What do architects and students perceive in their design sketches? A protocol analysis

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The present research aims at examining what information architects think of and read off from their own freehand sketches, and at revealing how they perceptually interact with and benefit from sketches. We explored this in a protocol analysis of retrospective reports; each participant worked on an architectural design task while drawing freehand sketches and later reported what she/he had been thinking of during the design task. This research lies within the scope of examinations of why freehand sketches as external representation are essential for crystallizing design ideas in early design processes. © 1997 Elsevier Science Ltd.

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

External representations, e.g. diagrams, sketches, charts, graphs and even hand-written memos not only serve as memory aids, but also facilitate and constrain inference, problem-solving and understanding. Geometry diagrams in theorem-proving tasks, e.g. guide solvers to explore only visually plausible inference paths [1], facilitate retrieval of perceptual-chunks that are useful for constructing efficient proofs [2,3], and provide visual cues for extracting new chunks from the current problem and assimilating them for future use [4]. Petre [5] showed that good use of graphical representations in programming environments, i.e. what she calls 'secondary notation' of graphics, prevents programmers from miscueing and misunderstanding. Larkin and Simon [6] enumerated general features of diagrammatic representation by which human problem-solving is facilitated, providing a list of how facilitation tends to occur. Tversky discussed how people use space for conveying meanings and abstract concepts, drawing on examples from ancient depictions and children's early drawing [7], as well as from comtemporary charts, graphs and diagrams [8].

1 **Gelernter, H** 'Realization of a geometry-theorem proving machine' in **E A Feigenbaum and J Feldman** (eds) *Computer and thought* MacGraw-Hill (1963)
2 **McDougal, T and Hammond, K** 'A recognition model of geometry theorem-proving' in *Proceedings of the 14th annual conference of the cognitive science society* LEA, NJ (1992) pp 106–111
3 **Koedinger, K R and Anderson, J R** 'Abstract planning and perceptual chunks: elements of expertise in geometry' *Cognitive Science* Vol 14 (1990) pp 511–550.
4 **Suwa, M and Motoda, H** 'PCLEARN: a model for learning perceptual-chunks' in *Proceedings of the 16th annual conference of the cognitive science society* LEA, NJ (1994) pp 830–835

0142-694X/97 $17.00 *Design Studies* **18** (1997) 385–403 PII: S0142-694X(97)00008-2

Facilitation by external representation derives, not just from its external existence, but from the interaction between the representation and the cognitive processes of interpreting it [9]. Architects' sketches are also a tool for this sort of interaction [10,11]. Architects put ideas down on paper and inspect them. As they inspect their own sketches, they see unanticipated relations and features that suggest ways to refine and revise ideas. This cycle — sketch, inspect, revise — is like having a conversation with one's self [12]. Goldschmidt [13] conjectured that sketches give access to various mental images, figural or conceptual, that may potentially trigger ideas in the current design problem. Furthermore, she claimed that visual design thinking is a rational mode of reasoning as well, although it has been set aside behind the dominant paradigm of linguistic, logical reasoning in cognitive science [14]. This claim perfectly coincides with a growing enthusiasm for diagrammatic reasoning in cognitive science, especially in the case of groups of researchers who claim that visual information is valid for reasoning and that visual reasoning has its own sound logic [15,16], just as conventional sentential reasoning does.

Why are sketches a good medium for reflective conversation with one's own ideas and imagery? This general question can be reduced to more precise issues to be addressed. One is the issue of what aspects or features of sketches themselves, as external representations, allow for reflective conversation, an issue addressed by Goel [17]. He found that because freehand sketches in the early design process are 'dense' and 'ambiguous' in Goodman's [18] sense, they work well for exploring design ideas. Another is the issue of what kinds of interaction architects have with their own sketches. This issue can, in turn, be divided into three separate problems; 'how do they see sketches?', 'what do they see in sketches?' and 'how and what do they draw?' Goldschmidt's work [13] pertains to the first category. She observed that there are two ways of inspecting sketches, i.e. 'seeing as' and 'seeing that', and that the former is an especially powerful means for what she calls interactive imagery. Van Sommers's work [19] looked at graphic production from a developmental and cognitive perspective, and hence pertains to the third category. The present paper addresses the second problem, 'what architects see', by focusing more precisely than the past work on the contents of information categories that architects 'see' in their own sketches. The purpose of the present paper is to analyze how those different types of information intermingle with each other in their design thoughts and to reveal how practicing architects differ from students in it.

