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Procedural Study on the Methods that Analyze the Design Process

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ABSTRACT: Empirical studies in the field of the design process started in the 60s. Protocol analysis is among the empirical research methods that have been developed simultaneously with the growth of empirical studies. Concurrent with the use of protocol analysis for researching in the field of the design process, analysis methods have been presented by some researchers, which can be used with the protocol analysis method in order to analyze the structure of the design process. Among these analysis methods, problem behavior graph, decision tree, linkography, and extended linkography could be mentioned. The problem behavior graph is based on problem-solving theories. In the decision tree method, the extracted data from protocol analysis is used for the perception of decision-making processes. Linkography is another method for analyzing the structure of the design process. In this method, the design process of a designer is unfolding by drawing a graph, which is called linkograph. This paper considers making a study and comparison of these different analysis methods by the use of systematic review. By comparison of diverse analysis methods, two approaches could be recognized, formal and informal ones. In the formal approach, the design is mentioned as a logical research process of solving the design problem. The second approach is informal. In this one, the design process is mentioned as a reflective conversation with the situation. In this approach, which is based on Donald Schon's theories, the design process is referred as an argumentative process.

Keywords: *Design process, Protocol analysis, Problem behavior graph, Decision tree, Linkography.*

INTRODUCTION

Design is a particular mental activity, which is known for creative activity. Research and study on design activity and making effort for reaching a true understanding of the design process is a process that has been started in the past decades and continues up today. This type of research, in addition to help for the discovery of some unknowns of the design field, has practical goals, too. For instance, it could be useful for improving the teaching methods in universities or developing design aid tools. So, according to the importance of the subject, research on the field of the design process has devoted the subject of much research to itself. In this regard, research methods and analysis methods of the design process structure have been developed by some researchers in order to reach a better understanding of this subject. The current study aims to analyze and compare some methods of analyzing the structure of the design process. In this regard, before addressing these methods, a brief description of the design research field and the position of research on the design process in this field will be described. In the next step, the protocol analysis research method which is an empirical research method in the design field will be presented. It is worth mentioning that much research on the field of the design process has been conducted by the protocol analysis research method and the resulted data have been analyzed by the design process analysis methods. Finally, the most prominent design process analysis methods including problem behavior graph, decision tree, linkography, and extended linkography, will be described. Studying these analysis methods has been started in the 70s by researchers, and making effort to expand and extend these methods continues

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to this day. The theoretical framework model of the study is shown in figure 1.

MATERIALS AND METHODS

The current study is done by the procedural research method, which is based on the systematic review. In the way of the research, 54 research is included in journal articles, conference proceedings, books, and Ph.D. theses. All of these sources are selected and analyzed by the Google Scholar website. Among these sources, 12 articles were not related to the design field. Thus, the index of specificity is 22%. The selection criteria for these sources are based on the extent to which they are addressed protocol analysis research method in the design field or the usage of this method in conducting research. Moreover, various methods used for analyzing resulted data are considered. Some related sources that were referred to the mentioned research were extracted and studied. Among 42 sources that are related to the subject, 38 sources were studied and analyzed carefully, and 4 other sources could not be studied due to the impossibility of access. So, the index of sensitivity is 90/4%.

RESULTS AND DISCUSSION

Protocol Analysis Research Method

The protocol analysis methodology is an empirical method for studying design behavior, which was first introduced in the field of cognitive psychology. Protocol analysis involves giving small but realistic design tasks to subjects and monitoring their behavior. A protocol is part of the recorded time of behaviors. Data was collected using video, plus any drawings produced. Design thinking is induced by the behavior captured from the protocol, including verbalizations, drawings, and gestures (Eastman, 2001).

This research method is classified as a subset of empirical research related to the field of design research. It is a very appropriate method to study the design process. According to Nigel Cross (Cross, 2001): "Of all the empirical research methods for the analysis of design activity, protocol analysis is the one that has received the most use and attention in recent years. It has become regarded as the most likely method (perhaps the only method) to bring out into the open the somewhat mysterious cognitive abilities of designers."

