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ANALYSIS OF INDIVIDUAL STYLES OF PROBLEM SOLVING AND THEIR RELATION WITH THE REPRESENTATIONS IN DESIGN PROCESS

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ABSTRACT
The objective of this communication is, through a literature review, identify and analyse the factors are of use to adopt problem solving structures. Thus, these factors, affect to choice and to apply some design strategies. Keeping in mind that the process of design is a creative process, the characteristics of the designer have been analyzed in order to identify the elements which caracterize the diferents styles of problem solving. We have researched in analysis and synthesis phases. Also have been studied the methodologies in empirical researches related to design process. These previous elements in relation to design methodologies, could be useful to obtain results in education, favouring the acquisition of advanced knowledge in the area of Engineering design.

Keywords: Design process, Problem solving, Cognitive process, Knowledge Engineering.

1 INTRODUCTION
The design process has been a subject widely studied in the last decades, its importance, at least in the industrial field, has been increased as a result of the increase in the competitive pressures product of the globalized markets. Also, the advances in the field of the computers have overturned the attention to the development of computer tools that facilitate the work of the designer and grant more efficient solutions to the created problems.

The conception of the design process, from the definition given by Asimow [1], to the acceptance nowadays has been modified, although it conserves several of his generic characteristics. For Asimow, the design process is composed of the definition stage of the problem (analysis), generation of ideas stage (synthesis), evaluation stage and selection stage. Although this description enunciates general stages of the process, it does not correspond exactly with the actions that are taken during design practice. Empirical studies have demonstrated that the creative process takes place during all the phase of design and that at the same time the stages of analysis and evaluation are repeated when they are begun to raise design solutions. In this way, as ideas as definition of the problem are jointly developed and refined throughout the design process, making constant iterations of processes of analysis, synthesis and evaluation [2]. After the exposition of Asimow, diverse oriented theories have been developed to describe the complexity of the phenomena related to the design process, some of these can be sorted out: the descriptive Model of Cross [3], Model of Pugh [4], Systematic Model of Pahl and Beitz [5], Theory of Resolution of Inventive Problems [6], Theory of the technical systems of Hubka, Eder; [7], among others.

However, in spite of the development of general theories and specific methodologies derived from these, the work of design continue as an activity in which the action of the designer as individual and independent cognitive agent is the key, transforming it in a creative and unpredictable process. In several studies, successful strategies of design were developed from classic methodology of design. Also, diverse experiments of design controlled in laboratories have corroborated that the individual styles of problem solving affect the design process and condition to a large extent its effectiveness [8].

Considering the previous thing, it becomes pertinent to analyze which factors determine the adoption of concrete schemes of problem solving and how these factors influence the election and application of strategies during the design process. The correlation of these elements with the existing design methodologies nowadays, will allow to sort important conclusions at educative level, related to the processes of formation of designers in the field of engineering.

2 ANALYSIS OF THE HUMAN FACTOR IN THE INITIAL STAGES OF THE DESIGN PROCESS

Keeping in mind that the process of design is above all a creative process in which characteristics of the designer, as individual cognitive agent, plays a major role. We have intended to identify, through empirical studies carried out, which elements characterize the individual styles of problem solving and how they, at the same time, influence the design strategy adoption.

Summing up, the main objectives in this work are:

- To investigate the influence of individual styles of problem solving on the processes of design.
- To identify differences between expert designers and novices at the moment to undertake problems of design.
- To determine the implication that the previous elements have in the designer education process in engineering domain.

The factors that determine the adoption of concrete problem solving plans have been analyzed and how they, at the same time, influence election and application of strategies during the design process. The correlation of these elements with existing design methodologies permits to sort important conclusions to educational level, in relation to the process of formation of designers in the domain of engineering.

Through the different problem solving styles studied in the bibliography, the relation between individual problem solving styles and the representations in the process of design has been established, identifying influencing factors during the problem solving process.

