VSDESIGN'06

Constructing and Understanding Visuo-Spatial Representations in Design Thinking

A Design Computing and Cognition 2006 Workshop

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VSDESIGN'06

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A Design Computing and Cognition 2006 Workshop

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Program Committee

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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

Keywords: Internal and external representation, problem solving, re-representation, visuo-spatial reasoning, design thinking

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:

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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, re-interpreting 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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NOVICE DESIGNERS' EXPLORATIONS THROUGH CONCEPTUAL DIAGRAMS

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Design situations often impose both conceptually and spatially challenging tasks and they require a coordinated exploration of the two. One of the initial difficulties for novice designers, e.g., design students, in the beginning of the design phase is the struggle to relate abstract design ideas to spatial arrangements, i.e., the difficulty in aligning the dual exploration space of design. Often, novice designers establish a quick and superficial correspondence between the two.

This study investigate how conceptual diagrams could potentially be helpful for novice designers to start thinking about relationships between concepts and space, about dual exploration space of design process and how it could be coordinated through conceptual diagrams. Dogan and Nersessian (2002; 2005) have suggested that conceptual diagrams are physical instantiations of mental models, whose correspondence to their target domain is governed by nomic constraints that are "easily" available to agents. Therefore, manipulations of their components are likely to change the structure of their corresponding mental models. For some expert designers, such as Kahn, Stirling, and Libeskind, the manipulation of either few or a series of conceptual diagrams resulted in changes both in the conceptual domain and in the spatial domain. These designers had managed to coordinate the dual exploration in design through conceptual diagrams. For novice designers, however, to establish the structural correspondence of the conceptual and spatial exploration space through conceptual diagrams seems to be difficult to grasp but acquirable in a length of time. What is not so easily acquirable is the understanding that manipulation of either one of the domain and coordination between the two explorations could be facilitated through conceptual diagrams. It is conjectured that what differs novice designers from expert designers is that novices lack a structured mental model of design situations.

The study presents the evolution of design ideas of 13 second year architectural design students based on their logbooks, illustrating and summarizing the evolution of their design, and documentation of their works at regular reviews. Students were asked to design a written and oral history center and were given approximately three months to complete the project. There were three midterm reviews and one final review. To start the design process, the instructors asked students to think about a concept or a series of related concepts to define their project. Subsequently they were instructed about conceptual diagrams with examples from architectural design with an emphasis on the significance of conceptual diagrams in relating ideas about concepts and space and were asked to draw diagrams. In the following phase, instructors gave students examples from architectural design that could relate to their design concept and were asked to proceed with space organization.

The logbooks and midterm and final review presentations were studied to determine whether students drew any conceptual diagrams, whether they used them in space organization, and how they introduced changes in the design process. It was possible to determine the course of each student's design process because the page order in logbooks corresponded to temporal order and because reviews had specific dates.

The study of the drawings shows that some students (6 out of 13) acquire an understanding that conceptual diagrams represent a design idea. Some students (7), however, drew bubble diagrams or zoning diagrams even though they were instructed in conceptual diagrams. Fewer students (5) seem to understand that conceptual diagrams represent both abstract ideas and ideas about spatial planning. The study of known precedents form architectural history often helps student to capture the relationship between abstract ideas represented in their conceptual diagrams and how they could be implemented through space. Even fewer students (2) seem to understand that conceptual diagrams are generic in the sense that the generic spatial structure of the conceptual diagram could be implemented in different designs. In contrast, expert designers such as Louis Kahn show us how the same conceptual diagram could help generate different variations. None of the students, however, did reach a point where she/he could manipulate the diagrams to invoke changes in the dual exploration space of design. In contrast, expert designers such as James Stirling and Daniel Libeskind show us how changes in the conceptual diagram may bring simultaneous, coordinated changes in the conceptual and spatial domain of design.