Protocol analysis is strongly based on information generated in the form of external representation, oral statements, drawings, and writings. To facilitate data analysis, all verbal protocols are divided into smaller components, called segmentation. One method of segmentation is to divide protocols based on what happens during verbalization such as pauses, tone, or even syntactic signs that can be the symptom of completing sentences and become the basis for starting a new segment. Another method for segmentation is based on the participant's intention. For instance, Goldschmidt (Goldschmidt, 2014) defines a segment as: "an act of reasoning which presents a coherent proposition about an entity that is being designed". She calls a segment, a "design move". Changes in the intention, the content of thoughts or activities of the participant indicates the beginning of a new segment. Therefore, a segment is sometimes consisting of a sentence, and other times consists of a lot of sentences.

Design Process Analysis Methods

Design process structure analysis is a process, which is mostly done by the analysis of the data gathered from protocol analysis. Therefore, the extension of these methods started simultaneously with study development of protocol analysis and gradually extended by the researchers of this field. Among

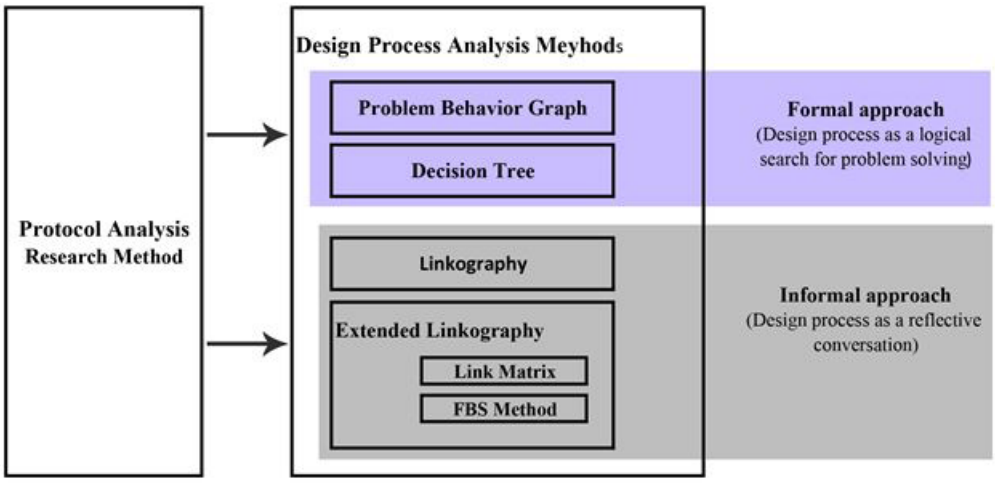

Fig.1: Theoretical framework of the study

the most significant methods for analyzing the structure of the design process, problem behavior graph, decision tree, and linkography could be mentioned. These methods will be explained in the following paragraphs.

Problem Behavior Graph

Newell and Simon (Newell & Simon, 1972) could be mentioned as one of the first researchers who analyzed the structure of the design process through protocol analysis and graphical representations. Their attitude toward the design process is considered as a problem-solving and information processing system, which has helped a lot in the field of design activity. In a taxonomy that is done by Oxman (Oxman, 1995), the approach of this group of researchers is considered as a "problem-solving" approach. This approach could be considered as a process-oriented model. Researchers, who belong to this model, study design as a logical process of problem-solving.

Newell and Simon used a graph called the problem behavior graph (PBG) to analyze the structure of the design process. In general, during the protocol analysis, it has been observed that a process that takes place at any given time is influenced by its previous process. In this regard, it is important to know what information is being considered at the moment and what process is intended to affect the present information. Researchers have found that showing these issues graphically can be efficient. So, they design a graph, which is named the problem behavior graph. The problem behavior graph is an accurate statement of the analysis and classification of the resulting protocols during protocol analysis studies.

Each node in the problem behavior graph represents a knowledge state. Each line represents a transformation involving specific information and the operations used. The problem behavior graph is coded according to the resulted data from protocol analysis. This graph is read from left to right, then down. Reiterations of part of the design process show up as branches in the processing sequence. Abandoned lines of thought clearly show through (Eastman, 1970). An example of a problem behavior graph is shown in figure 2. The design problem in this example was to remodel an existing bathroom for a house in California. During this experiment, Eastman (Eastman, 1970) classified the information into three categories and used this classification in order to analyze the protocol analysis and draw the problem behavior graph. Different kinds of information in Eastman's classification are as follows:

