Is Model-Making Sketching in Design?

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Abstract

Considerable research has been done by various scholars to assess the significance of sketching in the early stages of the design process. However, sketching in design studies usually corresponds to drawing and the extensive research on the cognitive aspects of sketching does not always include three-dimensional sketching through physical and digital models produced in the early phases of design process. The aim of the presented research is to question whether model-making in the design process and design cognition is a form of sketching. Departing from key research on sketching which articulates its uncertain nature as a positive drive in early design phases, this paper looks at whether physical and digital models can also be counted among ambiguous design tools. The inquiry is conducted with three graduate students of architecture having similar degrees of professional experience and skills of making physical and digital models. The participants are given three architectural design tasks which are similar in terms of contextual, functional and programmatic complexity and scale and are asked to solve the given design problems by using three different mediums: free-hand sketches, physical models, and digital models. The design sessions are recorded using cam-corders and the participants are asked to think-aloud during the design protocols. The Linkography method is used for the analyses of the protocol studies and linkographs are developed for each design session. Departing from the assumption that ambiguity of a medium is positively related with the amount of lateral transformations realized during a design session, the outcomes of the linkographs are compared in terms of the transformations generated. We conclude that having too many lateral transformations is not always an indication of ambiguity.

Keywords

design; design protocols; sketching; model-making; reflective practices; cognition; computer-aided design; Linkography.

Sketching is one of the most explored activities in design cognition studies and considerable research has been done by various scholars to assess the significance of sketching in the early stages of the design process. Gabriela Goldschmidt (2003), Vinod Goel (1992), Donald Schön and Glenn Wiggins (1992), Masaki Suwa and Barbara Tversky (1997), Bryan Lawson (2006) are among researchers who have conducted analytical and empirical studies focusing both on freehand sketching with conventional methods (using pen and paper) and sketching in contemporary media using computer-aided sketching tools. However, sketching in design studies usually corresponds to drawing and the extensive research on the cognitive aspects of sketching does not always include three-dimensional sketching through physical and digital models produced in the early phases of design process. Despite the general tendency in literature to underline the importance of model-making in the design process, its effects on the cognitive process are not sufficiently articulated.

Related Work

Key research on sketching articulates its uncertain nature as a positive drive in early design phases. Goel (1992) compares the effects of different representation techniques –drawings- on the cognitive design process. The results accentuate the importance of using ill-structured representations for ill-structured problems which are corresponding to using fuzzy (ambiguous, ill-defined) drawings instead of hard-line (well-defined) drawings during the early design process. Lateral transformation is a term developed by Goel and is defined as a transformation where "movement is from one idea to a slightly different idea rather than a more detailed version of the same idea". Correspondingly, vertical transformation is a transformation where "movement is from one idea to a more detailed version of the same idea" (Goel, 1995). According to Goel, ambiguous media enable lateral transformations, and lateral transformations enable the widening of the problem space and development of kernel ideas. Widening of the problem space is directly related with productivity.

Goldschmidt (1990) proposes the Linkography technique to assess design productivity and defines it as " a representation system that uses links as input and displays structural design reasoning patterns as output. A linkograph is "a simple graphic notation in which the sequence of moves is shown on a straight line and the links are nodes at the intersections of diagonal network lines connecting to related moves" (Goldschmidt, 1992). Design productivity is related to the link index value, which is the ratio between the number of links and the number of moves. According to Goldschmidt, the higher this value is, the more productive a design session is. This implies that having a higher link index value corresponds to having denser links among moves. This is in disagreement with Goel's proposition where design productivity is associated with lateral transformations and dense links are mostly representative of vertical transformations.

Rodgers, Green and McGown (2000) analyze the progress of design projects in the studio on the basis of transformations between successive sketches of the students. They report similarly to Goldschmidt, that over a period of a semester, students' sketches show both lateral and vertical transformations but that students who do well predominantly make vertical transformations and a student whose progress is marked by many lateral transformations makes poor progress in terms of achieving positive complexity.

Productivity towards creativity can be discussed both ways. However in this paper, we assume that expanding the design space laterally in the initial/conceptual stage is more productive in terms of exploration and we take Goel's (1992) argument that ill-structured representations give way to significantly more lateral transformations than do well-structured representations as our departing point in the study.

