IDEA DEVELOPMENT CAN OCCUR USING IMAGERY ONLY

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Abstract: This paper shows that expert architects can effectively develop ideas without sketching during early conceptual designing. We analysed design protocols of six expert architects working on two different design problems under two different conditions, one in which they were blindfolded and one in which they were sketching. Architects developed design ideas efficiently when they were blindfolded, as opposed to the common view that they would better develop ideas with sketching.

Use of mental imagery is a key process in problem solving, creativity, artistic output, and many other types of human activity and interaction. What makes its use crucial is that it is an internal and fundamental mental activity that is consciously or subconsciously used during the creative process. Internal processes (such as perception, interpretation, imagination and recall) are used interactively with what occurs "outside" the mind (such as bodily movement, modelling and sketching). Internal representations refer to imagery, constructed by mental visualisation and synthesis, while external representations refer to sketches, computer drawings/models, and product models.

In the early phases of the design process, architects begin with reading the design brief and understanding the problem. They usually visit the prospective site, meet clients, and negotiate the requirements of the brief Lawson, 1990. This initial period of conceptual designing can be lengthy, without even touching pen to paper, that is, without the need to externalize the ideas. Thus, before and after designers start to draw, the thinking process typically occurs throughout their daily routine as well; some architects' design ideas come when they are not concentrating on their project (Murty & Purcell, 2003). This thinking is of a visual type (Arnheim, 1969), not in the sense of "seeing", but a mechanism resembling perception (Kosslyn, 1980; Pylyshyn, 1984). Thus, designing occurs not only when designers sketch, but evolves through the timeline of an internal design activity. This process can be referred to as the use of mental imagery in designing, which occurs naturally to designers, whether consciously or subconsciously, and plays an important role in designing.

Ferguson, 1992 described designing without drawings as the "The artisan's way":

> The product is drawn only in an artisan's mind and worked out directly in suitable materials … First the ideas exist, where the idea could be a clear vision or a glimpse of a possibility. If the idea is in the head of an artisan, he can make the model of the idea directly… or he might make a sketch of an idea on paper in order to keep in mind the shape and the configuration of components (p. 3–4).

This view maintains that the ideas are the basis of conceptual design activity, whether they are drawn as they come into mind or not drawn. Ferguson, 1992 considered design as invention and reported anecdotal evidence on how creative engineers solved technical problems by using their mental representations. In this literature, the role of the mind's eye was described in terms of the use of tacit knowledge. Tacit knowledge is referred to as the knowledge of how objects would behave in the physical world, our judgments of relative speed, dynamic relationships between objects, knowledge about the use of the right material and so on. Some anecdotes on the use of imagery in Ferguson's book refer to imagery as dynamic scenes

wherein objects were animated for resolving a functional problem, while some of the anecdotes refer to a subjective experience of seeing the product or the solution. In the same vein Weisberg, 1993) presented anecdotes about scientists in various disciplines who had used their mental imagery for creative inventions. Other examples are often quoted of major architects, such as Frank Lloyd Wright, who could conceive of, and develop a design entirely using imagery with an external representation of the design only being produced at the end of the process (Toker, 2003).

Anecdotal views of engineering design, architectural design and of other creative processes put considerable emphasis on the role of imagery. In many of these imagery has been used in solving design problems or for aiding inventions. The tacit knowledge of the professionals could extend the range of the use of their mental representations which makes it possible for these experts to design buildings or invent structures. Use of imagery alone during conceptual designing can be a tool for idea development for generating thoughts on the fly without the need to settle them on a sketch sheet. It can support a brainstorming process where one is allowed to generate ideas without worrying about constraints and their implementation. This might have the potential to improve idea development.

1. Related Work

In the design literature the link between visualisation and engineering design drawing is well established (Hammond et al., 1971, Pare et al. 1987, Ullman et al., 1990, Ferguson, 1992). The research of Bertoline et al., 1995) suggests that visualisation ability is central to design, and that imagery provides a bridge between design ideas and their representation in sketching and drawing. It has also been argued that the ability to draw is directly related to the ability to imagine, and that the ability to imagine will feed back into the ability to draw (Laseau, 2000).