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EXAMINING THE DIFFERENCES IN SKETCHING AND 3D MODELLING IN COLLABORATIVE VIRTUAL ENVIRONMENTS

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New technological developments offer new collaborative design environments to designers. Design thinking and visuo-spatial representations change with the introduction of digital tools such as digital sketching, modelling, rendering and 3D virtual worlds. In design research, empirical studies have the potential to answer questions such as; (1) what is the role of new media in developing/generating design ideas and visuo-spatial design representation? (2) what is different between sketching and 3D modelling in terms of (a) making visuo-spatial models of a design, and (b) indexing meaning to visuo- spatial representations.

We conducted a series of experiments to study and compare the impact of different collaborative virtual environments on design behaviour using protocol analysis. Our study shows that there are differences in designing in a shared 2D sketch environment and a 3D virtual world (Maher et al. 2006a). First, we characterise how the designers generate/develop visuo-spatial representations while in a shared 3D modelling environment (Gül and Maher 2006b). They quickly decide to pursue a concept/idea without having much problem definition (and redefinition) behaviour, and spend more time on the making of the visual model of the design in the 3D modelling environment. In particular, they have longer model making actions that include engagement with the spatial relationships of the design objects. The designers focus on concretization and visual analysis of a design concept (Maher et al. 2006b) in 3D modelling mode. In addition they spend less time discussing functional issues when they are involved in 3D modelling. Second, we characterise how the designers generate/develop visuo-spatial representations while in a shared 2D sketching environment. The designers focus on abstract representations of the design and iterate from synthesis to analysis more times while they are sketching. In addition, they move/shift from one action to another very quickly (Gül and Maher 2006a), discuss more functional issues, and generate more abstract design ideas when they are sketching. Third, we characterise the differences in strategies used in generating 2D and 3D representations. In 2D sketching, the designers generate and communicate ideas while they are drawing 2D plans/layouts that show the spatial arrangements of spaces, and access of people and services. In addition, once they agree upon the design concept, they start sketching the forms of the spaces and the 3 dimensional design solution such as partial sections and perspectives. In 3D modelling, they verbally externalise and communicate the design solutions. They agreed upon a particular design concept quickly, and then they generate ideas about the structure (columns and beams), form, size, height, colour and material. In particular, the 3D modelling tools encourage the designers imagine the design solutions as a finished product before even starting to model it. Figure 1 shows the different design solutions in 2D sketching and 3D modelling modes.

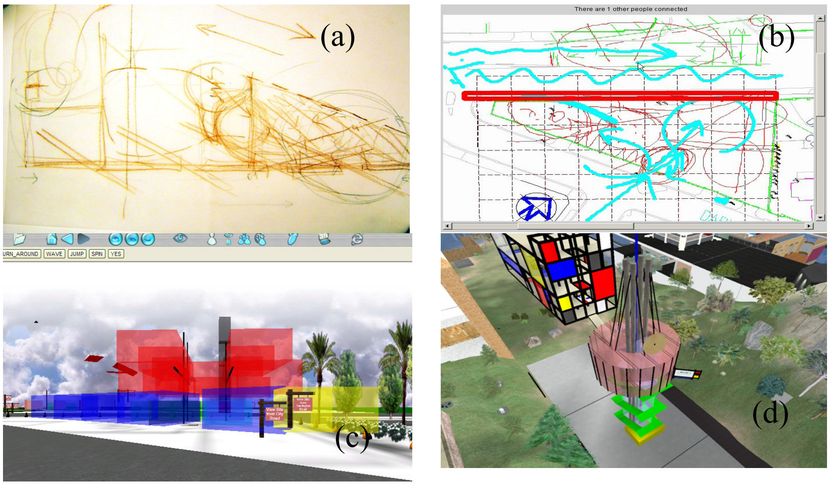

Figure 1. Design representations: (a-b) 2D sketches, (c-d)3D models

We observed that the designers engage with different aspects of the design problem when they are sketching compared to when they are making 3D models, even when given a design task of the same level of complexity and abstraction. With the development of more capable modelling tools, we may observe more situations where modelling would take place of sketching. Studying the role of sketching/modelling tools in the development of internal and external visuo-spatial representation provides insight into the impact of these technologies on designing. Sketches and 3D models correspond to visuo-spatial representations that are essential to design reasoning and focus the designer on different aspects of the design problem. The consideration of these different design environments goes beyond their ease of use and functional features, and should be considered in terms of their impact on visuo-spatial reasoning.