Goel believes that the ambiguous nature of the freehand sketch facilitate lateral transformations and prevent early fixations. Goldschmidt (2003) also points out that an ambiguous representation prevents the early crystallization of ideas, thus "helps defer commitment to a solution". Paynter, Shillito, Wall and Wright (2002) discuss the role of sketching and model making in design and the reasons why the computer is presently unable to provide appropriate support in the "germinal phase" of the design process. They consider physical model-making already as a sketching tool and argue that in contrast to current CAD programs, freehand sketching and physical model-making allows a designer to communicate multiple ideas rapidly and expressively without a demand for unnecessary precision.

Drawing from this fuzzy character of sketching, this paper looks at whether physical and digital models done during the early design process are also ambiguous and enable lateral transformations. The study is developed as an empirical study that will generate its own answers and does not consider anecdotal data as facts. It benefits highly from the related work cited above while developing its own analytical approach. Considering freehand sketch as an ambiguous media, it seeks to compare the outcomes of the experiments with physical

and digital models with the outcomes of the experiments with freehand sketch in order to reveal whether physical and digital models also have ambiguous properties.

Design of the Experiments

The inquiry is conducted as protocol analyses with three graduate students of architecture having similar degrees of professional experience and skills of making physical and digital models. The participants are given three architectural design tasks which are similar in terms of contextual, functional and programmatic complexity, and scale. They are asked to solve the given design problems by using three different mediums: free-hand sketches, physical models, and digital models. In order to neutralize the effect of the individuals, each participant is involved in all the design mediums mentioned. So at total, nine experimental sessions are realized. Table 1 shows the distribution of design tasks among designers and the design mediums used for each design task.

	Design Task # 1			**Design Task # 2**			**Design Task # 3**		
	Physical Model	Freehand Sketch	Digital Model	Physical Model	Freehand Sketch	Digital Model	Physical Model	Freehand Sketch	Digital Model
D1	●				●				●
D2		●				●	●		
D3			●	●				●	

Table 1 Design tasks, design mediums, designers (D1-3)

The design tasks consist of formal explorations for mixed-use buildings in urban plots. They are located at the same environment and have common specific topographic qualities such as being sloped, being next to a bridge and on the waterfront, having different levels, etc. that expectedly calls for three dimensional inquiries. The numbers on the satellite view from Figure 1 correspond to the design tasks presented in Table 1.

For design task (DT)1, the participants were asked to design a mixed-use building consisting of housing units and a cinema / a theatre. For DT2, they were asked to design a mixed-use building comprising housing units and an exhibition gallery. DT3 was again to design a mixed-use building with a dormitory and a café. Tasks were designed to be similar in terms of complexity but with programmatic differences. The reason why slight changes on the program exist is to prevent the transfer of experience from one task to another. No specific data were given about the total area of each program unit. However a simple site analysis was provided to the designers prior to the experimental sessions and the participants were allowed to ask further questions.

All the participants started the experiment first with physical model condition. They continued with freehand sketch and finalized with digital model conditions. For the physical model condition, they were provided a cardboard site model of 1/200 scale. On the model, buildings, pedestrian roads, vehicular roads, canal, and the bridge were clearly indicated. The participants were given cardboard, colored papers of different thicknesses, transparent papers, needles, glues, a ruler, and colored pens as materials. They were not allowed to sketch by making drawings to generate ideas. Cardboard and paper were chosen as the primary modeling materials since they correspond to the most commonly used modeling materials in architecture. If the experiment would have been realized by using other modeling materials (i.e. modeling clay, styrofoam) , the results could have been different.

For the freehand sketch condition, the participants were given 1/200 scale site plans and site sections of the design tasks, sketching papers, colored pens and pencils, erasers, and a ruler. The site section from Figure 1 is the site section provided for DT1.