We brought these phenomena into the laboratory in a protocol analysis of retrospective reports of subjects' design thoughts. The most typical method

5 **Petre, M** 'Why looking isn't always seeing: readership skills and graphical programming' *Communications of the ACM*, Vol 38 No 6 pp 33–44.
6 **Larkin, J and Simon, H A** 'Why a diagram is (sometimes) worth ten thousand words' *Cognitive Science* Vol 11 (1987) pp 65–99.
7 **Tversky, B** 'Cognitive origins of graphic conventions' in **F. T. Marchese** (ed) *Understanding images* Springer, New York (1995a) pp 29–53
8 **Tversky, B** 'Perception and cognition of 2D and 3D graphics' in *Human factors in computing systems: CHI95 conference companion* ACM, New York (1995b) p 175
9 **Miyake, N and Hatano, G** 'Socio-cultural constraints and beyond' *Progresses of Cognitive Science* (in Japanese) Vol 2 (1991) pp 105–131
10 **Laseau, P** *Graphic thinking for architects and designers* (2nd edn) Van Nostrand Reinhold, New York (1989)
11 **Robbins, E** *Why architects draw* MIT Press, Cambridge (1994)
12 **Schon, D A and Wiggins, G** 'Kinds of seeing and their functions in designing' *Design Studies* Vol 13 (1992) pp 135–156.
13 **Goldschmidt, G** 'The dialectics of sketching' *Creativity Research Journal* Vol 4 No 2 (1991) pp 123–143.
14 **Goldschmidt, G** ' On visual design thinking: the vis kids of architecture' *Design Studies* Vol 15 No 2 (1994) pp 158–174.
15 **Barwise, J and Etchemendy, J** 'Visual information and valid reasoning' in **W. Zimmerman** (ed) *Visualization in mathematics* Mathematical Association of America, Washington DC (1990)
16 **Stenning, K and Oberlander, J** 'A cognitive theory of graphical and linguistic reasoning: logic and implementation' *Cognitive Science* Vol 19 (1995) pp 97–140.
17 **Goel, V** *Sketches of thought* MIT Press, Cambridge (1995)
18 **Goodman, N** *Languages of art* Bobbs-Merrill, Indianapolis (1968)
19 **Van Sommers, P** *Drawing and cognition* Cambridge University Press, Cambridge (1984)

for analyzing subjects' cognitive processes is and has been, concurrent thinking-aloud verbal reports [20,21]. We did not employ it, because talking aloud may adversely interfere with participants' perceptions during their sketching activities [22]. This issue is discussed in more detailed in Section 5.1.

Another purpose of this study is to explore implications for ways that future design tools, especially sketching tools, assist designers/architects. Many researchers [17,23,24] claim that the currently available computational tools do not support naive freehand sketching processes in the early design phases. This is because they are intended for visualizing, comparing, testing and implementing the design ideas that have already been obtained in earlier design processes, not for supporting the very processes in which design ideas occur. Several projects [23–25] on pen-based sketch tools have recently addressed this problem. We believe that the present research will be able to provide important implications for more endeavors. This issue is discussed in Section 6.3.