1) Physical elements that are manipulated (design units), these

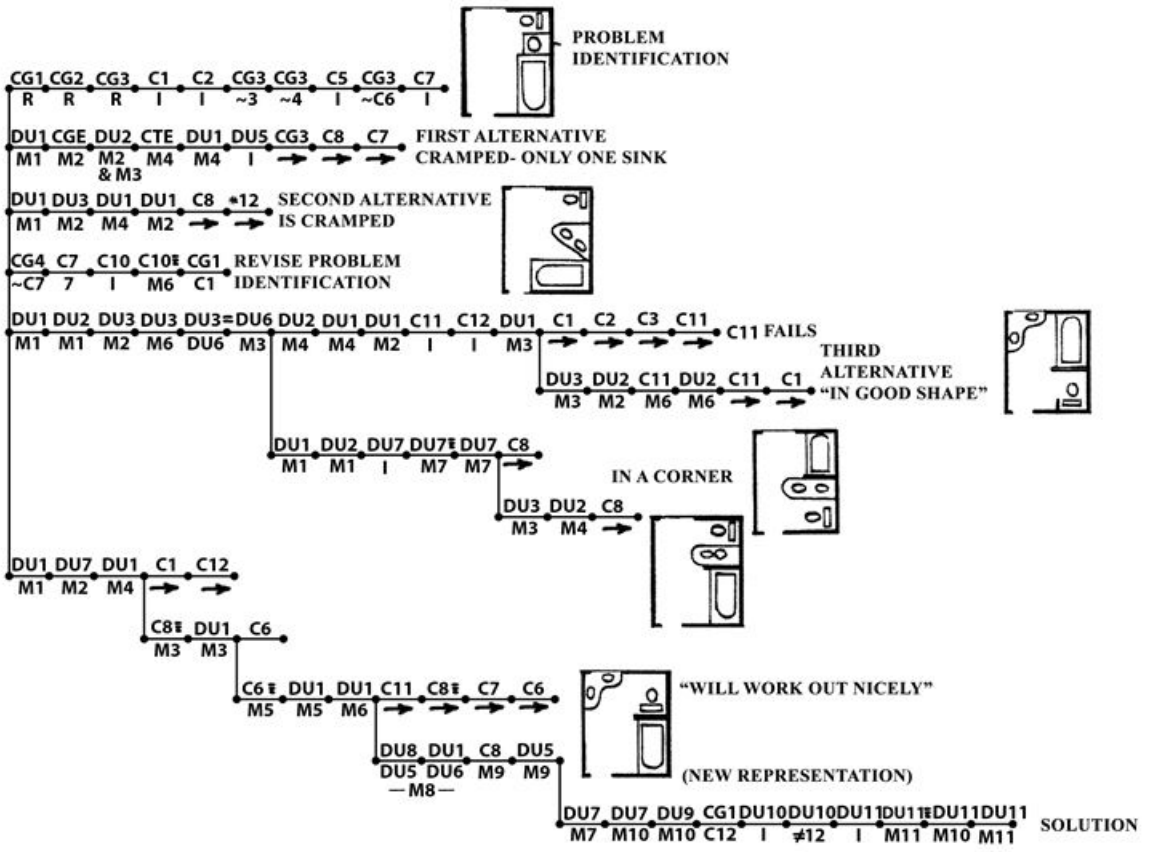

Fig. 2: An example of a problem behavior graph (Eastman, 1970)

elements are shown in the graph with the letter D.

2) Desired relationships between elements and the desired attributes of elements (Eastman called these constraints), these issues are shown in the graph with the letter C.

3) The manipulations made on a design to fulfill the relationships or attributes. These issues are shown in the graph with the letter M.

Decide on the information used, their sequence and operations applied at each stage in order to generate a new state is the first step to analyze the structure of the design process through protocol analysis.

Decision Tree

Among other methods used to analyze the structure of the design process, a "decision tree" can be mentioned. In this method, the data obtained from the protocol analysis are examined and analyzed in order to understand the decision-making process and the information used. Dwarakanath and Wallace (Dwarakanath & Wallace, 2007) have described this method through three steps:

Step 1. Identifying decisions: Identifying decisions is not easy, because designers seldom explicitly stated that they had made a decision. To identify retrospectively the decisions made, they were divided into explicit and implicit decisions.

Explicit decisions: When designers either explicitly said or wrote down that they selected an alternative or rejected one, an explicit decision was made.

