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RESEARCH STUDY IN SUPPORT CREATIVITY SOFTWARE AS TOOL TO ASSIST THE CONCEPTUAL DESIGN STAGE

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1 Introduction

This study is motivated by the interest in obtaining a better understanding of the creativity role within the processing of new products conceptual development, by means of the valuation of the utility that could have the use of a type of software, here denominated "support creativity software" (SCS), as a tool of attendance to the design engineer in the initial phase of the design process.

This paper presents the developed experimental process for this valuation, applied to four specialized commercial software that implement equal number of creative techniques: mind maps, brainstorming, synectics and TRIZ. For the valuation, four basic criteria were used that usually are recognized as indicators of the creativity: flexibility, fluidity, originality and elaboration. The first one appears with detail, considering that this shows, with clear form, the influence each one of the programs had on the engineers during the design session.

2 Objectives

The subject of this study can be defined as «the creativity in the conceptual phase of the product design» and the frame that was chosen to do with software as an instrument that allows the application of creativity techniques in the design process.

In this research, the initial hypothesis is that the computer can be used as a tool of attendance for the engineer of design in conceptualización or synthesis, but the designer continues being the protagonist of the process. This position is the one that Wang [1] denominates «creativity in design with human approach» (p.983).

The objective is to determine the utility and the effect that the SCS causes on the design process. In specific form, it is tried to determine characteristics of this type of software that are more useful for design engineers in the phase of conceptualización of solutions, that derive in the improvement of technological innovation capacity.

3 The creativity role in product design process

The initial stages of the new product design process demands high creativity to generate ideas that can be developed in more competitive success products. Nevertheless, computer tools available in the design engineering have been oriented to later stages of the design, such as detailed design, stress and strain analysis and automated manufacture processes (CAD, CAM, CAE). That is, the tools available in design engineering are oriented to advanced design stage.

The design process literature shows three main phases: identification and definition of the problematic situation, generation of solution concepts, and evaluation and selection of the best alternative. In the second, also denominates "synthesis", is where the design space for possible answers to the problem is explored. The best creativity expression of the design engineer is development in the synthesis phase.

This phase is considered crucial in the product development, especially when it is necessary to design innovating products [1,2,3]. The impact of the decisions taken at this phase is determining for the rest of the process. A poor product concept is practically impossible to improve in later stages.

The synthesis is understood as the earliest phase of the product development, when abstract solutions are obtained, generally incomplete, but with hopes that they satisfy the requirements and initial problem specifications. Its objective, therefore, is to explore the best alternatives to obtain one or more conceptual ideas that are transformed in functional ideas, physical and work principles, structural organizations and representation of the material forms.

It is accepted that this phase depends on creation of contextual associations between intuitive and learned concepts (contained in "packages" of knowledge), on intuition application and heuristic search in quasi-rational solution in a determined area, and of external expression of mental images in observable representations. Ottosson [4] speaks of the necessity to use very fast means of capture creative ideas that they are conceived. For it, having a pencil and paper at the hand usually is a very useful tool. The perception of the ideas even improves more if it is possible to represent them through quickly elaborated three-dimensional models. These tools are denominated PAD (Pencil aided design) y MAD (model aided design).

4 Tools for conceptual design

Two approaches exist to classify design tools: oriented to the designer and the oriented to the computer. In both cases the common challenge is to attend the combination of work principles to generate solutions feasible, but they are different in the way to develop the process. At first, the designer has control of the process and uses the tools under his own criteria. In the second, the computer simulates the human action in quasi-independent or independent form according to its operate principles and configuration.

The revision made to the commercial software with the first approach, keeps awake the existence of more than fifty programs that incorporate different creativity techniques [5]. Nevertheless, the few reported evaluations of this type of software used philosophical visions that consider only entrances and exits (black boxes), without identifying the phenomena that happens during the process.

There are not researches on the relation between the software variables, and between these and users, being that such relations could indicate which is the software architecture that facilitates and harnesses the process of creative solution of problems [6].