2.1 Determining factors in the initial stages of the design process

The main contributions to the design science have been centred in research of theories and methodologies that fix the guidelines to follow in the design activity. Diverse oriented strategies have been defined to establish a methodological structure that guides the designer all along the process, from the problem definition to the election of the best solution. However, empirical studies offer evidence that in many cases the designers act far from these strategies and nevertheless obtain successful results [9]. The previous study strengthens the creative character of the design work and the importance that in this one the designer has the attitude and capacity, like individual cognitive agent. These aspects entail to raise new line of investigation inside the design science, oriented to identify which are the factors that determine the adoption of a specific strategy by the designer. In the following sections it is tried to identify, through a bibliographical revision, some of these factors and to define also several criteria that are bases to make future investigations that allow having greater clarity on this subject.

In the first place, it is necessary to clarify what it is said by strategy and to define in which design situations its use is important. On the matter, a strategy can be defined based on the following characteristics [10]:

- The strategies are directed towards the last objective of an action process and not towards intermediate objectives.
- The strategies have a methodological character. They contain the information on like advancing to reach the final mission under certain conditions.
- The strategies structure and simplify action. They help to subdivide a problem in clear units of sub-problems. In a strategy, it does not have to plan each passage in the action, rather define the previous conditions that allow controlling the process of problem solving based on a limited number of alternatives.

Considering the previous characteristics, the strategies are useful in those situations of design that have great complexity, by the uncertainty associated or the degree of creativity which they demand. In this sense, and following the classification of the activities of propose design by Gero [11], it can be established that the strategies are especially important when activities of creative design are approached included innovating design, but not in the routine design, in which case, the designer applies a plan of action previously defined.

Nevertheless, in very complex and new situations, the designers can even initiate their actions without having a plan of action or a defined strategy. In this case the heuristic knowledge is used to define a personal system of rules, through which new strategies can be formulated. The following chart is a scheme of the diverse ways that the designer can take in function of the profile of the situation. In this chart, in addition to the concepts already mentioned, the one of "strategem" is presented [9], term defined as a set of rules through which the initial approach phase to the work of problem solving is regulated following specific characteristics (careful, analytical, etc.).

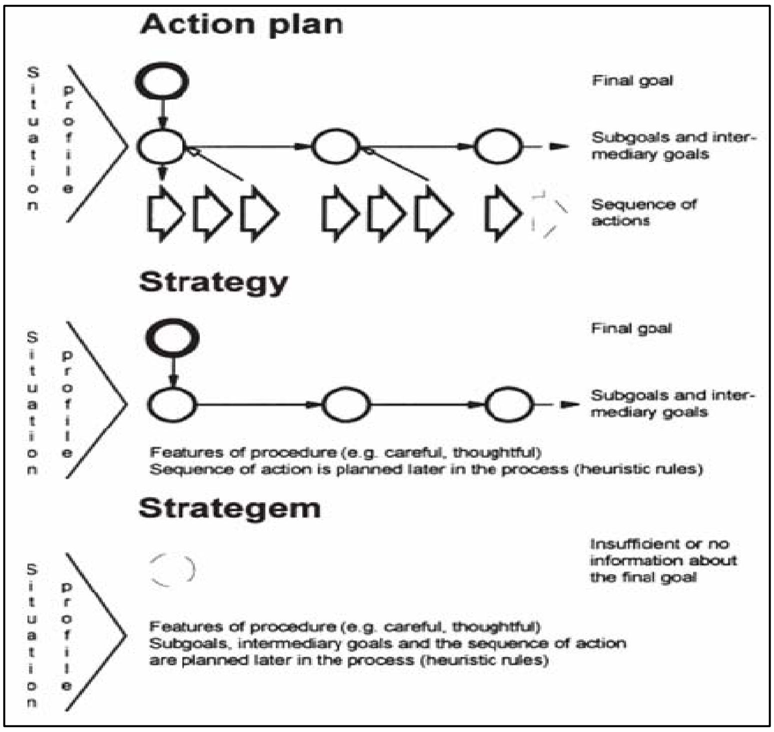

Figure 1. Different types of strategic knowledge (extracted from Von der weth, 1999)

These concepts allow explaining how people act when they face an activity of problem solving, based on the degree of complexity and newness of the situation. Nevertheless, it is not clear if defined requisite exist to ensure the success of the designer when approaching the design process, as well as aspects relative to the influence of the experience or the use of a certain strategy.
According to Von der Weth, the knowledge that the designer has on his own knowledge constitutes the fundamental requirement to approach the design activity. Through this knowledge, the designer can, in front of a given situation, identify the abilities needed to reach a successful result [9]. Factors that determine the action of the designer can be seen in figure 2.