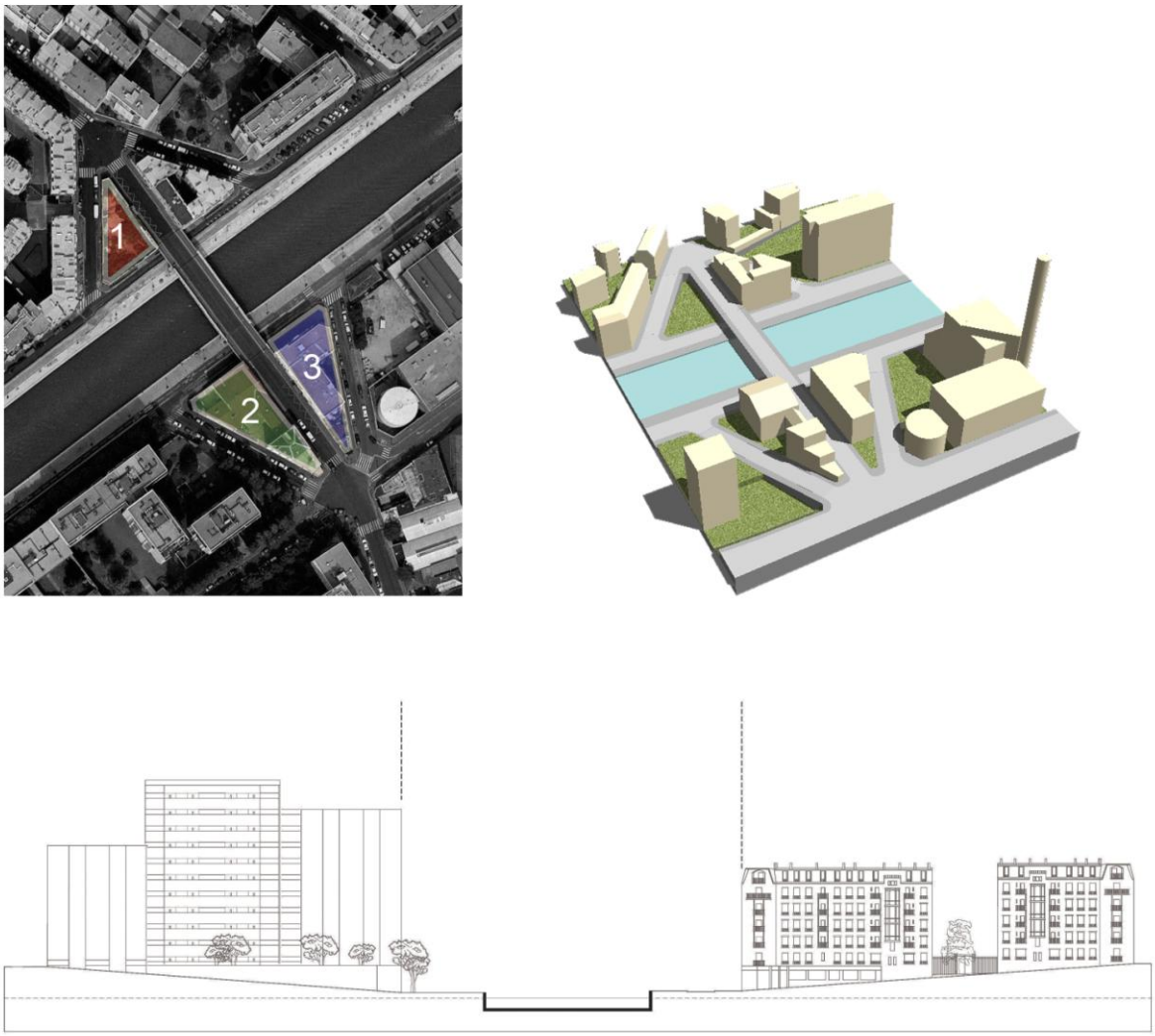

Figure 1 Satellite view, site model and site section

For the digital model condition, the designers were provided Sketch-Up, Rhinoceros, and 3ds Max models of the site comprising the same area as the physical model. Participants were free to chose among these digital modeling soft-wares. D1 has chosen Rhinoceros; D2 and D3 have chosen 3ds Max. The site model image from Figure 1 is the Sketch Up model.

A simple site analysis was presented to the participants prior to the sessions. All of the design sessions were recorded using cam-corders and the participants were asked to think-aloud during the design protocols in their native language.

Experimental Procedure

The experiment of each participant followed this procedure:

1. Presentation of the experiment

2. Presentation of the site analysis

3. A pre-interview with the participant about the experiment. He/she was asked to talk about his/her expectations about the experiment, whether he/she thinks he/she will be successful in the experiment with the given medium or he/she would be more comfortable with another medium and the reasons.

4. Presentation of the design briefs

5. Initial conceptual design phase. At this primary session, the participants were asked to generate conceptual design ideas. For the physical model condition, they were asked to make a match-box physical model of their idea that they will develop in scale further on. The physical model did not have to be in scale but had to clearly explain their ideas. For the freehand sketch condition, participants were asked to make a conceptual diagram of their design ideas. For the digital model condition, they were supposed to make a digital model representing their conceptual design idea. The duration of this initial phase was limited in terms of duration of the conception of their design ideas. It varied between 8 minutes to 21 minutes.