The creativity techniques taxonomy reported by Mulet and Vidal [7] divides them in five categories. At first the techniques by association are included (brainstorming with all its variants, mindmaps, Lotus). The second uses the creative confrontation (synectics, bionic, forced relations). The third category related to the reorganization of information (morphologic pictures, fan of concepts). The following one has to do with the exhaustive exploration of the problem (engineering of the thought, check lists, TRIZ). Finally, the fifth, is denominated revision of assumptions (SCAMPER, Why?). The utility of these techniques in the innovator product development process is reported by Lloveras et al. [8].

Based on this classification, a selection of four different computer programs where made that incorporate the more representative creativity techniques: brainstorming, synectic, TRIZ, mind maps, SCAMPER and check lists. These programs were used in the experimental phase to determine their influence on the conceptualización of new products.

5 Experimental method

A selection was made of four different computer programs, that incorporate the more representative techniques of creativity (brainstorming, synectic, TRIZ, mind maps, SCAMPER, check lists, etc). These programs were used to determine their influence on the conceptualización of new products.

The experimental phase looks to identify and to quantify in objective form, characteristics of use of software denominated generically in this study «creativity software». From such identification and the obtained values, it is tried to verify the influence that each of the programs has as tool of support for the design engineer in his (her) work of conceptual development of new products.

The research method used is the "protocol study" that already has been proven in several studies related to design engineering as well as to industrial design and creativity. In the design engineering area, the protocol studies appear from 80's and since its application has been extended. In the dominion of mechanical engineering design, it has had ample acceptance, as well as in electronics and, much more recently, in software design. In fact, after the meeting "Research in Design developed Thinking II" in Delft in 1994, the protocol method became the most used investigation in design engineering [9].

Although, there has not been any antecedent of application of the protocol analysis in which the designer is working aided by computer, it was necessary to introduce some special considerations.

First, a continued fluidity of the audible expressions of the designers cannot be expected. Therefore, it is necessary to have another source of events to capture. It wants to determine the form of interaction with software and the results that such interaction produce. It agrees to address the process captured in software, without letting take care of the expressions that the person does. Thus, parallel software to the evaluated one was used to record all the sequence followed by designers in the computer and that works without interfering with the design session.

Second, it does not try to identify the cognitive process that takes place for the participant to propose an idea in detail, but which has been the stimulant or reason for it. Eventually, it will be possible to identify the specific element of the software that influences the definition of ideas or concepts of solution. For this, the analysis unit will be the "produced idea" and the reference frame will be the time and the modules of each software.

Four programs of computer were evaluated and four repetitions for each case were made. In addition, with the purpose of comparing results, four additional sessions without use of software were included. The subjects were 20 design engineers.

The duration of each session was two hours. Videos, tasks made in screen captured by parallel software, file created by evaluated software and drawings made by the participants, constitute the four information sources that later allowed to the reconstruction moment by moment of the total sequence of actions, words, ideas, gestures and drawings made in each session in detail. The analyzed variables were: time of use and quantity of ideas produced en each module (of respective software), description of the ideas (verbal and nonverbal), difficulties perceived in the use of software and relation between the drawings and the ideas for solution.

The design problem consisted of proposing concepts for a device that allowed to reduce the volume of empty cardboard of milk, juices and others (Tetrabrik™ packages). It would have to allow to reduce and to store 25 packages in simple form so that a 10-year old boy could use it without difficulty.

6 Analysis model

The variables used for the result analysis of the protocol transcription in each session were: time dedicated to each design action, amount and origin of ideas, interrelation between ideas (evolution), validity of ideas and creativity of ideas in terms of the flexibility, fluidity, originality and elaboration.

To achieve this, each session was transcribed dividing them in segments [10]. In each of those segments, the ideas generated were identified in agreement with FBS model [11] (functions, functional modifiers and structures of solution).