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Visuo-spatial representations in Designing for Wayfinding

How do architects reason to anticipate user needs?

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Abstract for VSDESIGN workshop

It has been well-documented that finding one's way around complex public building settings is quite challenging for many people (Passini, 1992), with sites like airports and hospitals being primary examples. It is only marginally documented how architects reason when they try to integrate wayfinding-friendly factors into their designs. What knowledge is needed in the process and how is it represented? What tools are in use or required for such design tasks? We report on our work-in-progress to gain an understanding of such wayfinding design activities.

Designing for wayfinding places a specific burden on the designer: She needs to anticipate not only the building form but also how the building will be perceived by the users who are trying to orient themselves in it. This requires frequent changes in perspective, namely from the inherently allo-centric plan or section views characteristic for building design to the ego-centric view of a person immersed in the building.

Weisman (1981) describes four major types of environmental features that affect the orientation- and navigation-friendliness of buildings: visual access, signage/room number, architectural differentiation and floor plan complexity. These vary largely in scope and also in their applicability in different phases of the design process. How do architects manage the challenge of integrating these requirements?

While in a poster for the DCC06 main program we present our study in more general terms, the contribution for the VSDESIGN workshop focus on the potential role of internal and external forms of mental representations for the design process: We will share our observations about how the interviewees argued their design decisions with the help of sketches, to what extend they appear to use internal mental manipulation of spatial elements and what requirements for tool support were voiced. Note that our study

does neither provide a direct experimental investigation of visuo-spatial processes nor a general psychological theory of visuo-spatial reasoning. Instead our study is a first exploratory step towards an understanding of "designing for wayfinding" and for the workshop we intend to raise questions about the role of sketches, perspective and internal representations for these design processes. We intend to highlight that wayfinding design could provide a very fruitful domain for studying visuo-spatial reasoning processes as well as potential tool support in more detail.

We adopted basic knowledge engineering techniques to gain an understanding of the wayfinding design process: A series of semi-structured interviews were conducted with a sample of six architects and urban planners. An open set of questions was compiled beforehand and the interviews were supported by critiquing tasks. The interviewees analysed and commented on design cases, from their own portfolio as well as materials pre-selected by the researchers. The critiquing situation provided a natural way for the practitioners to explicate their design procedures, goals and requirements in context. Video-recording the sessions allowed us to analyse correspondences between verbal argumentation and sketches prepared by the interviewees to support and explain their cases.

We observed large differences in how the architects "naïve theories" of what cognitive principles underlie pedestrian path choices and what design features have impact on the building user's behavioural and cognitive processes. We identify a tension between a strong reliance on intuitive understanding of user needs and a desire for more systematic support in anticipating problems in navigation behavior and design soft-spots.

Currently, only the minority of designers in our sample employ 3d modelling tools to visualize the building from the perspective of a user immersed in it. Requirements for tool support were voiced, especially with respect to simulating user behavior in different stages of design refinement. We would like to start a discussion of whether realistic simulation of users' wayfinding behavior in proposed building designs could bypass the need for fully explicit design criteria, as the designer can rely on his/her intuitive design heuristics and assumptions, while getting objective feedback on behavioural consequences through agent simulation.