6. Development of the conceptual design idea. At this second stage of the experiment, the participants were asked to develop their design ideas. This time, they were asked to work in 1/200 scale for physical model and freehand sketch mediums and to fit into the given site model for the digital model medium. The sessions ended when the participants declared that they are satisfied with the result. However in cases when they exceeded 60 minutes, they were reminded to straighten up their designs.

7. A post-experiment interview. The participants were asked whether they were right in their expectations about the design session, what the difficulties they have faced were and whether they could have been more successful using another design medium.

Methods of Analysis

In order to analyze the protocols, first the transcripts of the protocols are written. While writing the protocol transcripts, both the verbalizations from the think-aloud sessions and the physical movements the participants have made are noted together with the exact movement time. Later, the protocol transcripts are segmented to the design moves. According to Goldschmidt (1995), a design move is "an act, an operation, which transforms the design situation relative to the state in which it was prior to that move" or "an act of reasoning that presents a coherent proposition pertaining to an entity that is being designed". This definition is taken as reference while segmenting the protocols to its design moves.

The Linkography technique is used for the analyses of the protocol studies. For this study, linkographs are generated only for the initial conceptual design phases since otherwise the linkographs would have been too long to manage. So, it is very important to underline that the following discussion concerns the initial conceptual design phase of a design process and not the detailing phase of a design idea.

The outcomes of the experiments will be analyzed first regarding the quantitative data obtained from the linkographs. Comments and observations of the authors concerning the protocol analyses will be made afterwards.

Limitations of the Study

There are certain severe limitations of the proposed experimental research acknowledged by the authors. These limitations are due to the methodology used to gather and analyze data, the quality and the quantity of the participants, the nature of the design tasks and the sequence of the experimental procedure. It is therefore, of crucial importance to cite that the protocols presented in this paper are not used to state generalizable facts concerning models and model-making in architecture.

Despite the fact that the protocol analysis method is counted among the most commonly used empirical research methods for the study and analysis of cognitive processes in design, it is also commonly criticized for creating an unnatural design process by forcing the designers to solve a design problem within a limited time while they are constantly filmed. Thinking-aloud during the protocol studies is also mainly criticized for obstructing the natural sequence of thoughts of the designers by demanding that they verbalize each thought.

Further on, the Linkography method, which seems as an objective analysis method, is criticized mostly for lacking objectivity in different levels: determining the moves (segmentation process), judging the links among moves (coding process) and interpreting the meaning of the resulting linkograph (analysis process). In order to overcome the subjectivity within the segmentation and coding processes of linkographs, inter-coder arbitration is advised (Mc Neill, Gero, & Warren, 1998).

The results of experiments may vary if the subjects, the design tasks, the settings of the study, the procedure of the study, the materials and software provided to the subjects, the time given for each task, the order of the design tasks were different. Therefore, this paper, instead of ending with a *de facto* argument, presents these protocol studies as an example of how ambiguity of model-making can be sought within design cognition studies and discusses the results only with reference to these specific protocols.

Generated Linkographs

With an understanding of the construction of a linkograph, one is able to comment on the design behaviour without studying the design protocol (Kan & Gero,2005). For each designer, three linkographs are created. These linkographs are shown on Table 2. The difference in length in horizontal direction is due to the number of moves generated to complete the design task. Duration of the experiments is not present on this table as a variable. Therefore lengths of the linkographs do not differ because of the time spent to complete the task but because of the number of design moves generated.