In design research there is a number of studies which focus on the use of imagery alone during designing. (Athavankar, 1997) conducted an experiment where an industrial designer was required to design a product in his imagery alone (with a blindfold on), without having access to sketching and the visual feedback it provides. The results of the study were qualitative, claiming that the designer was able to evolve the shape of the object, manipulate it, evaluate alternative modifications, add details and colour to it. Similar results were obtained in a study with software designers (Petre & Blackwell, 1999) where they were required to design using their mental imagery only. These studies emphasize that using imagery alone does not put a designer at a disadvantage. The further question is whether imagery might lead to a better performance than sketching in some aspects of

conceptual designing. There are implications in cognitive science that this might be possible for experts.

1.1. SKILLED IMAGERY: BLINDOFOLDED CHESS AND DESIGNING

Researchers on expert performance agree that expertise in the form of stored knowledge becomes readily available for performing relevant tasks. Experts can process recall of knowledge interactively with the generation of images in working memory (Ericsson & Delaney, 1998). The studies with the expert chess players identified a skilled imagery (Simon & Chase, 1973, Saariluoma, 1998, Ericsson & Kintsch, 1995) which shows evidence of the use of imagery for longer periods and with higher cognitive loads.

Blindfolded chess is played where the players do not see the pieces or the board. Research shows that it is a skill-related activity, and the more skilled a player is, the better s/he normally plays blindfolded chess (Saariluoma & Kalakoski, 1997). Skilled imagery research indicated that the memory load can be substantial, and the experts successfully play up to 10 games simultaneously (Saariluoma, 1998). This demonstrated extensive capacity is of interest to researchers for investigating the spatial memory and skilled mental images of expert players. Earlier empirical studies showed that mental transformation plays an important role in their perceptual processes and that these experts develop specific ways for chunking visuo-spatial information that enable them to rapidly retrieve and use it in a new context (Simon & Chase, 1973). This also means that experts have an extended long-term working memory to supplement their short-term working memory (Ericsson & Delaney, 1998).

Saariluoma et al. (2004) compared memory performance, attention and problem solving of highly experienced blindfolded chess players in a brain scanning (PET) investigation. They found that the memory task was performed spatially, such that the storage of information in LTWM involved spatial encoding. Problem solving tasks under imagery conditions involved mental transformation of the pieces, storing information in LTWM and thinking of related activities such as planning and conceptual information processing. The results maintain that skilled visuo-spatial representations are characterized by previously learned visuo-spatial chunks and automated processing habits (Saariluoma et al., 2004). The study concludes that experts' chess-specific images are not necessarily represented in the same way as ordinary mental images.

Experiments with blindfolded expert architects showed that they were able to design during an experimental period of 45 minutes, with complex design outcomes involving residential buildings (Bilda et al., 2006, Bilda & Gero, 2006). Protocol analysis of the blindfolded designing sessions showed that the expert architects constructed visuo-spatial representations through

verbalizations without a perceptual interaction with their sketches. Therefore the expert architects' blindfolded performance can be related to two factors: access to and use of previously learned visuo-spatial information and skills.

1.2. USE OF LINKOGRAPHS TO UNDERSTAND IDEA DEVELOPMENT DURING SKETHCING

Ideas are developed in the mind; they are thoughts, conceptions that serve us to reason with. Linkography is a system of notation and analysis of design processes that focuses on links among design ideas, developed by Goldschmidt (1990; 1997; 2003) and extended by others (Van-der-Lugt, 2003, Kvan & Gao, 2005, Kan & Gero, 2005). Linkography has been established as a technique for using in protocol analysis to study designers' cognitive activities and was first introduced to protocol analysis (Goldschmidt, 1990) to assess the design productivity of designers. In this technique the design process is decomposed by parsing the recorded design protocol into small units called "design moves". Goldschmidt defines a design move as: "a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move" (Goldschmidt, 1997).

A linkograph is constructed by discerning the relationships among the moves/segments to form links. It can be seen as a graphical representation of a design session that traces the associations of every design move. The design process can then be looked at in terms of the patterns in the linkograph which display the structure of design reasoning. Goldschmidt (1997) systematically analysed and compared an individual's and a team of designers' design process using linkography. In this study Link Index (LI) and critical moves (CMs) were devised as indicators of design productivity. Link Index is the ratio between the number of links and the number of moves, and critical moves are design moves that are rich in links. Design productivity is considered to be positively related to the link index and critical moves, that is, a higher value indicates a more productive design process.

1.3 SKETCHING AND BLINDFOLDED DESIGNING

In design research, sketching is considered as the medium to set out thoughts on the fly, that is to generate design ideas, concepts and further develop and elaborate them. For many designers, sketching is the medium for developing ideas because they have been trained to do this by using sketches. The benefit of externalizing ideas, concepts on paper is that they can be easily re-visited during later stages of designing. Therefore experts' sketching activity, is based on producing multiple sheets and tracing previous layouts, to help them to link and navigate between the ideas.

