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INFLUENCES OF REPRESENTATIONS ON DESIGNING AND IMPLICATIONS FOR COMPUTER-BASED DESIGN SYNTHESIS

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Abstract

This paper reports on the research carried out to connect the recent advances in computational models of creative design and the influence of representations in the design process, which can be defined as sentential, visual and objectual.

A design experiment was carried out to generate alternatives for a design problem using two variants of the brainstorming methodology. In the first brainstorming variant, sentential brainstorming, participants used pencils and cards to represent ideas after verbal communication with the group. In the second brainstorming method, objectual brainstorming, the participants represented their ideas by using physical parts.

The design experiment was followed by the protocol analysis technique. The results report the influence that is caused in the design process by the use of different representations and their relation to computational models and, also, the evaluation of the effectiveness of the design process to decide how a computational model should perform for a particular strategy.

Keywords: Creative design, synthesis, descriptive models of designing, empirical study, protocol analysis

1. Introduction

Computational support to creative design has been recently the focus of intensive research work in the field of engineering design. The achievements of this research effort include the development of computational models to support creative design. Among them, it has special relevance in this study the model developed by Takeda and his associates [1]. The authors believe that a key component of computational models to support creativity is their contribution to the understanding of synthesis in design. This paper reports on the research carried out to connect those recent advances in computational models of creative design and the influence of representations in the design process.

From a computational point of view, creativity models are divided into combinational, exploratory and transformational [2]. In combinational creativity, an innovative idea comes up through the establishment of unusual associations between known ideas. The exploratory methods sustain a constant evolution of the design space through the extraction of information from search processes, meanwhile the transformational methods can make changes in their own rules and some can also evaluate the novel results. There are a number of techniques associated to each one of these types of creativity models that have provided significant advances in the field of engineering design. For instance, it can be mentioned the application of evolutionary algorithms [3] and the mechanism library/analogy techniques compiled and reported in [4].

The combination of different known approaches to model synthesis in design was investigated by Chakrabarti [5]. This study analysed the possibility of concurrent use of these approaches (hybrid methods). Furthermore, it reported a number of case studies in which this combination was achieved. Another empirical study revealed that not a single but a combination of procedures related to the three types of computational techniques mentioned above are intensively used in the conceptual design stage [6]. Both studies illustrate the interest behind the development of computational tools to support design synthesis capable to make use of the three types of creativity models [2].

There is no doubt on the interest that has motivated the integration of the three types of approaches to design synthesis. However, the way in which this combination has to be tackled to assist conceptual design in an effective manner still remains unknown.

On the other hand, designers make use of diverse representations in the generation of concepts, which can be summarised in general as sentential, visual and objectual (physical). As these representations have different purposes, the design process is intrinsically related to them [7]. For instance, the action of sketching has been investigated by cognitive psychologists in order to find out its role in design [8], and to analyse visual aids and their impact on the effectiveness of the design, [9, 10]. However, the use of different representations in the creative design process needs further investigation. The research outcomes in this area may contribute significantly to the definition of computational models for creative design with enhanced capabilities.

The research reported here is aimed to asses the dependency between the procedures used in conceptual design and the design process. The knowledge gained in this study should contribute to improve the development of computational models of creative design. The main objectives of the research work are summarised as follows:

- To understand the influence that is caused in the design process by the use of different representations and their relation to computational models.
- To asses how a computational model should perform for a particular strategy.

2. Methodology

2.1 Design experiment

To meet the objectives, a design experiment was carried out. It consisted of the generation of alternatives for a design problem by following the brainstorming methodology. Each experiment group was made up of five students randomly selected. All of them were familiarised with design methods. Once the problem statement and the rules of the design session were clarified, the participants worked in group in a room during one hour time in order to find solutions for the design problem. All the members had the same role in the team and the experiment was conducted in Spanish language.

The problem stated in the experiment was the design of a drafting table. The table might be suitable for those professionals and students from design, engineering and architecture fields who want a table to draw on at home. The following design specifications were initially given:

- The table must take up as little space as possible when not in use.
- The cost must be kept to a minimum.
- The table must have a board that can be tilted. The adjustment of the angle of tilt can be either continuous or discrete.
- The board surface must be located at a height between 90 and 110 cm.
- The actual drawing surface must be large enough to take A2 format paper.
- It must be steady when it is in use.

The experiment consisted of 12 tests that covered 3 brainstorming variants. The main difference between those brainstorming procedures is the way in which the ideas are represented: verbal, visual and objectual. The reason behind the selection of these three variants was encouraged by the initial hypothesis, stated as follows: "the result of the design process is slightly affected in the conceptual stage by the way in which the solutions are represented". The research reported here considered the results from two of the three brainstorming variants. These two variants were identified in previous studies as the ones in which the resulting designs show significant differences between each other [7]. In the first brainstorming variant, sentential brainstorming, participants used pencils and cards to represent ideas after verbal communication with the group. In the second brainstorming method, objectual brainstorming, the participants represented their ideas by using physical parts. In addition to this, sketches were used to support the representation of ideas.

2.2 Protocol analysis

The experiment was monitored and registered on video tapes for subsequent protocol analysis in order to study how designers come up with solutions to the design problem. Special attention was paid to the progress of the design status caused by verbal exchange between the group, sketches and physical implementations. Table 1 illustrates a translated piece of verbal exchanges between participants extracted from one objectual brainstorming carried out during the experiment.