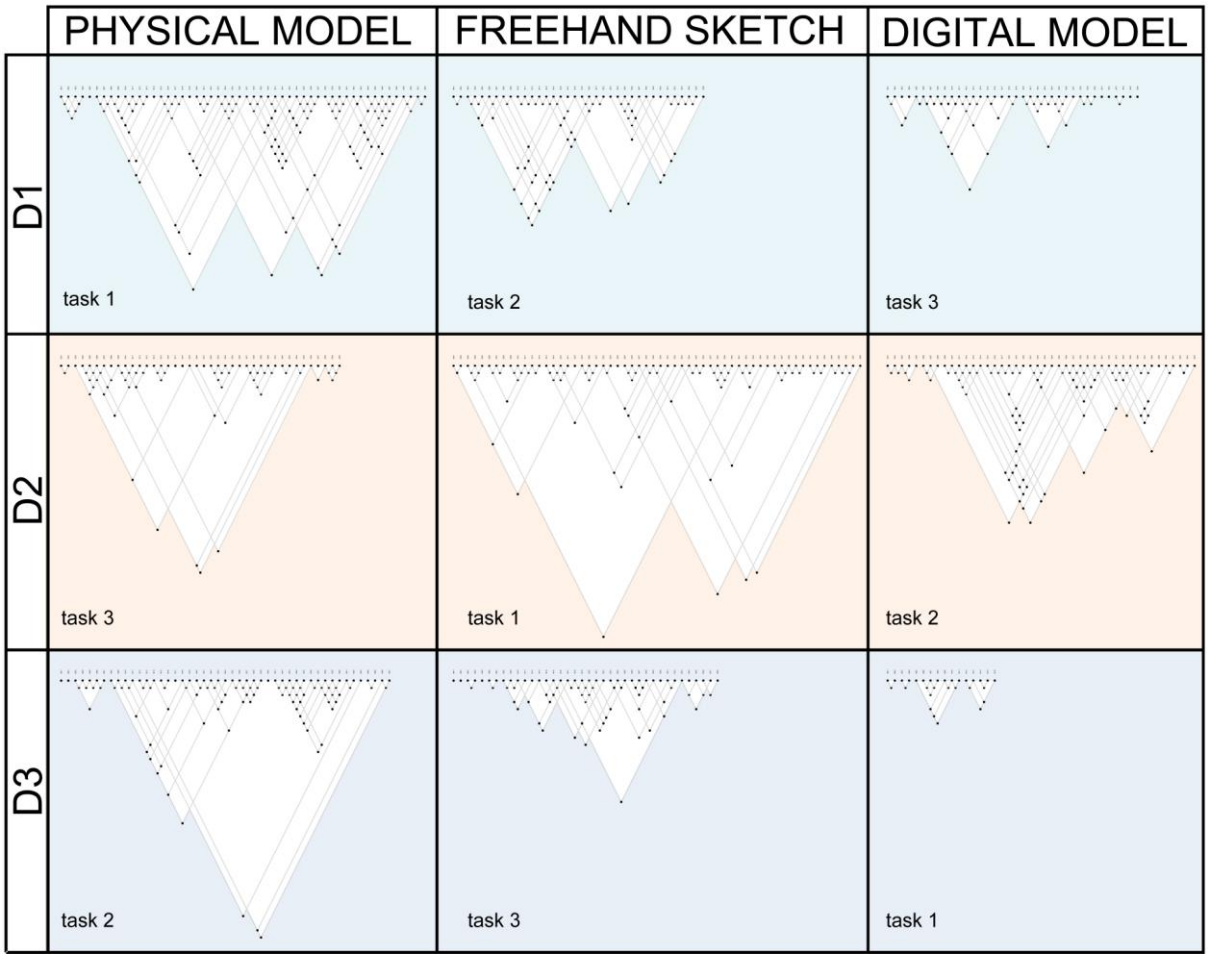

Table 2 Linkographs

Designer	Design Medium	Total # of moves	Total # of links	Link index	Time elapsed	Moves / min	Links / min
D1	Physical model	52	111	2,13	10' 50''	4,8	10,2
	Freehand sketch	36	59	1,63	8' 30''	4,2	6,9
	Digital model	36	36	1	20' 55''	1,7	1,7
D2	Physical model	40	47	1,17	15' 55''	2,5	2,9
	Freehand sketch	58	62	1,06	19' 30''	2,9	3,2
	Digital model	44	77	1,75	9' 25''	4,7	8,1
D3	Physical model	47	70	1,48	21' 50''	2,1	3,2
	Freehand sketch	38	43	1,13	9' 25''	4	4,6
	Digital model	16	14	0,87	9' 30''	1,7	1,5

Table 3 Total number of moves and links, link index values and duration of protocols

Table 3 shows link index values of each participant's design sessions with three design mediums. Time they have spent to finalize the initial conceptual design phase is also indicated and the moves and links they have generated per minute is calculated.

According to Table 3, the link index number was higher for D1 in physical model condition (2,13) compared to freehand sketching (1,63) and digital model (1,0) conditions. Time spent to complete the initial conceptual design phases however was more in the digital model condition (20'55'') than the physical model (10'50'') and freehand sketch (8'30'') conditions. These values indicate that the design session using physical model was the most productive and the design session using the digital model was the least productive process for D1.