The benefit of using mental imagery has been discussed in the context of creativity for facilitating discoveries. Designers consciously or subconsciously use their mental imagery to produce concepts and ideas (Murty & Purcell, 2003). Compared to sketching, use of mental imagery is considered more ambiguous in nature (Fish & Scrivener, 1990) which means ideas and thoughts remain on the fly. Therefore mental imagery has the potential to enhance idea generation, compared to sketching wherein the ideas are concretized once they are externalized.

In this paper we discuss whether it is possible to effectively develop ideas using imagery alone during conceptual designing. In the next section we describe the method, including experiment design and how idea development was analysed in the design protocols. Then we compare the effect of imagery and sketching on idea development by analysing idea links in design protocols.

2. Method

The six architects who participated in the study (2 female and 4 male) have each been practicing for more than 15 years. Architects A1 and A2 have been awarded prizes for their designs in Australia; they have been running their own offices and also teaching part-time at the University of Sydney. Architect A3 and A4 are senior designers in two of the well-known largest architectural firms and have been leaders of many residential building projects from small to large scales. A5 and A6 are the founders and directors of two award wining architectural companies. In summary all architect participants were outstanding in the area of complex residential designs.

2.1. DESIGN OF THE EXPERIMENTS

The first group of three architects, called Group 1 is initially engaged in a design process where they are not allowed to sketch. This phase is called the experiment condition where they receive design brief 01. Design brief 01 requires designing a house for two artists: a painter and a dancer. At least a month after the experiment condition the same three architects were engaged in a design process where they are allowed to sketch. This phase is called the control condition where they receive design brief 02. Design brief 02 requires designing a house on the same site as design brief 01 this time for a couple with 5 children aged from 3 to 17. Both design briefs can be found in Bilda et al (2006).

The second group of the three architects called Group 2, was initially engaged in the sketching (control condition) session, where they received design brief 02. Then after one month they were engaged in the process

where they are not allowed to sketch (experiment condition) and were required to work on design brief 01.

In the experiment condition, called BF (blindfolded condition), we had the designers engage in the design process while wearing a blindfold. In the control condition, called SK (sketch condition), designers were given paper and pencil and were asked to commence designing. Each participant was given the same instruction before the BF and SK sessions and the experiments were conducted in the same room, where no visual reference was present. The procedures for the experiment and control conditions are outlined in Bilda et al. (2006).

Group 1 architects (who were engaged in the BF condition first) were interviewed after the BF session. Group 2 architects (who were engaged in SK condition first) were also interviewed after the BF session. The interview questions were open ended, and the participants were encouraged to talk about their experience of the blindfolded design process. There was no specified duration for interviews; they varied from 15 minutes to 1 hour.

2.2. ANALYSIS OF IDEA LINKS

Ideas are the basis for conceptual designing; an idea is a conceptual entity that can be sketched or annotated. In our analysis of ideas we identified three different types; new idea, revisited/repeated idea, and an idea that is built on a previous idea. We identify an idea as new if the designer speaks about it for the first time during the design session. If we observe the repetition of the idea, then it is revisited. Third type idea occurs when a revisited idea is modified or elaborated.

"Idea generation" is generating new, revisited or third type idea, therefore it is quite frequent along the design process. On the other hand "Idea development" refers to evolution, an idea that develops into another idea, a process that eventually ends up with the third type idea.

The following scenario illustrates the idea types and what idea development is. An architect comes up with the idea of a designing a building around a courtyard garden (new idea) and later on she remembers, emphasizes this idea again (revisited idea). Maybe immediately after or a bit later, she details the idea adding on to it, by saying she likes to "build non continuous elements around the courtyard garden" (third type idea). At a later stage she revises the previous idea, by deciding to "divide the courtyard garden diagonally into two" (third type idea). She eventually designs the whole building around this idea of a courtyard garden. Other ideas come along with the initial one, and elaborate, detail or modify it. Eventually, the original idea may sound like a totally different one, and use of linkographs enables us to track the points in time where different versions of ideas occur. This is what we call idea development; the process of elaborating or

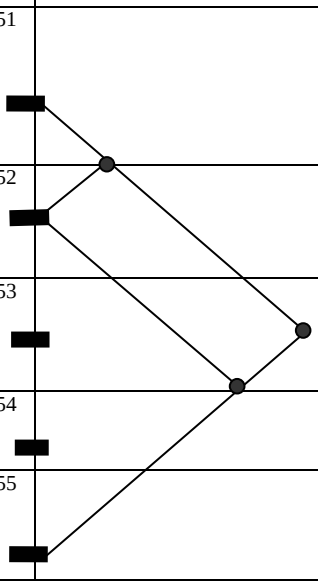
detailing or revising it along the timeline of design thinking. In other words idea development is establishing a network of related ideas progressing along the timeline of the design thinking.