Implicit decisions: These were not explicitly stated by the designers but could be identified retrospectively as decisions. They were identified by looking at the final design. If a designer working on a particular solution, say A, but left this and started working on something else, and solution A formed part of the final design, then an implicit decision was made to select solution A. If a designer working on a particular solution, say B, but left this and started working on something else, and this solution B did not form part of the final design, then an implicit decision was made to reject solution B. In this investigation, only those decisions which were related to the product were analyzed and not those related to the process

Step 2. Creating decision trees. Once the decisions were

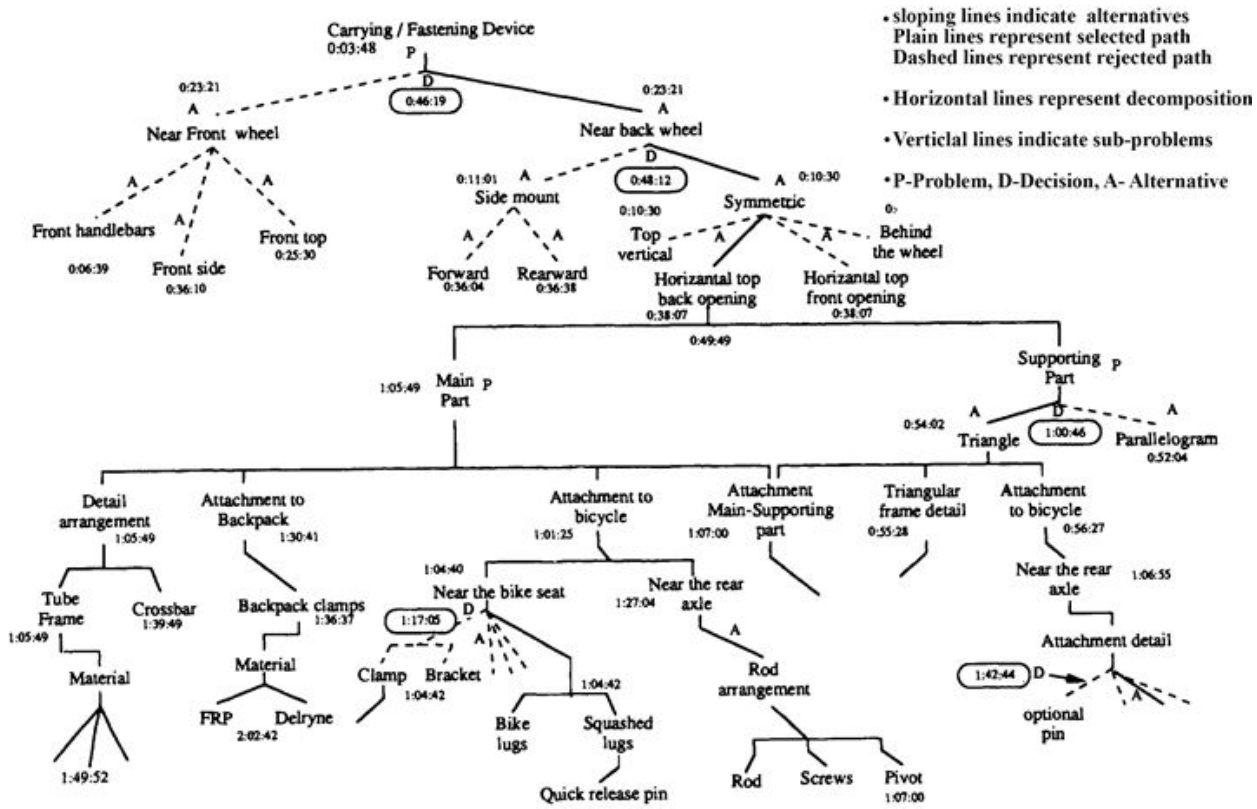

Fig. 3: An example of a decision tree which has been extracted from the design process of designing a carrying device for a bicycle (Cross, 2000)

identified, a decision tree is created for each experiment.

Step 3. Identifying the types of information used in the decision-making process. The types of information used for each decision are identified and classified.

An example of a decision tree is presented in figure 3. Sloping lines indicate alternatives, while the vertical lines indicate the issues and sub-issues. Discontinued lines indicate rejected paths.