1 Experimental design

The experiment consisted of two tasks, a design task and a report task. Two practicing architects and seven advanced students in an architectural department participated. In the design task, each participant worked on designing an art museum through successive sketches for 45 min. They were provided with a simple diagram representing an outline of the site, in which they were supposed to arrange not only a museum building, but also a sculpture garden, pond, green area and parking lot. The building was required to have an entrance(s), ticket office(s), display rooms for about 100 paintings, a cafeteria and gift shop. Participants were supposed to use freehand sketches as a tool for designing. They were not asked to report concurrently what was going on in their minds, nor were they interrupted by the experimenter during the design task. Their sketching activity was videotaped.

Following the design task was the report task. While watching their own videotape, participants were asked to remember and report what they were thinking as they drew each portion of each sketch. In case their reports lagged behind the videotape, they were allowed to stop the tape until reporting all that they remembered about the current topics. Therefore, the duration of the report task depended on the participant, varying from 1 hr to 1 hr 15 min. Participants were not interrupted with questions during the report, except for the following cases; when they obviously skipped reporting about certain portions of their sketching activity, then they were requested by the experimenter to rewind the videotape and report those

20 Ericsson, K A and Simon, H A *Protocol analysis: verbal reports as data* (revised edn) MIT Press, Cambridge (1993)
21 Dorst, K and Cross, N 'Protocol analysis as a research technique for analysing design activity' in *Proceedings of 1995 design engineering technical conferences* ASME, Vol 2 (1995) pp 563–570.
22 Lloyd, P 'Can concurrent verbalization reveal design cognition' *Design Studies* Vol 16 No 2 (1995) pp 237–259.
23 Landay, J A and Myers, B A 'Interactive sketching for the early stages of user interface design' in *Human factors in computing systems: proceedings of CHI'95* ACM, New York (1995) pp 43–50
24 Kramer, A 'Translucent patches — dissolving windows' in *Proceedings of UIST'94* ACM, New York (1994) pp 121–130
25 Gross, M D 'The electronic Cocktail Napkin — a computational environment for working with design diagrams' *Design Studies* Vol 17 No 1 (1996) pp 53–69.

portions. We recorded the participants' voices, as well as videotaping the screen itself on which not only their sketching activity in the design task, but also their pointing gestures in the report task were visible.

2 *Information categories*

In interpreting the data, the first step was to determine a set of information categories into which the contents of participants' protocols could be fit. Table 1 shows the four major categories and their subclasses. We derived the four categories from theoretical discussions and historical evidence on how external representations convey meanings and concepts, from past literature on design processes that suggest what architects generally think of in design process, and from intensive study of the protocols. Many theorists like Larkin and Simon [6] and Tversky [7] have suggested that the pictorial devices for expressing meanings and concepts consist of (a) depicted elements, whether objects, spaces or icons, and (b) spatial arrangement of them. They have also suggested that spatial arrangements have the ability to express not only literal spatial relations, but also abstract or conceptual relations. This analysis suggests three information categories: depicted elements, spatial relations and abstract relations.

Depicted elements are sometimes intentionally drawn, and thus possess explicit shapes and sizes, but sometimes they are embedded as partial elements or implicit objects, and emerge to the viewer's eyes only when he/she discovers a new way of restructuring the whole configuration that includes those elements [26]. Larkin and Simon [6], and Koedinger and

26 **Liu, Y-T** 'Some phenomena of seeing shapes in design' *Design Studies* Vol 16 No 3 (1995) pp 367–385.

Table 1 Information categories and their subclasses

Major category	Subclasses	Examples of phrases in protocols as evidence
Emergent properties	Spaces	"Areas", "places"
	Things	Descriptions or names of something
	Shapes/angles	"Round", "prolonged", "wavy line", "too sharp a corner"
	Sizes	"Big", "tiny", "narrow"
Spatial relations	Local relation	"Adjacent", "far", "connected", "lined up"
	Global relation	"Symmetrical", "configuration", "axis"
Functional relations	Practical roles	"A ticket office should be close to an entrance.."
	Abstract features/reactions	"Waves/forces (from this shape)", "good show to visitors"
	Views	"View line", "the appearance (of this building)"
	Lights	"(This place is always) bright, having sunshine"
	Circulation of people/cars	"People meander through (this narrow space)"
Background knowledge	-	"Post/beam structures", "An important thing in an urban setting is..."