The linkography technique involves parsing the protocol into units, and looking at the design process in terms of relationships created by the links between those units. The process of idea development is represented in terms of those units. Goldschmidt's (1997) original notion of a unit (which is called a move) is smaller than the notion of a "segment" used in this study. The links are established on the basis of determining where the design ideas occur in the protocol and connecting the related ideas in one or more segments to each other. The process of linking the ideas and related considerations in SK and BF protocols has been discussed in Bilda et al (2006).

During linking the ideas in the sketching protocols, idea connections were coded not only based on verbalization but also on what the architect draws on paper. In order to achieve linking of drawn ideas and keeping track of them, the video footage for each segment was visited during establishing the links in the SK protocols. When the previously drawn elements or geometries recurred, then the current segment was connected to the segment in which the related drawn elements first occurred. For example an architect may have the idea of having a courtyard garden, and s/he can sketch it in many different ways; by drawing one big rectangle which encloses a smaller one, by drawing the whole building layout, by writing "courtyard garden" on an emerging space on the sketch, or by just drawing an arrow.

Below (Table 1) is an excerpt from the verbal protocol of Architect 2 under blindfolded condition. He came up with the idea of a courtyard building (segment 51), repeated it in the next segment and decided that it should have "parts which are built and parts which are unbuilt" (segment 52). Because the idea of a courtyard house/ building is repeated segments 51 and 52, a link is established. In segment 55, the architect refers back to the courtyard structure (parts built, parts unbuilt); therefore the idea in segments 52 and 51 is repeated, and two links are established.

Table 1 Excerpt from a blindfolded protocol

Segments	Idea links	Content
Segment 51		(15.50) Look, the thing that I'm thinking now is that because I've got such an overwhelming desire to design a courtyard house, and I think that in this kind of situation where you've got a very large site and, umm, a semi-public space that it can borrow, in a way,
Segment 52		(16.07) that what you'd start to plumb for is a courtyard building; parts of which are built and parts of which are unbuilt.
Segment 53		(16.14) So, I'd be inclined to organise the dancer's studio and the living spaces and parts of the, the bedrooms…
Segment 54		(16.29) or no the bedroom spaces I think should go down to the east…to give them some separation…
Segment 55		(16.34) So I'm imagining now a broken form, something that's got the courtyard essentially as its organising structure, but which then has parts built, parts unbuilt.

3. Effects of sketching and imagery on idea development

We test the following hypothesis in this section:

Hypothesis: Expert architects can effectively develop ideas by using imagery alone during conceptual designing.

We have provided a conceptual description of idea development, and how this is going to be analysed in design protocols is first via representing the ideas in linkographs, and then quantifying the density, connectedness and criticality of these ideas.

3.1. ANALYSIS OF LINKOGRAPHS

Figure 1 shows example linkographs from A1, A3 and A6's BF and SK sessions. These figures are complete representations of established links over the timeline of the design sessions. A smaller linked unit was shown in Table 1, where triangular lines and dots were connecting the segments. In Figure 1, horizontal axis (top of the triangle) shows segment numbers, and the "V" shapes illustrate the connections between the segments. The linkographs showed that the architects demonstrated different idea connection patterns in each session. In the next section we define some terms for measurements of linkographs.