Linkography and its Applications

Linkography is another method for analyzing the structure of the design process that is performed through protocol analysis studies. A linkograph is a modified representation of a matrix. In the general approach of this method presented by Goldschmidt, one protocol of a design task parsed into "design moves. For each design move, the presence or absence of a link with other design moves is considered. These links are finally displayed as linkograph. The design process can be analyzed through the structure shown in the linkograph and patterns formed in it. The components of the linkograph and the patterns that may be formed in its structure are as follows:

Design move: Goldschmidt (Goldschmidt, 1995) defines design move as a step, an act, an operation, which transforms the design situation relative to the state in which it was before that move.

Link: If there is a connection between a design move and another design move before or after it, a link is established between them. Goldschmidt's approach to link-coding relies on "common sense", and clarifies that "a link between two moves is established when the two moves pertain to the same, or closely related, subject matter(s), such as a particular component of the designed entity, its properties and functions, a concept or a design strategy" (Goldschmidt & Weil, 1998)

Chunk: A chunk is a block of links among successive moves, which form links almost exclusively among themselves and are barely or not at all interconnected with other moves.

Web: A web is formed when a large number of links is formed among a relatively small number of moves.

Sawtooth Track: In some instances, a sequence of several moves link each to the one preceding it. In such cases, the link-lines along the move-line describe a pattern similar to a sawtooth.

Forelinks and backlinks: Each design move may have a link with previous or subsequent design moves. Goldschmidt (Goldschmidt, 2014) named the links that connect a design move to its previous one's backlinks of that design move. On the other hand, the links that connect a design move to its subsequent design moves named forelinks of that design move. (Goldschmidt, 1992; Goldschmidt, 2014; Hatcher et al., 2018)

An example of a linkograph, the components, and patterns that can be found in its structure is shown in figure 4.

In figure 5, the process of protocol analysis research method, which provides data for analysis by linkograph is shown. As mentioned before, every segment in protocol analysis is a

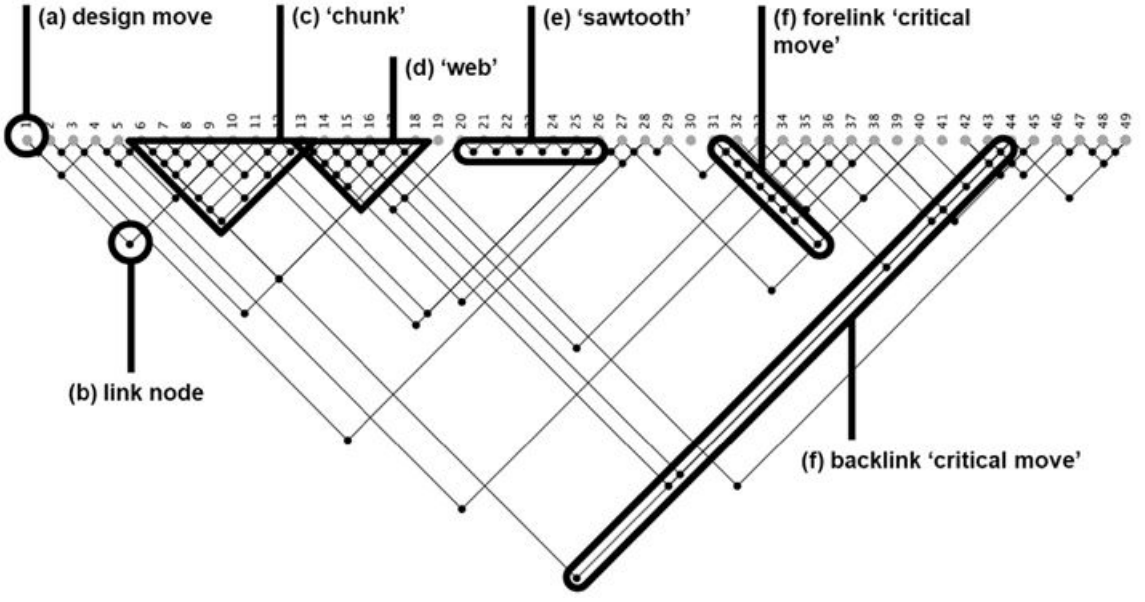

Fig.4: An example of a linkograph, the components and patterns may be found in its structure. (Hatcher et al., 2018)