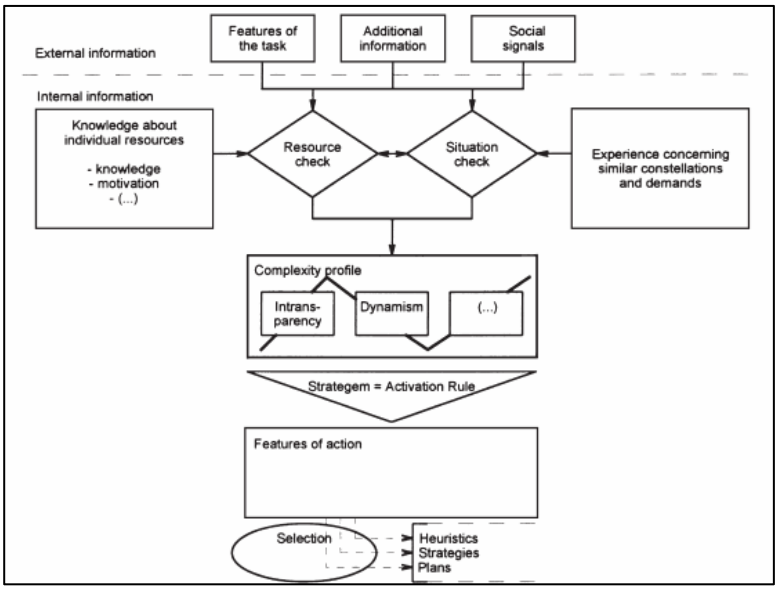

Figure 2. Development of the profile of complexity and activation of strategies (extracted from Von der Weth, 1999).

The information needed to define the complexity of a situation and to activate a process of specific action (plan, heuristic strategy or rules) is available in two dimensions: one external to the designer, and another internal to him. The external information is fundamentally related to the characteristics of the design work and the social signals, whereas the internal information is related with the resources of the designer, like the knowledge, the motivation, the creativity, the experience, etc.

This model offers a general typology of the factors that determine the action of the designer but does not show in deep the effects of each specific characteristic. The analysis of these factors has been the central subject of numerous investigations, which have characterized its characteristic every time more empirical. So, we have analyzed the influence that factors like the experience [9], [12]; [13], the individual styles of problem solving [14], the creativity [15], [16], the precision of the design problem [17] have in the design process.

Most of the investigations have used as investigation method the protocol analysis. The application of this technique has made possible advancing in the analysis of the general processes of problem solving, allowing us to specify the cognitive abilities of the designers, which through other methods would remain hidden. At the moment, this technique is the most suitable to undertake study of the design activities, despite it presents certain limitations due to the difficulty to express verbally all cognitive abilities or to express them suitably. On the other hand, the reviewed studies previously have been centred in the initial stages of the design process, that is to say, in a the analysis and the synthesis, identifying the existing strategies for the definition of the problem and for the generation of solutions, as well as the factors that determine the use of each one. To continue, we have analyzed separately stages before mentioned, following the general division of internal and external factors [9]. With this form to display the analysis, it is tried to identify with greater clarity the determining strategies of action of the designer and factors of the same one, but it is necessary to indicate that in the practice, the definition of the problem and the search of solutions evolves of interdependent form, constructing a process more cyclical that linear [2], [12].

2.1.1 Determining factors in the analysis stage

Following the exposition of Asimow, the analysis constitutes the first stage in any process of design. In this sense, diverse models corroborate that the definition of the problem is the initial step within any creative process [18]; [19], [20]. This definition can be characterized like a passage from a badly structured problem, to a suitably structured problem [21]. The badly structured problems are characterized to have manifold objective, multiple forms to solve them and diverse possible and acceptable solutions. The structured problems, on the contrary, are characterized to have a well-known objective, a well-known methodology, a form to find an answer and a correct solution, which can or not be well-known by the designer [16].