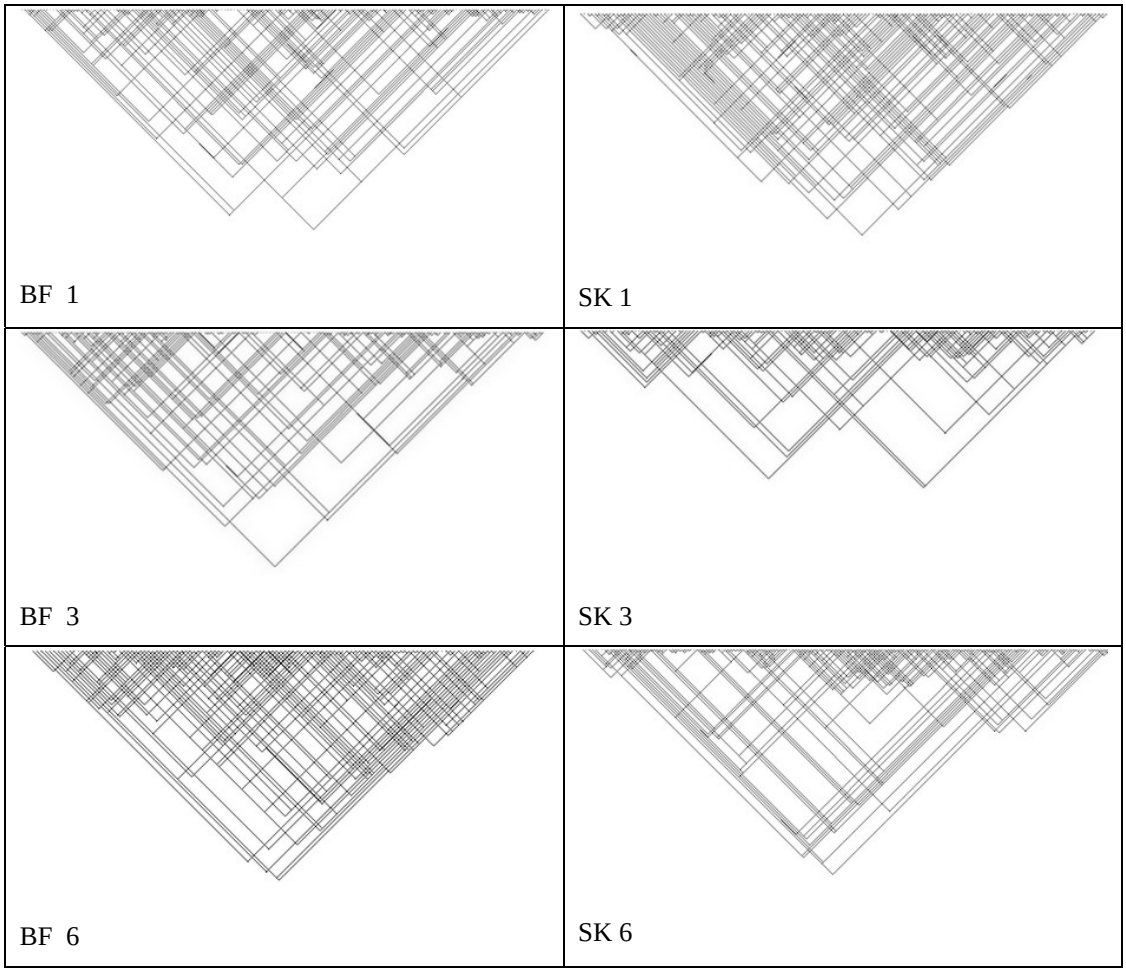


Figure 1 Linkographs for A1, A3 and A6's BF and SK sessions

Link Index and Critical Moves (CM)

Link Index is a measure of how connected the design ideas are in a design session. Link index represents connectedness because a "link" is formed between two ideas only if they are conceptually related, i.e. connected. In order to calculate the link index (LI) in the overall session, the total number of links is divided by the total number of segments in the design session.

Critical moves (CM) are the moves that generate a higher number of links (backward or forward). CMi is defined as a critical move carrying "i" number of links. Goldschmidt (2003) stated "CM identifies design concepts that are deemed "successful" in the sense that the designer values them enough to devote time trying to develop the concepts or at least to promote them at various points in the protocol". Goldschmidt (2003) established a

threshold criterion that identified a "critical move" (CM) as a move/segment that typically varies between three and eight links. This criterion is based on an estimate of the numbers of critical design ideas in a design protocol as a percentage of all ideas that occurred in moves. The threshold value is chosen arbitrarily; however a rule of thumb for setting out a threshold is that the percentage of CMs should not exceed 10 percent of the total number of all segments in the protocol. We have identified the threshold for CMi by looking at CM percentages with five to eight links in SK sessions, since the linkographs have so far been produced with sketch protocols. CM 5 gave us an average of 9.4% for all SK sessions (Table 2). We had a higher CMi threshold compared to Goldschmidt's (2003) study where it was set at three. The reason for a higher threshold is based on the size of segments in the current study. Our segments include more information than a "move" includes, thus a segment might have a reference to more than one idea in it. Consequently a critical segment could carry more links, compared to a move. We maintained the term CM (critical move) to refer to critical segments throughout the paper.