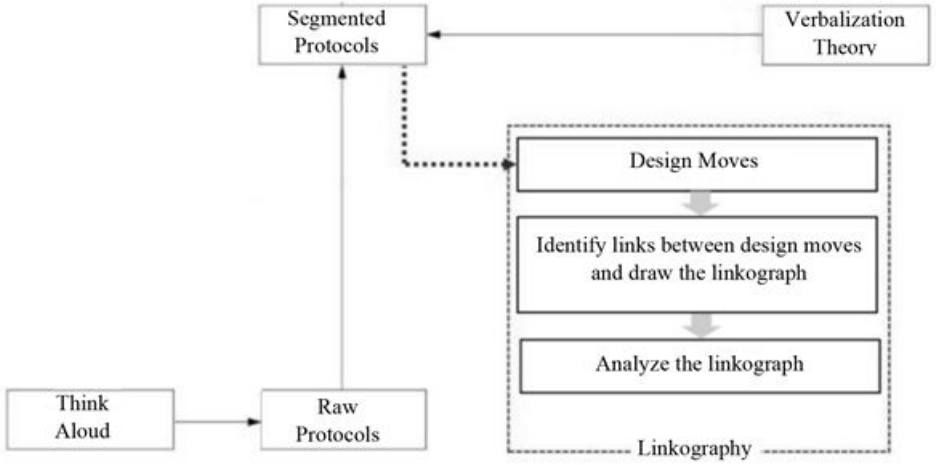

Fig. 5: The model of protocol analysis research method and analysis the data by linkograph

design move in linkograph.

Extension of Linkography by Some Researchers

Linkography, has had a wide range of reflections among researchers of different disciplines in the field of the design process. This analysis method was later considered by some researchers and efforts to provide extensions of linkography were done. Mentioning a few examples of these extensions in this section can be effective in a better understanding of this process.

Link Matrix

Van der Lugt (Van der Lugt, 2000) developed Goldschmidt's linkography to show the process of ideation in the design and the relation of creative qualities of ideas. As mentioned above, a linkograph is based on a simple matrix, van der lugt, which has listed the data resulted from protocol analysis in a matrix-type linkograph with some extensions to the linkograph such as the concerning the identity of each link. In Goldschmidt's approach, the only criterion for determining the links between design moves is the researcher's correct judgment. Goldschmidt mentioned:" in practice, a link between two moves is established when the two moves pertain to the same, or closely related, subject matter(s), such as a particular component of the designed entity, its properties, and functions, a concept or a design strategy, and so on (Goldschmidt & Weil, 1998)." In this case, the reliability of the researcher's judgment in identifying links in creative problem-solving

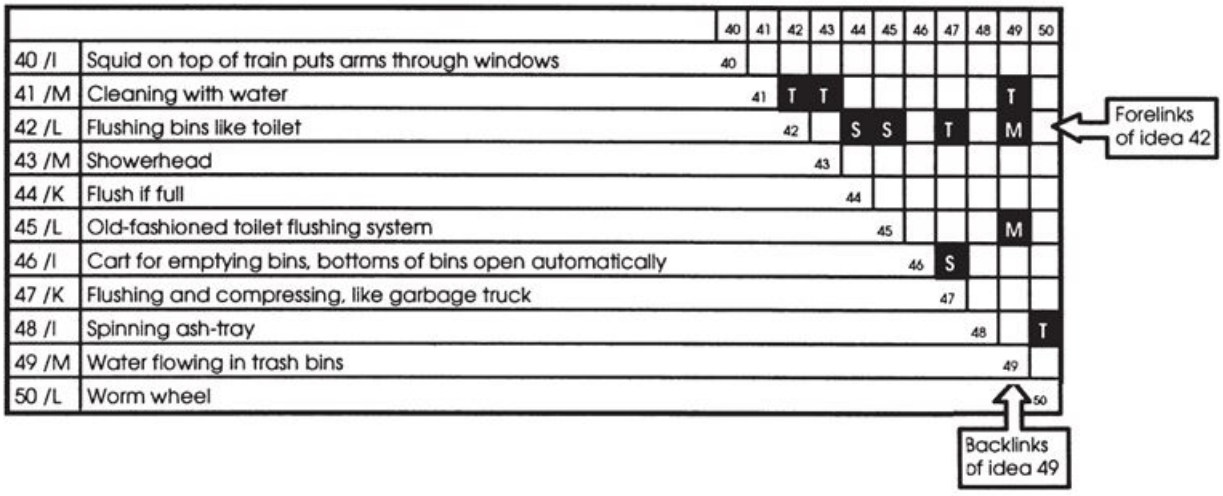

Fig. 6: A part of a link matrix in which the designers were asked to generate ideas for a new litter disposal system for a new Dutch railway carriage (Van der Lugt, 2000)