For D2, the link index number was higher in the digital model condition (1,72) compared to physical model (1,17) and freehand sketch (1,06) conditions which have closer values. D2 spent very less time to complete the initial conceptual design phase in the digital model condition (9'25'') when compared to physical model (15'55'') and freehand sketch (19'30'') conditions.

According to these values, the design session using the digital model was the most productive and the design session using freehand sketch was the least productive process for D2. For D3, the link index number was higher in physical model condition (1,48) compared to freehand sketch (1,13) and the digital model (0,87) conditions. However, the time spent during the physical model condition (21'50'') for the conceptual design generation is comparatively very high than the freehand sketch (9'25'') and the digital model (9'30'') conditions. For D3, the design session using physical model was the most productive and the design session using the digital model was the least productive process. So for D1 and D3, physical model condition resulted with the highest link index value and the digital model condition, ended with the lowest link index value. On the other hand, D2 had the highest link index value with the digital model condition and lowest with freehand sketch condition.

Link index numbers might be useful in discerning productivity of the design sessions (Goldschmidt,1992) however are not sufficient to analyze the protocols. Linkographs can generate different linking patterns. Designers who start the design process with exploring different options and then select one to develop will produce a very different linkograph compared to designers using a holistic approach without exploring different options (Kan & Gero, 2005).Therefore analysis of these linking patterns are also necessary along with quantitative data while commenting on design productivity.

Through linkographs, Goel's (1992) typology which distinguishes between lateral and vertical transformations can be read. Linkographs can easily indicate what types of transformations are being made by displaying link patterns: dense clusters of links correspond to vertical transformations while scattered links denote lateral transformations (Goldschmidt & Tatsa,

2005). Correspondingly, vertical transformations generally form chunks and webs, while lateral transformations remain as non-interlinked moves or form sawtooth tracks. In this study, linkographs of the nine experimental session are observed with the aim of determining vertical and lateral transformations. Figure 4 shows how this exploration is done through the linkograph of the freehand sketch session of D3. On the given linkograph, first the links forming chunks and webs are identified as triangular areas and those triangular areas are colored to be easily perceived. Later the links that exist only between two sequential moves are explored and the triangular area between two moves are colored. The total number of triangular areas that are formed on the linkograph iscounted.