Table 2 shows that CM5, CM6, CM7 and CM8 percentages are higher under the BF conditions for five architects. A1 is an exception to this, in that A1's SK session has relatively higher percentage of critical moves at 5–8 link levels. In BF sessions 5 out of 6 architects' CM5 percentage ranged between 12.3 and 17.2, except for A1 who demonstrated a very low CM5 percentage (1.2). In SK sessions the range of CM5 percentage was larger (4.2-14.3) producing 9.4% on average.

Table 2 Link index and critical moves

	# of links	Link Index	% CM^5	% CM^6	% CM^7	% CM^8
BF 1	201	1.2	4.8	1.2	1.2	1.2
BF 2	259	1.7	12.3	4.5	3.9	1.3
BF 3	217	1.3	16.0	8.9	4.1	1.2
BF 4	414	2.5	14.9	9.5	11.3	9.5
BF 5	319	2.2	15.8	13.7	11.6	4.8
BF 6	307	2.5	17.2	8.2	11.5	6.6
BF av	*286.2*	*1.9*	*13.5*	*7.7*	*7.3*	*4.1*
SK 1	205	1.4	11.0	4.8	0.7	2.1
SK 2	272	1.5	7.1	4.3	3.3	2.2
SK 3	171	1.2	4.2	3.5	2.1	0.7

SK 4	409	2.4	8.3	10.7	7.7	5.9
SK 5	253	1.7	14.3	7.1	4.5	3.2
SK 6	302	1.8	11.6	4.1	7	1.7
SK av	*268.7*	*1.7*	*9.4*	*5.8*	*4.2*	*2.6*

CM^i: critical moves with i links

Comparing the SK and BF conditions, link index values in the BF sessions of the five architects were found to be similar or relatively higher than the link index values in their SK condition (Table 2). A1, whose SK condition link index was higher, was an exception. Average link index value for the BF sessions was 1.9; average value for the SK sessions was 1.7. Average number of links was relatively higher in BF sessions (286) than the SK sessions (269). Under the BF conditions, the percentages of CMs for five architects were higher compared to their SK sessions except for A1. On average, % CMs in BF sessions were higher than % CMs in SK sessions.

Our findings in this section can be summarized as follows:

LI (link index) was found to be relatively higher in the BF sessions.

BF sessions showed higher percentages of CMs (on average) compared to SK sessions, which could indicate more productivity in idea development.

Link density in clusters

A link cluster is formed by links that occur in consecutive segments. Goldschmidt (1995) says “In an ideally structured process, a suggestive move is productive if it is followed by a series of moves that explore issue(s) raised by that initial move or related subjects”. This means that clusters indicate the structured units of idea development. Finding the clusters can be useful in analysing the idea development phases; they indicate a continuous development and elaboration of ideas because the links occur in consecutive segments. Each cluster of consecutive links indicates that a designer focused on a connected set of multiple concepts to form a partial solution. Estimating the number of backward or forward clusters and their sizes in a design session would be a useful measure for efficiency of problem-solving: how well integrated the design thoughts are towards a tentative or a partial solution.

Link clusters are determined by visually inspecting the linkographs. If there are links in more than three consecutive segments, then that group is considered as a cluster. “Cluster size” refers to how many segments form a cluster. Inspecting the overall linkographs, it is possible to visually determine the starting and ending segments of a cluster. Figure 2 shows the starting portions of two clusters (marked by ellipses) inspected in a

linkograph. The links that extend towards the right hand-side of the graph (that is, forward on the timeline of the design session) are marked as a forward cluster. The links that extend towards the left-hand side of the graph are marked as backward clusters (Figure 2).