sessions may be limited. Especially when the relations between design moves are somewhat vague. Therefore, Van der Lugt's effort was to increase the reliability by developing signs for links. In this way, direct connections or "links" with all earlier ideas are determined by gathering and evaluating evidence of connections. Evidence can be found within the content of the ideas. He divided the links into three groups and developed them. These three types are supplementary link (S), modification link (M), and tangential link (T). Supplementary link (S) shows Small and auxiliary change in the general idea. Modification link (M) provides structural changes in the idea while maintaining the existing line of thought. Tangential link (T) is a representative of a fundamental change from the previous idea (Van der Lugt, 2002). A small part of a link matrix is shown in figure 6. Forelinks and backlinks are defined in the link matrix as a linkograph. In the present example, the idea number 42 has four forelinks and the idea number 49 has three backlinks. The type of the links is specified on them.

FBS Method

Another extension of linkography was raised by John Gero (Gero, 1990) in 1990. His method was a design model based on "function-behavior-structure" that is known as FBS. From 1990 onwards, this model was developed by Gero and his colleagues, and several essays were published around this subject matter. Including, can refer to essays in which FBS is used as a coding system in line with linkography.

The coding system based on FBS includes function (F), expected behavior (Be), behavior derived from the structure (Bs), structure (S), design description (D), and requirement (R). Design description and requirements are both describable in terms of function, behavior, or structure. In this approach, the purpose of design is to transfer a set of functions to a set of the design description. A design description is never transformed directly from the function, but it goes through a series of processes. These processes include 8 items which are as follows:

-Formulation transforms functions into a set of expected behaviors,

- Synthesis, wherein a structure is proposed to fulfill the expected behaviors,

-An analysis of the structure produces derived behavior,

-An evaluation process acts between the expected behavior and the behavior derived from the structure,

-Documentation, which produces the design description,

Based on the structure there are three types of reformulation:

- Reformulation of structure,
- Reformulation of expected behavior,

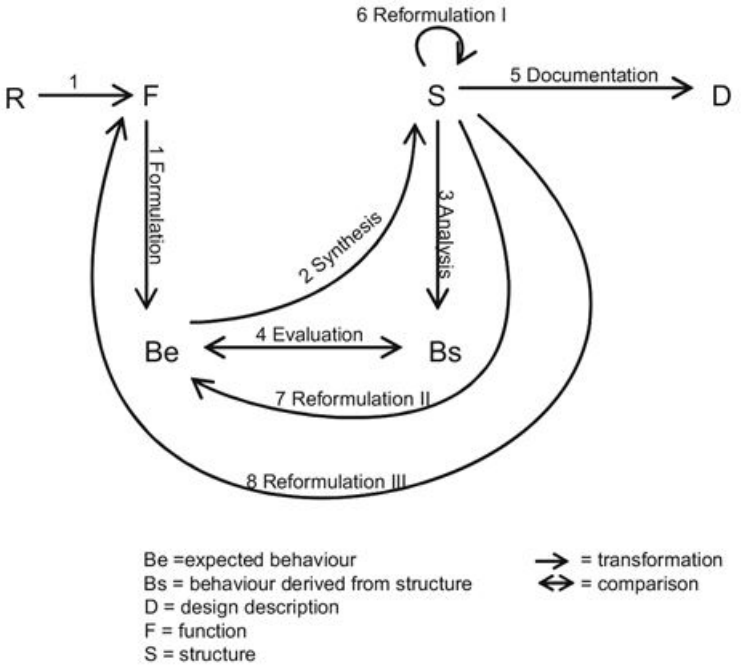

Fig. 7: FBS method (Kan & Gero, 2017)

Table 1: Comparative methods for analyzing protocols in design process, based on (Suwa & Tversky, 1997)

	Protocol Analysis Method	Description
Protocol Analysis for Design Process	Formal AnalysiS	Design is seen as a rational problem-solving search process
	Informal Analysis	Design is not just a rational process, but a reflective conversation with the situation the designer is experiencing.

Table 2: Types of design process analysis methods and their approach

	Formal approach (Design process as a logical search for problem-solving)	Informal approach (Design process as a reflective conversation)
Design process analysis method	Problem Behavior Graph (PBG)	Linkography
	Decision Tree	Extended Linkography (Link Matrix, FBS)

-Reformulation of function (Kan & Gero, 2017).