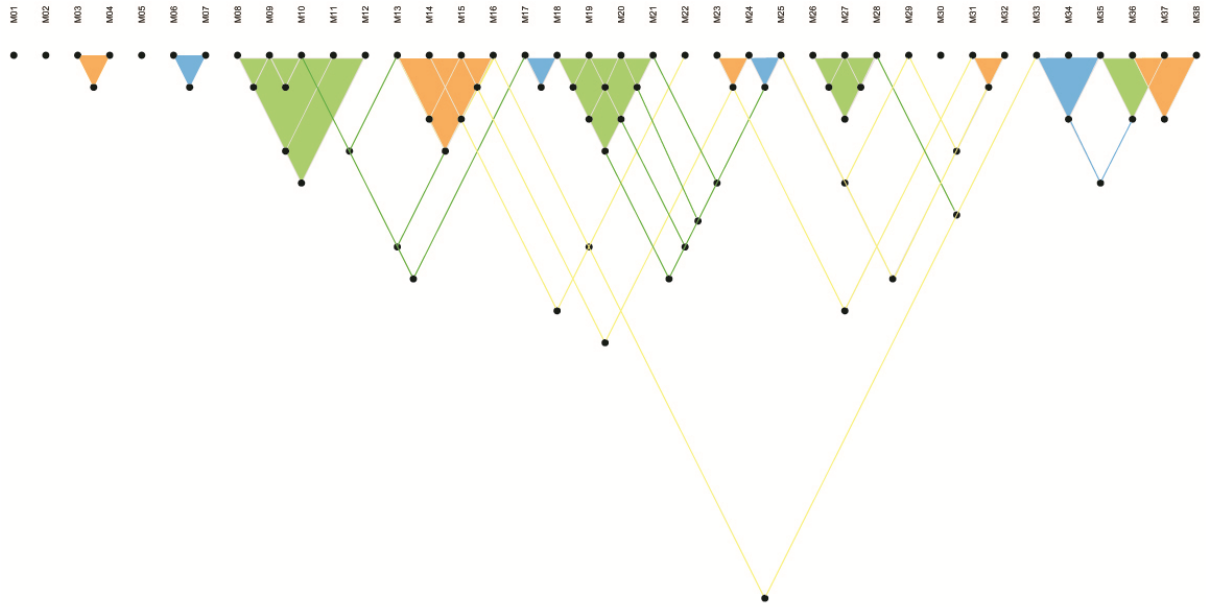

Figure 4 Example of Lateral Transformation Determination on Linkographs

Moves that are unlinked with other moves are also considered as lateral transformations since they are sudden changes in the design process. The sum of these unlinked moves is added to the number of the colored triangular areas. The final value gives the total number of lateral transformations that appear during the design session. Links that are not within a chunk or a web, but are back-links to previous ideas are also indicated on the graph. However since they are not new ideas the triangular areas formed with these back-links are not colored and are not counted as lateral transformations. Vertical transformations are not easily identified as the lateral ones. Kan and Gero (2008) have developed a method where they consider the linking nodes as points in Cartesian coordinate system and find the mean value of X, which is the average location of the nodes in the X-axis and the mean value of Y, which is the average location of the nodes in the Y-axis. The mean value of X is calculated to find whether more nodes appear through the beginning or through the end of the design session. The mean value of Y, is calculated to find out how deep the ideas process, therefore to find out the lengths of the links. In this study, Kan and Gero's method is used to calculate the mean value of Y of the linkographs and those values are used to compare the design sessions in terms of vertical transformations. Table 4 shows the number of lateral transformations and the vertical transformation value of each design session along with the link index numbers.

	Design Medium	Total # of Lateral Transformations	Vertical Transformation Value (Mean Value Y)	Link index
D1	Physical model	15	5,85	2,13
	Freehand sketch	18	6,05	1,63
	Digital model	25	2,66	1
D2	Physical model	16	4,53	1,17
	Freehand sketch	29	5,16	1,06
	Digital model	16	5,98	1,72
D3	Physical model	21	4,88	1,48
	Freehand sketch	17	3,42	1,13
	Digital model	6	2,28	0,87

Table 4 Lateral Transformations and Vertical Transformation Values

According to this table, D1 has made quite a high number of lateral transformations during the design session with the digital model (25) compared to the design sessions with freehand sketching (18) and the physical model (15). However, the vertical transformation value is very low for the digital model condition (2,66) compared to the freehand sketching (6,05) and the physical model (5,85) conditions. These values, together with the link patterns of the linkographs presented in Table 2 indicate that D1, during the protocol with the physical model and the freehand sketch, had generated ideas that she also could develop. Her protocols with these mediums display dense clusters of links. Moves are generally inter-related but not totally connected indicating that there are multiple opportunities for good ideas for potential development. During the digital model session, on the other hand, she has jumped from one design move to another but her moves are random trials that do not have a contribution to the design concept. Her protocol with the digital model, therefore, displays many unrelated moves or moves that are only related to directly preceding them. This indicates that either there are no converging ideas, and hence, low opportunity for idea development, or that the process is progressing but not developing (Kan & Gero, 2008). Link index values of these sessions also corroborate this interpretation with the highest value for the physical model condition and the lowest value for the digital model condition.

During the design session with freehand sketching, D2 made many lateral transformations (29) than in his design sessions with the physical model (16) and the digital model (16). The session with the digital model has the highest vertical transformation value (5,98) and the session with the physical model has the lowest vertical transformation value (4,53).Therefore, D2's protocol with the digital model displays dense clusters of links compared especially to his protocol with the physical model. In his protocol with the physical model, there are quite a number of moves but the chunks are not deep. This indicates that D2, with the physical model, either, could not deepen his ideas, or that he had an already crystallized idea that he did not need to explore further.

D3 had the biggest number of lateral transformations (21) and highest value of vertical transformation (4,88) from the design session with the physical model and the smallest number of lateral transformations (6) and the lowest value of vertical transformation (2,28) from the design session with the digital model. Similarly, her protocol with the physical model displays dense clusters of links forming chunks and webs when compared to her two other protocols. Her protocol with the digital model is radically poor in moves and links. The very few number of design moves indicates that either she could not make use of the design medium to generate ideas, or she had an early crystallized design idea. Eventually, links that are very few in number could not form webs or chunks, indicating that she could not deepen her ideas with the digital model medium.

Observations and Remarks About the Experiment and Comparison with the Linkographic Data

Data deducted from the linkographs concerning the design protocols might be sufficient to analyze the protocols. However personal observations and remarks of the authors must also be taken into consideration.