The precision with which the design problem is formulated, constitutes then the first factor that determines the action to follow of the designer, and can be classified like an external factor, within the category of characteristics of the design work.

When a designer find an ambiguous and vague problem, he begins to structure the problem and to identify the objectives, the procedures, the restrictions and the information necessary to solve it [22], [23]. On the contrary, when the problem is formulated with a suitable level of precision, the phase of construction is almost automatic and the designer searches information and solutions [23].

A second determining factor in the construction of the problem is the experience, which unlike the previous one is an internal factor of the designer. Diverse studies indicate that experts use a considerable amount of time in structuring of badly defined problems, whereas novices directly go to their resolution [24], [25], [26]. Experts are more conscious of the multiple conceptualizations that can have a badly defined problem and therefore before initiating the search of solutions, they dedicate an important part of the time to the construction of these problems.

On the other hand, during the definition of the problem, experienced designers tend to decomposed it in sub-problems, more concrete and structured, from which they initiate their search strategies [12]. Chun-Heng Ho established that the designers with greater experience follow an explicit strategy of decomposition of problems, structuring them until a third level of abstraction (table 1) before coming to generate possible solutions. This action allows them to find solutions more precise and to approach of more effectively all the phases of the design, from the conceptual one, to the detailed design. On the contrary, inexperienced designers follow an implicit strategy of decomposition and their structuring of the problem arrives in best cases to the second level of abstraction, contemplating the single subsystems and not detailed design.

Table 1. Categories of problem, Gero & Nelly (1997)

Level of abstraction		**Definition**
0	System	El The designer considers the global problem
1	System y Sub-systems	El The designer considers the problem in terms of interactions between subsystems
2	Sub-systems	El The designer considers details of the subsystems
3	Detailed design	El The designer considers a subsystem from the point of view of the detail works of each subsystem

During the process of problem solving, experts try to settle down a general structure from the beginning, directing their efforts towards the objective initially proposed and developing each one identified sub-problems. In the case of novices, a noticeable direction exists to redefine the initial situation and to formulate a new problem, without defining a precise structure of the situation of originally raised design. In this initial stage it is where the main differences between expert and inexperienced designers are demonstrated, because when the problem has been defined, the following strategies of search of solution are very similar [12].

A third factor that influences in the definition of the design problem is the styles of problem solving of the designer. The activity of the design is generally accepted like a complex process of problem solving in which action of human regulation plays an important role [27], [28]. In this sense, the individual pre-requirements which the designer has represent the main source of variation in the course of the design process and therefore in the effectiveness of the results. The study of these aspects constitutes a line of classic investigation in the field of psychology and recently it has been complemented with similar studies in the area of engineering.

Eisentraut presents an approach on the influence of the individual styles of problem solving in the design process [8]. From this investigation two important conclusions are come off: on the one hand, the individual styles of problem solving describe the preferred mechanisms of action of any individual at the time of approaching complex problems and they are characterized by his stability, that is to say, independently of the kind of problem that approach (common problems, structured problems of design, affluent problems, badly structured problems), the styles are always the same. On the other hand, the success in a design problem depends on the adaptability of the individual styles to the specific situation, that is to say, a style that is successful in all the cases does not exist.

The styles of problem solving are fundamentally determined by five characteristics: the amount of required information, how to approach the problem, the planning and action, the effect of monitoring and the profit of the goal. Some people whom before a situation problem they do not require of much information take actions from quickly without needing a rigorous planning. Consequently, generally, they must make many interventions later to correct non-predicted disadvantages. These people approach the problem without a systematic vision and only contemplating the influence of determined variables. On the contrary people who, in front of a problem situation, make an exhaustive search of the information, although they use initially a greater amount of time, gain in the end because they make few and effective interventions. This type of person does not begin the action until they have not developed an suitable plan, considering the effects of the different existing variables, that is to say, they approach the problem with a systematic vision.

Until now three factors that influence the initial activity of the design process, that is to say, in the definition of the problem have been identified. These are: the precision of the design task, the experience of the designer and the individual styles of problem solving. Following the structure general of Von der Weth [9], the two last factors constitutes internal elements related to the resources of the designer, whereas the first one is an external factor related to the characteristics of the design work. We have now to consider the second activity in the analysis stage, concerning the search of relevant information.