Anderson [3] referred to this property of diagrams as 'emergent properties'. Therefore, we chose to name the first category as 'emergent properties', instead of just depicted elements. 'Spatial relations' hold among these depicted elements and are inherently visual features in the sense that architects/designers can see them in their own sketches, just as emergent properties are also visual. In the domain of architectural design, abstract relations typically correspond to 'functional relations'. Forms and functions are the two major concepts in the domain that are conceptually distinct, and yet intertwined [27]. Functional relations in this domain denote interactions among spaces, things, people visiting or using them, and/or environments. Unlike emergent properties and spatial relations, functional relations are inherently non-visual aspects of architectural designs.

In addition to the previous three categories, we established a fourth one, i.e. 'background knowledge', because the past history of studies of cognitive science has indicated that every cognitive task performed by human beings is mediated by background knowledge about the domain to which the task belongs. Background knowledge in the domain of architectural design includes (a) domain knowledge about structures and materials for fulfilling certain functions, and spatial arrangements; (b) standards for doing the aesthetic and preferential evaluations for their own design decisions; and (c) knowledge about the relevance and influence of the architectural designs to/from the social contexts, and the environments in which the architecture is built.

After reviewing all the protocols, we distinguished subclasses of each category. For emergent properties, in cases where participants discovered or created certain areas for something or some functions, or referred to already depicted (e.g. encircled) areas, we encoded the evidence as spaces. In cases where subjects depicted things, referred to already depicted things, or even observed that things which were not actually there by the appearance of other surrounding depictions, we encoded the evidence as things. Shapes/angles denote the shapes of things or spaces, or the angle that two items form against each other. Sizes denotes the size of things or spaces. The latter two are visual attributes of the former two. These four subclasses constitute emergent properties.

Spatial relations were subdivided into two classes, local relations and global relations. Local relations includes (a) adjacency, (b) remoteness, (c) physical connectedness by mediation of other things and (d) alignment, which holds between two or more different spaces or things. Global relations includes (e) a configuration of spaces or things within the whole

27 Arnheim, R *The dynamics of architectural form* University of California Press, Berkeley (1977)

site or a certain area in it, (f) symmetry of spaces or things, and (g) axes, or a sense of direction which spaces or things inherently possess.

Functional relations were subdivided into five categories. Practical roles refers to semantic relevance, conflict, separateness among practical roles of spaces or things. This is a subclass concerning how people use them. Abstract features/reactions include interrelations among the abstract features of spaces or things, as well as interactions and feelings which people may have from experiencing spaces or things. This is a subclass concerning how people react to them. The other three subclasses are more specific types of interactions between people, spaces and/or things, which are typical in architectural design. Views includes the actual appearance of spaces or things imagined by participants, and the visibility of a space to and from another space within the site. Lights denotes interactions between depicted elements and sunlight. Circulation of people/cars is an encoding of participants' reports about people/cars moving around within or outside the site.

We did not divide background knowledge into subclasses, because the precise distinction of what types of knowledge participants refer to is not relevant to the present research.

3 *Protocol analysis*

3.1 *Encoding into information categories*

For each participant, we first encoded all the information in the verbal protocols into the subclasses of information categories. Basically, verbal protocols were the main target of our analysis; we analyzed words, phrases and sentences as evidence of each subclass of information categories. To supplement the verbal protocol, we employed the visual data of videotapes which had recorded participants' pointing gestures in reporting, in two ways. First, because verbal reports contained abbreviations and ambiguous pronouns, the participants' pointing gestures helped to clarify what was being referred to. Second, participants sometimes omitted reporting certain depictions that were used in their sketching activities. Visual data revealed these unreported depictions. In these cases, we encoded that some 'unknown' thoughts were actually there.