Identified and classified the different elements from the process, it was possible to associate them to the module or technique of the software that originated the idea and the time in which it is generated. This way the quantitative information of the session is obtained, in terms of: amount of ideas, flow of ideas by time unit, source that originate them, time used in each module and sequence or evolutive process idea generation.

For the valuation of creativity the proposal given by Shah [12] was used, modified to adapt it to objectives of this research, considering that interested to evaluate it in all of design process and not only the obtained final results as the original proposal. The measurement of *flexibility* in the product development, is understood as using different principles for generation of solution alternatives. The use of one or several physical different principles to solve a function can cause that two ideas are very different.

The procedure implies to group the ideas under different physical principles used to satisfy the required functions, as well as work principles (forms in which a physical principle can be applied), the basic structures (general forms that makes specific the work principles in devices), and details of the structures (specific details of the solutions).

The aim is, then, to classify the conceptual ideas origin in four different levels. The greater level corresponds to the different physical principles used to develop the proposals; evidently ideas using different physical principles will be conceptually different ideas. In the second level, the different work principles in which a concept can be developed although it shares the same physical principle, are included. In the third level the ideas already take shape in basic structures, whereas in the fourth level are included details of those structures.

It is clear that a greater flexibility is associated with the physical principles, which establish true differences between the concepts generated in the design process. For that reason, the qualification of this criterion will be greater in those levels. The score scale is: 10 points for physical principles, 6 for work principles, 3 for general structures and 1 for details. The equation 1 proposal by Shah [12] allows to calculate the total flexibility:

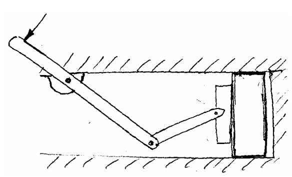
$$Flexibility = \sum_{j=1}^{m} f_j \sum_{k=1}^{4} S_k b_k / n \tag{1}$$

where:

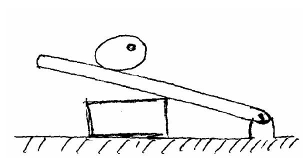
- m = quantity of principal functions required by the problem.
- k = 1,…, 4. level of the genealogical tree
- f_j = weight for function j
- S_k = 10, 6, 3, 1. score for flexibility degrade in each level.
- b_k = quantity of branches in level k
- n = total ideas for function j.

The objective is to elaborate for each case of study a structure that shows the organized process of functional evolution under the vision of used physical and work principles. For this purpose, those principles were identified doing a revision of the complete set of solutions generated during all sessions by all participants. In total, 12 physical principles and 35 principles of work were identified.

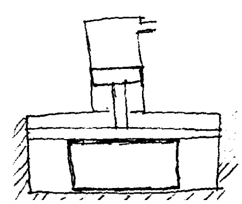
The construction of the genealogical tree will be understood better with one example, illustrated in Figure 1, based on structures to develop the function "to fold", propose by one of the participants.



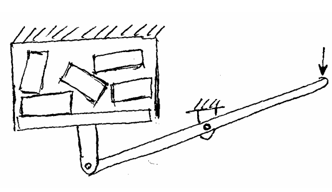
a. Mechanical handle press of horizontal displacement.



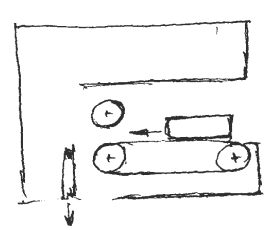
b. Cam system to press.



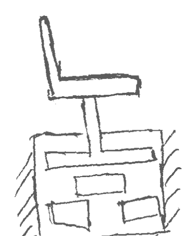
c. Pneumatic system to press.



d. Mechanical handle press with vertical displacement.



e. Rolling device.



f. Pressed system with weight of a person seated in a chair-piston.