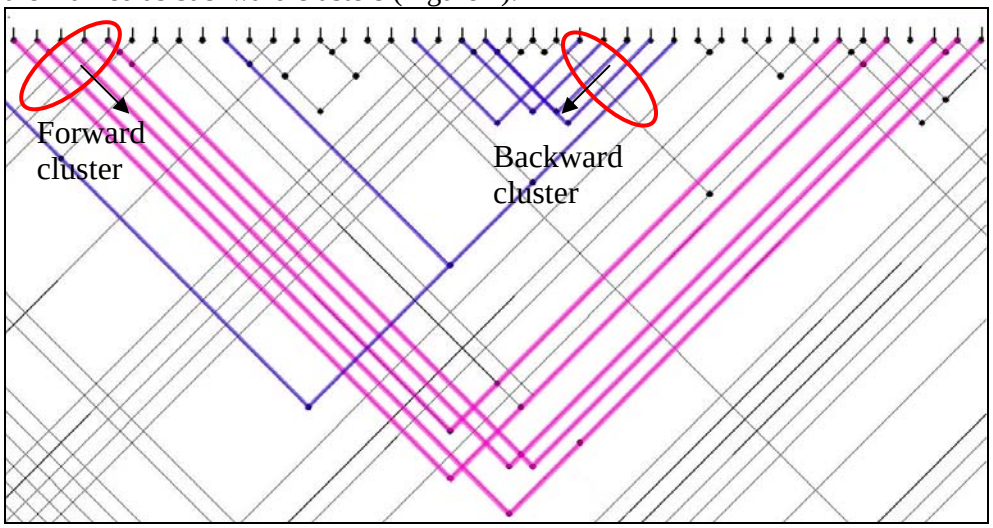


Figure 2 Demonstration of link clusters

A link is shown as an intersection point (shown as black dots) on the linkographs (Figure 3) where one segment is connected to the other. Each link in a cluster is counted. For example, the first move in the (forward) cluster has four links connecting to the latter segments 2, 3, 5 and 9 (circled in Figure 3), the second segment has three links connecting to 3, 4 and 9, and so on. The total number of links in each cluster is divided by the size of the cluster, which gives us the link density in each cluster (in Figure 3, the total number of links is 18, the size of the cluster is 5 and the link density is 18/5 = 3.6).

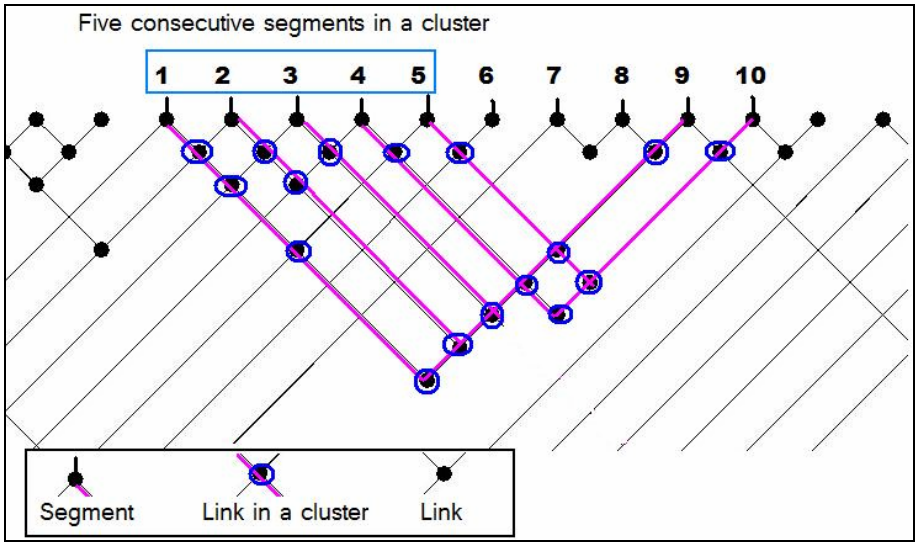


Figure 3 Links in a forward cluster

Table 4 shows the total number of forward and backward link clusters, size of clusters, and density of links in the clusters for all participants under BF and SK conditions. The results in Table 4 indicate that the number of backward clusters is higher than the number of forward clusters in all BF sessions. In SK sessions the numbers of backward and forward clusters are closer to each other.

Table 3 Link density in clusters

	Number of clusters in the whole session		Average size of clusters		Link Density in clusters	
	Forward	Backward	Forward	Backward	Fore-link	Back-link
BF1	6	9	5.5	4.6	2.3	1.7
BF2	5	9	6.4	5.2	2.5	2.0
BF3	2	5	5.0	5.2	3.6	2.1
BF4	11	16	5.6	5.8	3.5	2.8
BF5	11	12	5.7	5.8	3.6	2.9
BF6	7	11	8.1	6.1	3.6	3.1
BF Av	7.0	10.3	6.1	5.5	3.2	2.4
SK1	5	7	7.6	6.4	2.4	2.2