Table 2 displays a 3-min portion of a protocol of a practicing architect, beginning 9 min into the design task. When we encoded raw protocols, it was necessary to augment ambiguous phrases with interpretations. We did this by seeking justifications. One kind of justification was to know which areas or depictions the participant was talking about from his/her gestures of pointing to the screen while reporting. Another kind was to interpret phrases or pronouns from contextual, pragmatic and semantic information. [p:..] corresponds to the former, and [s:..] to the latter. In the right column, the encoded subclasses and phrases for which we encoded are listed.

We did not encode goals or intentions for future actions, as they typically referred to meta-level control over cognitive processes rather than interpretations of sketches. A typical example is seen in segment 43 in Table 2, i.e. 'yes, don't forget this'.

3.2 Segmentation

Then, we divided the entire encoded protocol into segments. A segment, whether consisting of one sentence or many, is defined as one coherent statement about a single item/space/topic. If a participant contributed more than one statement about an item/space/topic, the statements were regarded as different segments; e.g. see the portion of segments 42 and 43 in Table 2. This portion includes statements about a 'tension' between two areas, but should be divided into two segments as such. In segment 42, he devised a notion of 'tension', suggesting its importance in a surburban setting. Then, in segment 43, he explored the idea by placing water or sculpture elements in one of the two areas. Even if participants omitted reporting a depiction which was actually recognized in the videotape, the depiction should stand for a segment, because we are sure that some design thoughts had been actually there.

A segment usually included several information subclasses, and an entire protocol for a participant typically consisted of hundreds of segments.

Although we devised the notion of 'segments' independently, we learned afterwards that Goldschmidt [13] had already proposed a similar way of decomposing design processes into small units, 'design moves' and 'arguments'. According to her definition, a design move is 'an act of reasoning which presents a coherent proposition pertaining to an entity that is being designed', and arguments are 'the smallest sensible statements which go into the making of a move' (p 125). This definition and the examples shown suggest that a segment in our notion corresponds to a design move in its granularity.

3.3 Conceptual dependency among segments: two types of segments

Next, we analyzed conceptual dependency among segments. We define a segment to have a conceptual dependency (CD) to a past segment, whether

Table 2 An example of encoding protocols into information categories

Segment no: protocols (interpretations)	Encoded categories ("phrases" which are encoded as such)
37: I try to shelter my parking back behind that [s: building mass] Just a note behind this area [p: building area]. Other things [s: some events in the building] would go on if I try to shield using this bigger mass of this space [p: building area]..	space ("parking", "this space") local spatial relation ("back behind that") practical roles ("shelter", "shield") size ("bigger mass")
38: I've got features. Sculptures, water, trees. ..It's become points [s: visual points]. If I am going to develop this [s: the design of this area]...since I don't know what's out there [p: the outside environments], we have kind of a magical project here with the gallery ... with lots of outside water and lots of sculpture ... have the building control all of our visual points. Where you are and what you see. We have some control over that.	things ("sculptures", "trees"), space ("water") views ("visual points", "what you see") background knowledge ("don't know what's out there") circulation ("where you are") abstract features/reactions ("magical project", "control all of our visual points", "control over where you are and what you see")
39: This wavy line [p: between sculptures and the outside water] is just a rapid, just a note to myself. Something's going to happen here between. Maybe will look at other things but I am going to see this. This is going to stop my view [s: a note to stop my view].	abstract features/reactions ("something's going to happen") spaces ("here") local spatial relation ("between")
40: Just trying to fill in the notion that maybe parking is feeding backward [s: of the building] in this area [p: parking area] ... It's difficult because it's an awkward access...	spaces ("parking"), circulation ("access") local spatial relation ("backward") background knowledge ("awkward")
41: What did I do there?.. you know I don't know... Oh looking at the sequence of what I'm doing [s: trying to remember his past thoughts]. I know exactly what I'm doing... That is from here ... You have a spatial relation ... carry on ... You can see from here [p: the sculpture area drawn in segment 38] back to the entry point [p: the entrance from the nearest public road to the site]. So you can see these elements [p, s: something located near the entry point].	local spatial relation ("spatial relation") views ("see") space ("here", "entry point") things ("these elements")