Figure 1. Sketches of structures for “to fold” function, make during experimental session

In these proposals, one physical principle predominates: compression by external force; developed in five of them (a, b, c, d, f) and only the fifth proposal includes a different principle: rolling. Therefore, although they are six different basic structures, they only develop two physical principles. Now, in the work principles, it is appraised that proposals “a” and “d” use the same principle of pressure by means of handles system. The idea “b” use cam action, the “c” uses air pressure, the “e” rollers and “f” a sliding piston operated by weight. Thus, they are five principles of work.

The same participant develops some of these structures with specific details. An example, that is not in the figure, was the proposal to use a bar or roller to guarantee that the application of the force of the mechanical press (structure a), was on the middle of the box. Another example was the specification of the capacity and the form of packages container. They were seven structures of detail, which develop the same principles that the corresponding basic structures.

Thus, it is possible to construct the genealogical tree of the Figure 2. Classified the structures and identified the principles that represent, it is come to determine the total flexibility of the participant by means of the equation (1). For this example the calculated flexibility index calculated with this equation, was 13.4.

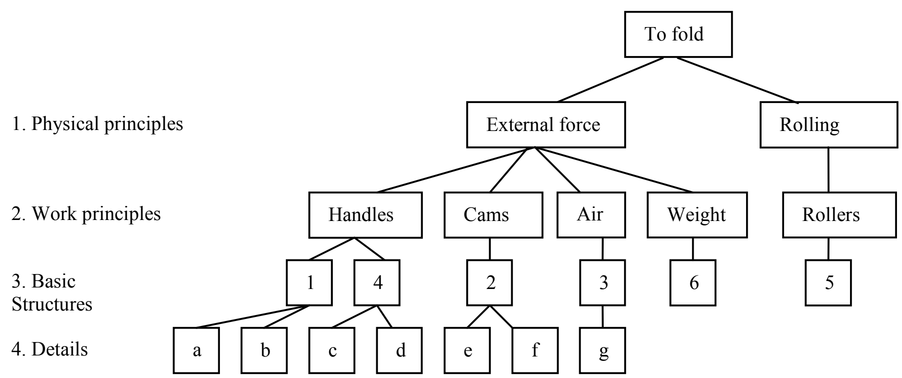


Figure 2. Genealogical tree of Shah’s model for ideas set of one experimental session

As it is wanted to analyze the behaviour during all session, it is necessary to distribute this global flexibility index throughout the design process. The distribution is made having in account that different classes of ideas (functions, modifiers and structures) can be naturally associated at the different levels of the analysis model.

The structures (basic and detailed) correspond directly at last the two levels of the genealogical tree, whereas the functions and their modifiers also can be associated to each one of the levels (physical principles, work principles, basic structures and details structure). In the previous case, for example, the "to roll" function is associated to the physical principle “rolling”. The other site, the functional modifier "to drive of above downwards the press handle" is associated to the basic structure “d” of same figure 1.

Each FBS elements will be located in some of the four commented levels. Once made this association, it is come to distribute the calculate flexibility global index between all the elements of the session. For this, it is necessary to distribute the calculated flexibility value in each level according to the established proportions: 50% for the physical principles level, 30% for the work principles level, 15% for basic structures and 5% for detailed structures.

This way, for the participant of the example that obtained a flexibility of 13.4 points: 6,7 correspond to physical principles; 4.02 at the work principles; 2,01 to basic structures and 0.67 to detailed structures.

In each level, to distribute the corresponding proportion between the different elements of the process, it is necessary to consider the weight of each one from them: 50% for the structures (definitive elements of the design), 30% for functions and 20% for modifiers. Then, if hypothetically there are 4 functions and 5 modifiers associated in the level of basic structures, the 2.01 points corresponding to that level will be distribute: 1.005 points (50%) between the six basic structures, reason why each one will have 0.1675 points; 0.603 points (30%) between the 4 functions, that is to say, 0.1508 points for each one; 0.402 points (20%) between 5 modifiers, which gives 0.0804 for each one.