SK2	7	7	5.7	5.4	2.3	2.4
SK 3	3	6	4.7	5.8	2.0	1.6
SK 4	12	10	6.8	7.4	3.2	3.3
SK 5	7	9	7.1	6.6	2.6	2.1
SK 6	6	5	5.4	5.4	2.7	2.7
SK Av	6.7	7.3	6.2	6.2	2.5	2.4

Table 4 shows that the fore-link density is relatively higher than back-link density under the BF conditions for all architects except for A1. Note that for A1 the fore-link density in the BF and SK conditions are very close (2.5 and 2.4). If the fore-link density is higher in forward clusters, this means that certain design ideas initiated relatively more ideas later on during the design session. Therefore higher fore-link density indicates a richer idea development, and that the design ideas in the specific cluster were potentially successful. This is one of the factors indicating an efficient idea development along with higher link index and % CMs.

3.2. DOES IMAGERY ENHANCE IDEA DEVELOPMENT?

Our hypothesis stated that use of imagery alone does not put the expert architect to a disadvantage over sketching during idea development in conceptual designing. In order to test this hypothesis we identified and illustrated three quantitative factors contributing to the efficiency of idea development: Link indices, percentages of CMs and link densities in clusters.

The link index (LI) results supported our hypothesis; for five of the six architects, the LI under the BF conditions was higher than the LI under the SK conditions, Table 2. Hence, BF condition supported architects' idea development at least as good as sketching condition did.

Percentage CM analysis was used to demonstrate how integrated the idea development was in BF and SK sessions. Higher percentages of CM pointed to a more coherent idea development. Table 2 showed that critical segments with 5 to 8 links had higher percentages in the BF sessions of the five architects compared to their SK sessions. This indicated that previous ideas have been repeated, detailed, and developed into other ideas. In summary, architects quite efficiently developed and integrated their design ideas to develop their conceptual designs when they were blindfolded as they do when they were able to sketch.

Inspecting the clusters in the linkographs are useful because they can indicate formulation of tentative/partial solutions to the design problem. A

cluster analysis of the links assisted us in finding density of the fore-links and back-links.

Table 3 showed that the average back link density was same under SK and BF conditions while fore-link densities in clusters were higher under the BF conditions for all architects except A1. Higher fore-link density is one of the factors contributing to a richer idea development.

Hypothesis 1 can be accepted based on the results of five out of six architects; the use of imagery alone supported idea development as well as sketching did.

3.3. DISCUSSION

Analysis of linkographs showed that the density of the idea links, the percentage of critical moves and link densities in clusters were almost the same or higher under BF conditions compared to SK conditions. We assume that the participant architects achieved this efficient idea development under BF conditions based on their expert knowledge. This assumption is supported by the skilled imagery and long-term working memory (LTWM) studies.

LTWM studies have shown that experts with skilled imagery performance can maintain and transform associative connections between the elements in their imagery effectively over extended time periods of WM (working memory). Similarly, expert architects in the current study could have built this skilled imagery through using and learning the architectural language with the use of sketches. Design education requires an intensive learning process through drawing; students learn the design precedents through drawing and learn how to think with sketches. Thinking with sketches is also associated with the ability to develop design ideas, such as starting with one design concept and developing it into another one. Students learn how to progress their ideas through sketching. It is assumed that when novices become experts, they might have reached a state where they could progress a design via thinking only, because their repository of experience and design knowledge would allow that. Consequently, when experts are in a situation in which they have to design using their imagery alone, they might be using their experience of conceptually developing a design. This could be an important component of expertise, that is, the ability to simulate how the ideas are developed. This may be the key to our participants' abilities in blindfolded designing.

According to skilled imagery theory, architects in the current study relied on retrieving and using the visual and spatial information from their LTM. Similar to expert chess players, expert designers could have used pre-existing dynamic chunks of visual features or spatial relations encoded with their past experiences. The theory suggests that the previously learned visuo-

spatial chunks would be distributed throughout the working memory subsystems which could result in a quick development of solutions through the use of imagery. Further, architects often re-represent their problem space for each sub-problem and re-interpret the related visuo-spatial information.

4. Conclusions

We analysed idea links in design protocols of six expert architects working on two different design problems under two different conditions, one in which they were blindfolded and one in which they were sketching. Architects developed design ideas efficiently when they were blindfolded, and this condition did not put them to disadvantage compared to the sketching condition.

Idea development is considered to be enhanced by sketching activity only; however, the results of this study showed that it may also be enhanced by use of imagery alone. Use of imagery can be a design tool for idea development of expert designers.

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