[s: ..] - this interpretation is obtained from pragmatic and semantic inference by the experimenter.
[p: ..] - this interpretation is grounded by the subject's act of pointing to areas or things in reporting.

immediately preceding or anywhere in past, when (a) the item/space/topic in the current segment derives from its relationship with another item/space/topic which the past segment was concerned about, or (b) the current segment explores the same item/space/topic which the past segment was concerned about, or (c) a design idea or a constraint established in the past segment has been generalized and is applied to the current segment.

As a result of this analysis, we found that the entire design process includes many blocks of contiguous segments. We call each block a 'dependency

Table 2 Continued

Segment no: protocols (interpretations)	Encoded categories ("phrases" which are encoded as such)
42: There is a sense of tension between where you came from [s: entry point] and also where you are coming to [s: the area in topic]. I think that [s: this tension] is important in a suburban setting where you are trying to attract people in here, to make a good show out here and use the light to focus on what I hope.	abstract features/reactions ("tension") space ("where you came from and where you are coming to") background knowledge ("it is important in a suburban setting ... to ...") abstract features/reactions ("attract people", "make a good show") lights ("use the light")
43: I am making an assumption that the water and the sculptural pieces are going to be a nice draw in a surburban environment.. These [s: water and sculptural pieces] stand for a tension between things in my thought ... yes don't forget this. This is important to me.	things ("water", "sculptural pieces") abstract features/reactions ("draw") abstract features/reactions ("tension") background knowledge ("important to me")
44: I am still not sure whether or not this be a hard line or a soft formed building ... If I follow that basic diagram before, this is a large block of the museum space around this zone ...	shapes/angles ("hard line or soft formed ...") spaces ("museum space", "around this zone") sizes ("large block of")
45: With an entry form between common space [p: the museum space] and these ancillary functions. The cafe, the ticket booth, and the gift shop.	spaces ("cafe", "ticket booth", "gift shop") local spatial relation ("between ... and ...") practical roles ("ancillary functions") circulation ("entry form")
46: And we have this linkage [p: between the museum building and the ancillary functions]	local spatial relation ("linkage") practical roles ("linkage")
47: And something's gonna happen at this very controlled outdoor area.	abstract features/reactions ("something's going to happen", "controlled") spaces ("outdoor area")
48: Just a scribbled note to just say ... some kind of a plaza texture [p, s: on the controlled area] can be glass, can be anything, but it's gonna be a controlled surface. That can be out here.	things ("plaza"), spaces ("surface", "out here") abstract features/reactions ("controlled") background knowledge ("texture", "glass or anything")

[s: ..] - this interpretation is obtained from pragmatic and semantic inference by the experimenter.
[p: ..] - this interpretation is grounded by the subject's act of pointing to areas or things in reporting.

chunk'. We call segments which stand alone, not forming a chunk with others, 'isolated segments'. The contiguous segments that should form a dependency chunk are determined such that, for each chunk, every constituting segment, except for the first segment of the chunk has a CD from at least one of the preceding segments of the chunk, whether or not it is immediately preceding. The first segment does not have a CD from its immediately preceding segment ('segment P') nor from any segments in the dependency chunk, if any, to which 'segment P' belongs.