Once it has been assigned the score to each FBS element, it will have the total value for every period of the process since it is known in what moment the corresponding idea was out. It is obtained when adding the flexibilities of all the present elements in the respective period, from equation 2:

$$flexibility\ of\ the\ period\ j = C_{1j} = \sum_i flex_{ji} \tag{2}$$

where:

$flex_{ij}$ = flexibility index of the element *i* in the period *j*

7 Results

The results are referred to the four evaluated programs, each one of which develops different creativity techniques: Software Nº1: Mind maps and questions; Software Nº2: Brainstorming, role play, SCAMPER and False rules; Software Nº3: TRIZ; Software Nº4: Synectic; and the last case without using software.

The total flexibility for each participant was obtained by the simple sum of the indices of every period. Statistical analysis ANOVA was made to determine if it is significant difference in the mean value of each software. The data for each treatment and each repetition are in Table 1. The existence of an atypical value for case 4 in the repetition 2 can give origin to mistaken conclusions. The revision of the data that take to the calculation of this index reveals that the cause of its particularity does not have statistical origin, but that must to the fact that this participant used only half of the time available for the session. This induced to a poor performance characterized by its low flexibility.

Table 1. Total flexibility

	Participant			
Software	1	2	3	4
Software nº 1	15,30	14,50	14,10	14,40
Software nº 2	16,98	16,81	14,63	16,03
Software nº 3	15,03	14,28	13,25	14,85
Software nº 4	14,40	7,70	14,30	16,50
Without Software	13,56	13,40	13,63	13,40

The other hand, Figure 3 shows the curve of average value of the flexibility during the process for the treatment without software. It demonstrates a very high initial value in period two but soon it falls gradually. Also it shows tips in some periods, but always smaller than the precedents, in such a way that the tendency is clearly descendent.

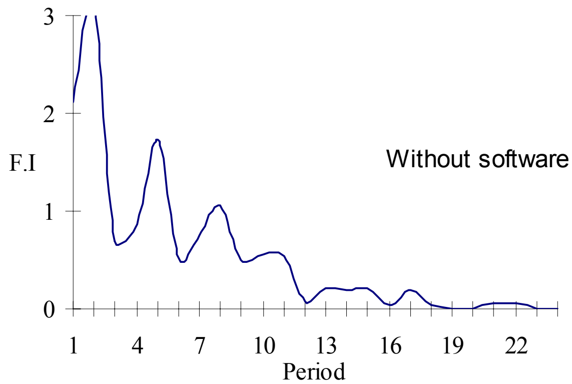


Figure 3. Flexibility index without software

And the flexibility tendency in the design process using software is shown in figure 4.