According to the linkographic data, D1 and D3 had the highest link index value with the physical design medium, while D2 had a comparatively low value. The linkographs of the physical design condition of D1 and D3 displayed dense clusters of links while in D2's linkograph links did not deepen. This difference however is probably not due to the physical model medium but to the design approach of the individual designers. D1 and D3 did not have an early crystallized design idea during the protocols. They explored the problem space with different options and progressively developed their design. D2, on the other hand, had an holistic approach. He came up with a very early idea about the form of the building, and during the protocol, he did not search for other alternatives. This approach continued at the second phase of the experiment where the designers were asked to develop their initial conceptual ideas with a 1/200 scale model as well. D1 and D3, while developing their ideas through physical models, have made unexpected discoveries, but comparatively D2 had very few discoveries of that sort.

D3, at the pre-experiment interview had stated that she was used to conceptualize her ideas through physical models and she thought she would be more comfortable designing with physical model. Although she had the highest link index value with the physical model medium, she spent more than twice the time she spent with freehand sketching and the digital model to generate the conceptual design idea. She later claimed in the post-experiment interview that being supposed to think-aloud was confusing her ideas and that she could not focus on her design. She said that while she is on her own, she makes random moves without knowing the consequences and that these moves end with surprising discoveries. However, she argued that since she is asked to verbalize each move, she could not benefit from that discovery process.

Another very important observation to underline is concerning D2's design session with the digital model medium where he ended with the highest link index value. He might have had the highest link index value with the digital model medium, but most of the moves presented on the linkograph were moves conceived because of his verbal acts and were not totally related with a search or exploration with the digital modeling media. So, it can be said that at least during the initial conceptual design phase of the experiment with digital model, he made intensive use of the mental imagery instead of searching alternatives through digital modeling media. Linkographs however do not reveal this fact.

The reasons why D1 and D3 had the lowest link index values with the digital design medium in the early conceptual design phase are different. D1 had control over the CAD software, she knew the commands and she could do what she wanted to do. However, she did not have control over the design process as much as she had with the physical model condition and the freehand sketching condition. She could not develop her ideas and she made random trials which are not connected with each other. Goldschmidt (1992) notes these kinds of design sessions as being non-productive. D3, on the other hand, did not have control over the CAD software. She spent a lot of time searching for the right commands and ended up by using very few of them for generating her design. She claimed that this caused too much discomfort during the design session and that probably while searching for ways to control the interface of the software, she lost the sequence of the design process and missed good ideas.

Conclusion and Further Discussion

Goel's (1992) experiment reveals the importance of using ill-structured (ambiguous) representations for ill-structured problems instead of well-defined ones in the early design process. His experiment shows evidence that significantly more “lateral transformations” are developed with the ill-structured representations than with the well-structured representations. According to this argument, the ambiguity of the design medium is positively related to the number of lateral transformations done during a design process.

We have utilized linkographs in order to detect lateral and vertical transformations and find linkography very successful for the task. We assumed at the beginning of the research that the reverse was also true and that higher the number of lateral transformations is, the more ambiguous is a design medium. We tried to identify and count the lateral transformations within the nine experimental sessions for the three design mediums in order to be able to comment on the ambiguity of these mediums. However, we perceived that having too many lateral transformations is not always an indication for the ambiguity of a design medium and that considerable amount of lateral transformations may also occur when the designer faces a well-defined design medium. This work thus complements Goel's argument about the relations between lateral transformations and ambiguity. Our follow-up research focuses on identifying factors of ambiguity in the acts of model-making rather than with reference to the generic characteristics of its medium alone.

Despite the immense number of cognitive studies on freehand sketching, there are very few cognitive studies concerning physical and digital models. Further research can be done to compare the design productivity of these mediums in the way that Goldschmidt defines it. We find it challenging to discuss the sketchy aspects of physical and digital models on that level.

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Mine Özkar

Mine Özkar holds an MS in architectural studies and a PhD in design and computation from MIT. Her research and publications are on design thinking, the history and theory of basic design education, cognitive processes in design, computation in design processes, and visual computation. After working as George Stiny's assistant (2000-2004) as he prepared his most recent book, SHAPE she became a member of the faculty at Middle East Technical University, Department of Architecture, where she coordinates and teaches design studios and computational design courses at the graduate and undergraduate levels. She is also a partner in two interdisciplinary research projects on implementation of shape algebras and curriculum development for architecture education.