Once the problem is created, it becomes necessary to integrate an ample and diverse set of information, from internal and external sources, and it must be synthesized and codified to facilitate production of a creative solution [29]. In this process of search of information, the initial definition of the design work constitutes a determining factor again. When the designer faces badly defined problems, the search of information depends to a great extent on the existing knowledge. The designer uses this knowledge to evaluate the importance of the search of information [30] and to support the creative thought [31]. On this way, throughout the construction of the problem, the dominant knowledge orients behaviours of search and structures the codification of the new or modified information [23].

However, the dominant knowledge is insufficient to generate a creative solution. In this case, the cognitive ability of the designer to create new concepts and to modify the existing ones becomes a critical element. Those people who can combine and modify the information, have greater possibilities to get to a creative solution and, with an additional advantage, they can identify new signals that are used for the search as additional information [16].

The individual styles of problem solving also exert a direct influence in the search of information. One of the multiple characteristics that define these styles is the relation with the amount of information required by the designer before initiating the action [14]. On this way, those people who require little information limited their search strategies to information of general character, concentrating themselves in the existing knowledge. On the contrary those individuals that need to have detailed information before initiating any action will deepen their strategies search, without limiting themselves to existing knowledge and trying to generate new cognitive structures.

Fricke [17] offers another classification of information search strategies, which, unlike the previous one, is not based on the type of knowledge used, but on the tactics of questioning that follows the designer. It distinguishes two basic strategies: the tactics of structurally oriented questioning, and the tactics of changing questioning. According to Fricke, a characteristic that differentiates the good designers from the mediocre ones is in the use of these strategies. The good designers generally begin with a clarification of the requirements of the work of design and a structuring of theses requirements in different functional areas, which serve to guide their information search process. On the contrary, the mediocre designers give continuously jumps in their search process and must go back to the definition of the problem; they are all following poorly planned questioning tactics.

From all that has been said before, it is come off that, during the analysis stage, the precision of the design work, the individual styles of problem solving and in some cases the experience constitute determining elements that guide the action of the designer. The empirical studies until now offer some indications on how this influence is pronounced.

2.1.2 Determining factors in the synthesis stage

The synthesis stage consists in generating possible solutions that fulfil the specifications of the design problem. These solutions can be generated through the application of systematic methods (transparent box) or by means of the use of creative methods (black box). These last ones are those that are mainly approached in terms of creativity [16]. The process of generation of ideas constituted the central axis of most of the initial investigations on the creativity, beginning with the work of Guilford on divergent thought [32], [33]. Whereas some investigations have found weak relations between the divergent thought and the creativity [34], [35], other studies has related the divergent thought to the creative behaviour in an ample variety of atmospheres, occupations, and populations [36]; [37]. The approaches the most common towards this subject have been centred in the study of the team work (analyzing the interaction of group like source of generation of ideas), analysis of decomposition of the problem (reducing the whole in the parts), remote stimuli (those that are not directly related to the task of problem solving), and the search of relations, among others [16].

In the present work, some of the classic solution search strategies reviewed in literature have been analyzed in order to identify, like we did in the previous section, factors that determine in a given moment the use of each strategy on the part of the designer.

A first classification of the solution search strategies is provided by Dylla [38], [39], that identifies two different types of approaches: the generated variation and the corrected variation. The factor that determines the use of anyone of the two previous strategies is the experience. The corrected variation is a suitable strategy, commonly used by expert designers. They have greater ability to choose advisable solutions from the beginning and to find complex relations between sub-problems. The use of this strategy provides solutions in a shorter time, but it supposes greater risks since the important decisions are taken in early stages of the design process and in some cases without having all the necessary information [38].

What Dylla has raised corroborates the study of case made by Chun-Hen Ho [12] who found that less experienced designers raised diverse solutions during the initial stage of the design work, whereas those of greater experience normally formulated a single one, which they developed as they advanced in the process. Another difference found was that the inexperienced designers developed to depth the different generated ideas, whereas the experimented ones initiated the process with a much more ample search, guided by the structuring and decomposition of the problem carried out during the analysis stage.