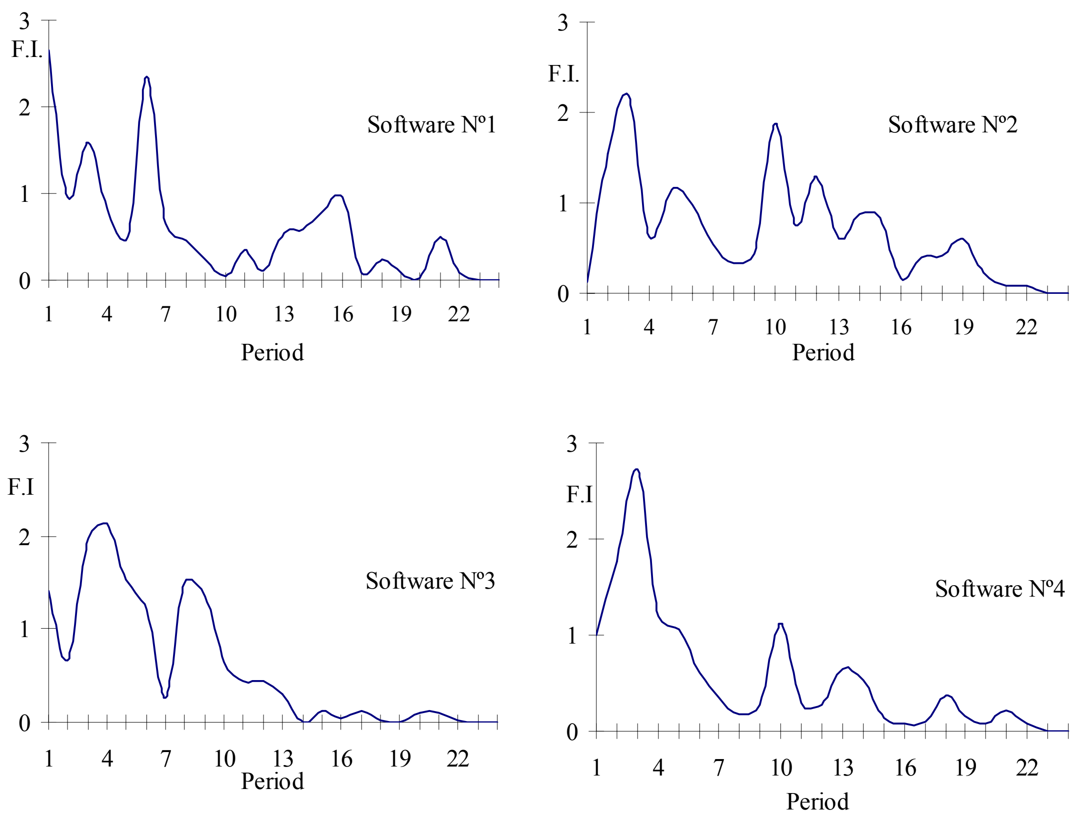


Figure 4. Flexibility index with software

All the cases show a high value in the first periods of the session, although some initiate with a low value to grow quickly (2 and 4). These high values are maintained by short time (three periods of 5 minutes) and then they begin to descend. Software 2 shows the most flexible behaviour throughout the process, characterized by its instability, but to have several periods with high index, comparable indices to the initials. Software 1 also shows high values although in less periods than the previous one.

It is possible to be concluded that the software use (in all the cases) caused that the flexibility throughout the process was greater than the obtained without using software. The treatments with better behaviour were, in decreasing order: 2, 1, 3 and 4.

Each software has their own virtues and defects to originate new ideas. In the treatment 2, for example, the module "random picture" had special participation, since it caused 51% of the ideas, which emphasizes the potentiality of this technique to stimulate the generation of new ideas. In treatment 1, 83% of ideas correspond to "mind maps" technique, which demonstrates the little utility of other alternatives, basically by problems of inter phase design. On the other hand in the treatment 3, the 47% of ideas obey to the identification of "resources of the system", whereas the rest is distributed with greater balance among other modules. It emphasizes, in this case, the fact of the null utility of the most well-known tool of the TRIZ "the contradiction matrix". Case 4, by other side, shows a balance between the different ideas sources. It is because the form in which the program guides the user through a pre-established and somewhat rigid process.

Thus, it is possible to be generalized that software helps when this is known and simple to use. For that reason, almost all the results show software Nº2 as the best one, being simplest of all the studied software. Their characteristics of simplicity and use of graphs like one of their tool preferred by the participants, influenced definitively in the results. It can hope, therefore, that a program designed specially for these intentions must have this characteristic of simplicity and intensive use of graphics tools.

8 Conclusions

The use of SCS in the conceptual design phase allows greater flexibility (and then, greater creativity), since it is possible to extend the feasible design space beyond the limitations that the own experience of the designer imposes, besides to break the "mental inertia" that all designer has by his education and skill, and his tendency to select few physical principles to solve design problems and to concentrate in the development of details of common structures of solution. This makes possible the accomplishment of proposals of new products with high newness. Nevertheless, it is necessary that such software reunites certain characteristics that stimulate their use: rapidity of learning, ease of use, graphical visualization and availability of several classes of stimulus to the generation of ideas, so that the user has the possibility of selecting the one that better adapts to his personal characteristics. These characteristics combined with conventional CAD software could to improve significantly this type of aids for development of first stage of the innovating product design.

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