A dependency chunk stands for a sequence of conceptually interrelated design thoughts, each of which was evoked in relation to preceding thoughts in the chunk; e.g. suppose that a participant designed an entrance of the museum building, and then turned to design a ticket office and a gift shop. If the participant designed the ticket office and gift shop, considering that a ticket office should be practically located near the entrance and a gift shop should be located near the entrance/exit for allowing visitors to browse around just before going home, then this sequence of design thoughts should form a dependency chunk. Figure 1 is a schematic representation of a configuration of segments, conceptual-dependency links and dependency chunks, for the portion of the protocols of Table 2. Each rectangle node represents a segment and each link between two nodes a CD. The numbers written beside nodes correspond to the segment numbers. Segments are depicted from the left in the order of their occurrence. The segments forming a dependency chunk are depicted in the same vertical level.

The first segment of a dependency chunk and an isolated segment indicated that the participant's focus of attention departed from the preceding thoughts and moved to another item/space/topic. We classified such a segment as a 'focus-shift' segment. It corresponds to the gray nodes in Figure 1. Each focus-shift segment is depicted such that it is displaced lower than its immediately previous segment. We call all the other segments, those belonging to a dependency chunk but not the first segment of the chunk, 'continuing segments'. In a continuing segment, the participant keeps exploring a topic which is conceptually related to the past segment(s) within the same chunk. It corresponds to the white nodes in Figure 1.

A central tenet of this research is that architects' acts of shifting the focus of attention in an opportunistic way and their acts of exploring related

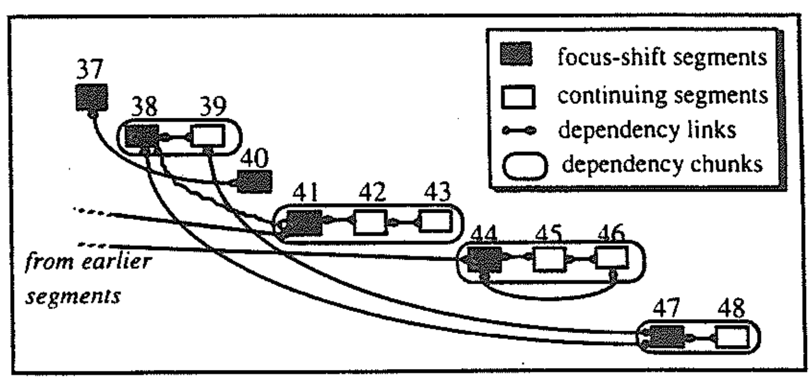

Figure 1 A schematic representation of segments, conceptual dependency links and dependency chunks

topics consecutively are the two important constituents of their design activity. This view was derived from our notion of dependency chunks. Shifts of focus allow for a lateral variety of design topics/ideas and a sequence of related thoughts allows for detailed, deep exploration of design ideas. The former corresponds to what Goel calls 'lateral transformation' and the latter to what he calls 'vertical transformation' [17].

4 Results

4.1 Observations about the design process

Table 3 shows the percentage of continuing segments and focus-shift segments for average students, and for the two architects. Architects have remarkably more continuing segments than students. Table 4 shows the total number of dependency chunks, the number of dependency chunks whose length is 2 and the number of dependency chunks whose length is more than 2. Architects have many more dependency chunks than students. Importantly, this difference comes mainly from the number of chunks whose length is more than 2, while the number of chunks whose length is 2 does not differ greatly between architects and students. These results, that architects have more and longer dependency chunks than students, indicate that once architects shift their focus of attention, they think more deeply about the topic. What causes this difference? We believe it occurs because architects are able to 'read-off' more different types of information from their sketches. In the following section, we will discuss what types

Table 3 The percentage of both types of segments in the protocols of students and architects

Segment types	Students (%) (aver. ± std.)	Architect 1 (%)	Architect 2 (%)
Continuing	35.2 ± 4.2	49.2	46.8
Focus shift	64.8 ± 4.2	50.8	53.2
Total	100	100	100

Table 4 The number of dependency chunks for students and architects

Kinds of dependency chunks	Students (aver. ± std.)	Architect 1	Architect 2
Two in length	13.7 ± 4.0	18	16
More than two	12.6 ± 2.7	39	19
Total number	26.3 ± 3.8	57	35