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Visuo-Spatial representations : generation and manipulation

An abstract for the vsdesign'o6 workshop

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This is a short abstract in response to the stance taken in the position-paper presented. The views presented here are what I have gleaned in the three years I have pursued this field. My aim here is to present one perspective to this attempt to understand the nature and purpose of visuo-spatial representations. Design is a problem solving activity. The chief aim in preparing a design "brief" is to set a goal or a fixed final state which one current state (if at all it exists) does not satisfy. Intuitively, a design "deliverable" can declared as a list of properties or attributes (a_i) that may not always be absolutely quantifiable (1 or 0) but rather objectified on a scale (1 to 10). The aim is in this effort to understand design thinking may be to better judge a design process (and hence better teach it) or possibly to objectify a design process to get a computational model. This brings us to the design process itself.

I believe that the design process starts with listing the attributes of the desired "solution" and then considering each attribute and comparing it with a "tentative" solution (ts_i). The "form" and nature of these tentative solutions is what the issue now is. We hypothesize that most solutions to design problems are in fact, visuospatial representations (Tversky, 1999). Mental representations are by definition loose and pliable. Complexity is design processes arises when the factoring on of an attribute contradicts the "acceptable" representation reached for an earlier attribute. For example: a brochure's desirable traits might be attractive and cheap. If the designer proposes a design with lots of colour for an "attractive" brochure, it might become too expensive to print and he will then have to reconsider his design. With mental representations, such comparisions happen fast. The problem might arise when more attributes are factored in. How many situations can the human "working memory" store and compare? This brings us to external representations. Research shows the monumental role sketches play in a designer's "thinking" (Athavankar 1999). Why is this so? We can postulate that sketches represent stages of "tentative" solutions as discussed earlier. A sketch is one type of external visuospatial representation, highly effective because of the speed with which it can be generated. This is not as fast as the mental representation but is more "concrete" in that it gives us a fixed "form" that we can then mentally compare with other attributes and modify as we cycle through the attributes. The proven indispensability of sketches may also stem from the human minds inability to simulatneously create permutations of solutions owing to the limitations of the working memory (Baddeley 2002)

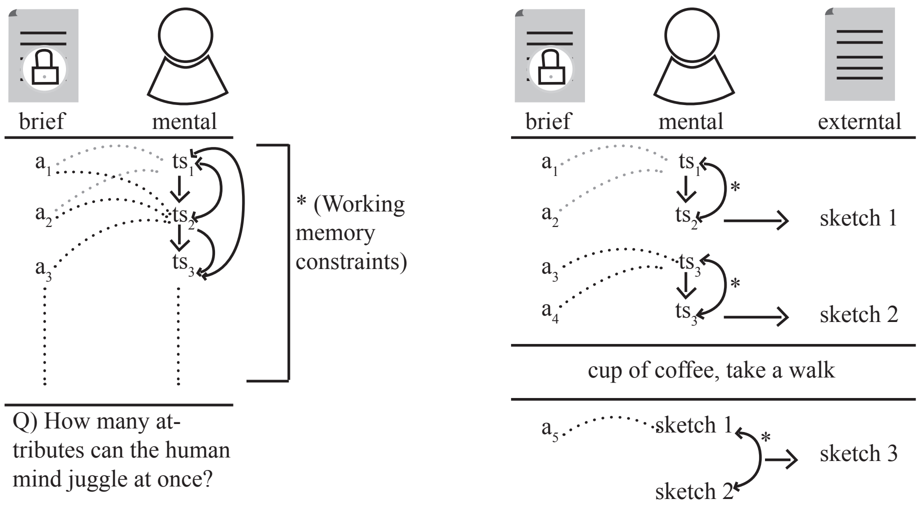

Figure 1: Two different possibilities for the design process

As postulated here, the main "reason" for external representations is the limitations of the human mind. A computer however might follow the first model as it relatively has no such constraints. The problem arises with the quantification of attributes. How one can objectify aesthetics is an issue and a whole different topic. Sketches also provide room for detection of unintended relations (Suwa, M 2000) which is a very welcome phenomenon in a design process. Another perspective at the nature of visuospatial "externalization" arises when a design team works together. In that case the "sketch" shown in fig.1 may be substituted by a verbal articulation which is then internalized by another teammate who then compares it with other attributes and so on. Attributes may also be weighted with weightage determining the "importance" and hence the amount of time spent deliberating on provisioning for that attribute in the solution. This weightage "may" also be subjective in a team.