Figure 7, shows the relationship among the eight transformation processes.

During protocol analysis, where protocols are divided into separate segments, for each segment, one of the codes of the FBS method is considered. In this process, drawings and handwritings get the structure (S) code. Each segment is a design move in linkograph. Thus the linkogrpah will be formed based on the links between segments (design moves) and the specified code of each segment.

Comparing Different Methods of Design Process Analysis

Analyzing the structure of the design process is a process, which is done through data, resulted from protocol analysis. According to research conducted in the field of protocol analysis, Suwa and Tversky (Suwa & Tversky, 1997) have identified two main approaches, including the Formal approach and informal approach. These two approaches can be used in classifying the design process analysis methods. A comparative method for analyzing protocols in the design process is shown in table 1.

In formal protocol analysis, the design is considered a rational problem-solving search that is looking for a solution. An informal protocol analysis, the design is seen as a process in which each designer constructs his/her reality by his/her actions that are reflective. This approach is close to Donald Schon's (Schon, 1983) view, which seen design as a process of reflection in action. According to Schon, the design is not just a rational process, but a reflective conversation with the situation the designer is experiencing. In this view, each design problem is specific, and the designers' main skill is in deciding how to deal with each design problem specifically. Dort and Dijkhuis (Dorst & Dijkhuis, 1995) argued that Schon's well-written description of his architectural protocol sparks immediate, intuitive recognition by designers. It inherently combines the content- and process-component of the designer's actions. The essence of Schon's theory is that designers are active in structuring the problem, and that they do not evaluate concepts, but that they evaluate their actions in structuring and solving the problem. Analyzing contents in the study of Dorst and Dijkhuis (Dorst & Dijkhuis, 1995) means to reveal what information, resources, and knowledge are involved there.

In the study process of different methods for analyzing the structure of the design process, the two approaches mentioned above can be identified. Problem behavior graph and decision tree are both analysis methods that see the design process as a rational and linear process and analyze the structure of the design process formally. In these methods, the researcher must reverse the design process in order to analyze it, because the design process is considered a linear process. On the other hand, Linkography and extended linkography methods, do not consider the design process to be a linear and rational process and analyze the structure of the design process in an informal manner. In table 2, the classification of various methods for analyzing the structure of the design process is provided.

CONCLUSION

The classification which is mentioned above that categorized different design process analysis methods into two groups clearly shows the approach behind them. Problem behavior graph and decision tree follow a formal approach, which considers the design process as a linear process. This is in contrary to what thinkers like Rittel have pointed out. First-generation design methods[1]" does not exist anymore. So, Analysis methods such as problem behavior graph and decision tree, cannot be useful and accurate methods for analyzing the design process as an argumentative process.

Moreover, methods such as linkography and extended linkography follow an informal approach. In this approach, the process and content of design activity are inextricably linked to each other, and it does not follow a linear process. Linkography is an analysis method that identifies links between decisions in the process of designing and is a good representative of this approach. According to the essence of the design process, linkography is an appropriate method to analyze the structure of the design process. Other methods for optimizing linkography were developed in later years. For instance, Van der Lugt developed linkography by giving identity to links, or Kan and Gero provided FBS coding, which became the basis for the development of new software for drawing and calculating the linkograph, called linkoder. In fact, both link matrix and FBS methods take into account a coding system, the difference is that in the link matrix, links are coded, but in the FBS method moves are coded.

This process that develops new methods for analyzing and studying the structure of the design process, continues to expand in this field, and the growing use of interdisciplinary teams of researchers who are working on more complicated and realistic design tasks is observed. The use of these methods in analyzing the design process has been effective for a better understanding of this field and can be used to improve teaching and design methods. Moreover, an accurate understanding of these methods and use them can play an effective role both in the university and in the professional field inside the country.

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ENDNOTES

1- Design methodology was temporarily saved, however, by Rittel's (Rittel, 1973) brilliant proposal of "generations" of methods. The first generation (of the 1960s) was based on the application of systematic, rational, "scientific" methods. The second generation (of the early 1970s) moved away from attempts to optimise and from the omnipotence of the designer (especially for "wicked problems"), towards recognition of satisfactory or appropriate solution-types and an "argumentative", participatory process in which designers are partners with the problem "owners" (clients, customers, users, the community) (Cross, 1993).

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