Anderson [40], offers another classification of the solution search strategies. This author differentiates the strategies of Working-Forward (WF) and Working-Backward (WB). Experienced designers follow a WF strategy whereas novices follow a WB one. However, this relation seems to be nonexistent when less structured problems are approached as those of design [12]. In figure 3, displayed previously, it is observed that after applying a strategy of decomposition of problems, the way followed by expert and inexperienced designers is very similar.

The initial formulation of the problem has also been considered as another determining factor during the search of solutions. In this sense, Fricke exposes that when a designer works with vague problems, a pre-fixation of the developed principles of solution can be seen during the analysis stage, causing that the designer concentrates himself in a limited number of ideas. On the contrary, when he works with precise problems, the designer tends to generate diverse variants of solution principles, which will be analyzed and developed in later stages [17].

In the study made by Fricke [17] offers empirical evidence on three possible solution search tactics, these are:

- Excessive expansion of the space of research
- Balanced search
- Irrational restriction of the space of research

Fricke found that of the three previous tactics the one which offers better results is the balanced search tactic. In his study, designers who obtained suitable solutions, without considering the degree of precision of the created problem, followed a systematic process of generation and evaluation of ideas during all the phases of the design (conceptual, preliminary, detailed) based on the level of abstraction of the solution. The analysis showed that, in any case, generation of few ideas as well as synchronize existence of many principles of solution can carry a negative effect in the quality of the final solution.

Also, in the study of Fricke [17], certain relation between formulation of the problem and use of certain strategy search is demonstrated. In general terms, when the design problem is properly formulated, a favourable tendency to expand the space search exists. On the contrary, when problem is vague, the action of the designer is oriented in greater degree to a reduction of the problem. If greater initial information is available, it is easier that the designer settles down diverse principles of solution, whereas if information is little or ambiguous, the designer is more prone to consider few alternatives and to define a single principle of solution that guides all the process.

3 CONCLUSIONS

In diverse studies, it has been verified that suitable solutions to complex problems have been obtained when the designer moves away from the classic strategies of design. This fact has caused development of new line of investigation oriented to identify intrinsic factors, and to the activity of design like the designer that finds the course of the process. The studies made within the framework of these lines have been characterized by their empirical nature and to try to specify the thoughts and the actions that regulate the action of the designer. The protocol analysis has become of this form the methodology but used by the investigators for the sake of clarify the cognitive process that advances the designer during the resolution of problems.

These investigations corroborate that, in most of the design situations, important decisions are taken at the initial moments, and all the process of problem solving is structured based on these decisions. They imply the adoption of a certain strategy by the designer, as much for the problem construction and information research, like for possible solution generations. In this process, a great variety of factors influences, some related to the task of design and other concerning characteristics of the designer. Identification of these factors is the objective of the presented studies and although the obtained results are not absolutely forceful, and in some cases are a little contradictory, they even offer important signals on which elements must be considered and serve of base for development of future investigations to clarify the subject.

In analysis stage, designer experience influences the level of decomposition of design problem. Experienced designers make generally a deeper decomposition of the assigned task, getting even to clarify from the construction of the problem some aspects of detailed design [12]. Similarly, individual styles of problem solving become decisive aspects when designers have to follow an information search strategy.

During synthesis stage, the experience is still a decisive factor. According to Dylla [18], experienced designers generally define a principle of general solution in which they analyze and develop guidances for the structure of decomposition of the problem which they have generated. On the contrary, inexperienced designers define diverse variants, which, in many cases, they do not get to analyze in detail. The previous exposition has been corroborated in some empirical studies [12].

To conclude, the level of precision that there is in the definition of the problem, experience of the designer and individual styles of problem solving constitute some determining factors during the initial stages of the design process. These factors are not the only ones, but they are the most analyzed nowadays. It is possible to emphasize that in this revision the success of the design process was contemplated fundamentally based on the fulfilment of the raised requirements, without considering the level of newness of the solution. This field alone constitutes an area widely analyzed, in the interior of design science and in the general discipline of problem solving and in the creativity, however there are still diverse questions to solve. Analyzing influence of the previous elements when obtaining of successful solutions, evaluated not only by the profit of the goal but also by the intrinsic creative level, constitutes a interesting line of study.

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