda et al, 2006).

### **Visuo-spatial Re-representation (#4)**

Most designers are skilled at constructing and interpreting the variety of external design representations inherent to their domain. Typically, design representations used in the early stages of designing such as sketches, drawings and models differ from pictorial images in that they reflect conceptualisations, not reality (Tversky 1999). Here, again, we find re-representation as a design method.

Thus, a key aspect of constructing and understanding visuo-spatial representations lies in the designer's (or a computational model's) development of appropriate re-representation methods. The re-representation of visuo-spatial information describing a design has a profound effect on the structure, operation, and capabilities of a reasoning system – be it cognitive or computational. Since re-representation lends itself to different interpretations it enables emphasis to be shifted and placed on specific properties and features. As a result of such shifts a re-interpretation can be triggered, (e.g., through underlying ambiguities) and enable the perception of different (implicit) features (Gero 1997).

From a computational perspective, one of the main weaknesses of current approaches to internal and external visuo-spatial representation is the lack of recognition of what is being symbolically presented. For example, in modelling external representations, technology's symbolic treatment of shapes and their spatial relationships creates discrepancies between human and computational ways of recognising visuo-spatial representations and therefore in reasoning about them. Arbab (1990) attributes these discrepancies to the differences in the designers' and the computer system's use of a representational 'language'. It is therefore seen as essential that approaches to visuo-spatial representation and re-representation provide a mapping from the problem domain and reflect the type of cognitive processes that

involve perceptual pattern finding (Larkin & Simon 1987). Crucially, not all mappings are equal, and for effectiveness identified patterns should allow for the detection of meaningful features (Ware 2000). Consequently, the effectiveness of visuo-spatial representation and resulting reasoning system depends to some extent on how well re-representations are constructed as an input to the system.

### Open Questions and Challenge Statements

The following provides a list of questions and challenge statements which are aimed to be addressed by the workshop.

#### 1. *Understanding visuo-spatial representation:*

☞ How can we empirically and theoretically assess the relevant processes and representations involved?

☞ What kind of phenomena and visuo-spatial information should we look for? How should we look for them without influencing the processes?

☞ How can we optimize investigations and keep data collection and analysis efforts tractable?

#### 2. *Constructing percepts and concepts:*

☞ What are factors involved in constructing percepts and/ or concepts (i.e., representation types, process types, phenomena, etc.)?

☞ What is the role of sketching as a reasoning activity? How does sketching as an activity which combines internal/ external processes relate to both internal and external representations?

☞ Is an understanding of the problem a prerequisite to constructing internal and/or external representations? Or does understanding follow largely from the construction process itself?

☞ If design problems are situated and ill-defined, does the problem type influence the construction and/or the understanding of visuo-spatial representations?

#### 3. *Visuo-spatial representation and problem solving:*

☞ What roles do visuo-spatial representations play in understanding the design problem and in structuring the problem domain?

☞ What is the role of redefining ill-defined problems in constructing and understanding visuo-spatial representations?

#### 4. *Modelling reasoning by construction:*

☞ How can we conceptually and computationally model the relevant processes and representations involved?

☞ How can we model processes and representations involved both adequately and effectively with respect to:

a. Developing a better understanding and description of phenomena,

b. Developing a better understanding of a specific designer's behaviour and cognitive states during design processes, and

c. Developing computational tools and agents that are well tailored to the specific designer's behaviour and cognitive states and are able to offer assistance in constructing and understanding representations during specific design processes.

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