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VISUAL REASONING AND DESIGN

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Abstract

McKim viewed the design ideation process as composed of the iterative interactions of the following three processes; *imagining* process to synthesize in mind, the *drawing* process to represent the synthesis results, and the *seeing* process to analyze the drawings (McKim 1972). McKim's drawing could be regarded as *representation*, while seeing and imagining combined can be regarded as *reasoning*. The nature of design reasoning as the iterative process of seeing-moving-seeing has also been discussed in (Schon & Wiggins 1992). This could be viewed as *analysis, synthesis* and *evaluation*.

As design tasks often involve spatially structured objects and physical spaces as the workshop chairs mentioned, visuo-spatial aspects of the above design ideation process are naturally emphasized. Yet, we believe the design ideation process of seeing, imagining and drawing would be essential for all kinds of design tasks. The ability for this design ideation could be enhanced through suitable trainings where visuo-spatial aspects could be used to lead this ideation process in more natural ways. We hope that this view would help in supporting design learning.

With the above intent, we define *visual reasoning* as an iterative process composed of visual analysis, visual synthesis and modeling so that these three would account for seeing, imagining and drawing, respectively, in a more visuo-spatial way from the context point of view and in a more flexible way from the methodological way. A typical problem for visual reasoning could be the missing view problem, which requires visually constructing a valid 3-D solid object by analyzing two 2-D orthographic projections (Figure 1). Note that due to the incompleteness of the constraints given with two orthographic views, there are multiple solid objects satisfying these geometric constraints. Thus, the solution process requires visual synthesis with partial clues and corresponding internal and external representation of the synthesis result in order to go through the next

reasoning step starting with visual analysis. In our earlier research, we found out that visual reasoning ability, that is, missing view problem solving ability, is closely related with design experiences (Kim et al 2005). We are building an intelligent tutoring software system to help learning this visual reasoning in a personally customized manner for individual learners.

Currently we are expanding the visual reasoning tasks to be used in assessing individual ability and in supporting design learning. Particularly, we have devised a few visual reasoning tasks and are conducting experimental study to find further relations between design capability and underlying cognitive ability in visual reasoning. A plan view of an architectural structure is given, then pictures of multiple structures similar to the plan view are given together with a picture of the very correct architecture as shown in Figure 2. With a few iterations of these for about 15 seconds each, a correct one is to be selected. Emergent shape reasoning capability, that requires finding several meaningful shapes from architectural sketch, has also been devised. An architectural design task is used to evaluate design problem solving capability.

Using these visual reasoning tasks, we intend to observe reasoning procedures and behaviours as well as the performance results. We hope this experiment will help our goal to develop an intelligent tutoring software system for visual reasoning, and design eventually. We will discuss some experiment results and implications for design learning and education.

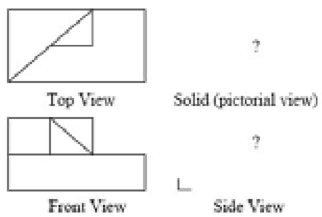

Figure 1. Missing View Problem.

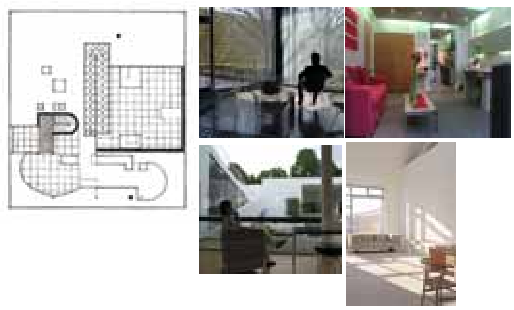

Figure 2. Layout and Pictures.

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