Table 1. Fragment of one objectual brainstorming of the experiment

Time	Protocol
2:20	A1: Instead of completely folding it up like this, maybe an A4 paper size table and leaves that come out.
2:30	A3: but you'd get lines
2:32	A4: of course, the drawing would have (they talk about how the drawing wouldn't look very good because of the marks)
2:36	A1: it'd have lines
2:41	A4: it's got to be a one-piece board (they talk about how to write it up)
2:43	A2: it should be foldable
2:46	A5: hung off the wall
2:49	A3: do it like an ironing board with folding legs, then you can put it anywhere
3:21	A1: like the mechanism for opening and closing the blind, depending how much you pull it, the angle goes up, and it sticks in that position
3:29	(A3 says that they should start constructing it with the pieces, they talk about building it)
4:29	(they talk about writing it up on cards)
5:15	A4: (taking a piece) look, this piece bent here might do to fit the legs. If we do it

	like this you can fit it in, if you're saying to put this like this, if you bend it, it can be fitted
5:49	A3: what we've got to do is join two of these legs, join two of these legs and then we make it, this one we make so as it folds on itself too. Then it's smaller.
5:55	A4: how?
5:56	A3: you join the leg like this and that stays like it is, and it becomes smaller
6:07	A2: I've just thought that if the legs were tubular, one inside the other, then all you have to do is push it in, like a tripod for instance, and the board lies flat.
6:15	A3: like a telescope
6:24	A4: and this is like, one leg here that completely folds up
6:30	A3: that's what I just told you, like an ironing board.
6:30	A4: it should have wheels here so you can put it under the bed

To carry out the analysis, co-evolution and FBS framework concepts have been taken into account as a reference model of design. According to this, the design process is analysed as a process in which solutions are generated from the initial problem definition. The process is iteratively repeated as the solutions generated previously contribute to redefine the problem and cause the generation of new solutions [11]. The FBS framework is used here to describe the design status by means of its functions, behaviours and structures [12].

Functions, behaviours and structures were elicited from the protocol analysis. Then, the initial definition of the problem was graphically represented by terms of functions and specifications or function modifiers. The set of functions established from initial specifications are:

- Support stress.
- Support drawing surface.
- Adjust tilt angle.
- Decrease space.

Figure 1 shows the evolution of the design state since the initial definition by means of new functions and specifications added to the design problem and throughout the evolution of the behaviours and the structures which identify the design object. The lines represent the evolution of functions and structures by expressing the relation of new elements with those that existed previously. The FBS model corresponding to a sentential brainstorming is depicted in Figure 1. The different paths correspond to the design alternatives associated to the demanded functions. A frame depicted around several structures indicates a design alternative in the FBS model. Additional functions derived during the design session have been intentionally omitted to simplify the graph.

Once a FBS model was extracted from the design process, an analysis to identify operations related to the computational creative models and to determine the progress of the design state was done. As we hypothesize that there are significant changes in the evolution of the design state that can be described in terms of the use of these operations, the differences in the design process will be expressed by means of the kind of procedures employed and the role which they played.

Finally, an evaluation of the effectiveness is done taken into account the quantity and the quality of the design alternatives. The quantity is measured by the amount of different design alternatives for each one of the demanded functions. The quality is measured by the performance of the design alternative for each function considering two levels: valid or invalid, where the invalid level is assigned if there is any contradiction of the design alternative with the initial specifications.

3. Results

The analysis of the design protocol and its representation into a FBS model has provided insights about a set of identified procedures or operations:

1. A structure that comes up from the behaviour required to accomplish one or more functions is elicited through a searching process.
2. A searching process that ends up in a structure to address certain behaviour from one or more functions is followed by associations to adapt that existent solution to the current design problem.
3. Structures are created through the fusion of (at least) two separate structures into a new one.
4. New structures are generated by the addition of elements from an existing structure into the structure originated in the searching process and vice-versa. In many cases, the structures do not remain as they are partly substituted by other structures.
5. Structures are built through operations that exchange elements between multiple structures to generate new ones.

The study of these results has identified certain characteristics of these procedures that link them to the computational models of creative design:

- The first procedure is related to exploratory methods.
- The second case is related to combinational methods.
- The third, fourth and fifth procedures are linked to transformational methods. These operations identified are closely related to those used in genetic algorithms and genetic programming, such as the ‘crossover operator’ and the ‘reproduction of the best fit elements’ operator.

Some results of the experiment are those concerned to the occurrence of these types of operations in the two variants of brainstorming carried out in the experiment. This analysis was achieved by mapping the procedures used to generate the structures associated to initial functions for both the sentential and objectual brainstorming. The resulting model of one of the sentential experiments is depicted in Figure 1. Similarly, Figure 2 illustrates the FBS model during the first 20 minutes of one of the objectual brainstorming experiments.

More than one procedure for the formation of structures takes place simultaneously during the design process. Starting with a small number of searching and association structures, new structures by transformations are formed, in which use is made of other known structures. However, new structures are also formed by the application of other different operations on structures that exist at a given moment. It can also be observed that combinational and transformational procedures for forming structures, without distinction, arise out of a structure obtained by transformation or by association with a known element.

As can be seen in Figure 1 and Figure 2, the fact that exploration, combination and transformation are used simultaneously is what leads to a greater wealth of alternatives. On one hand, the number of solutions is dependent on how many solutions are known. But moreover, the transformation operations applied to form new structures lead to the appearance of new solutions at certain given moments. The formation of design solutions therefore takes place in two interacting ways, and this interaction leads to a greater number of solutions.

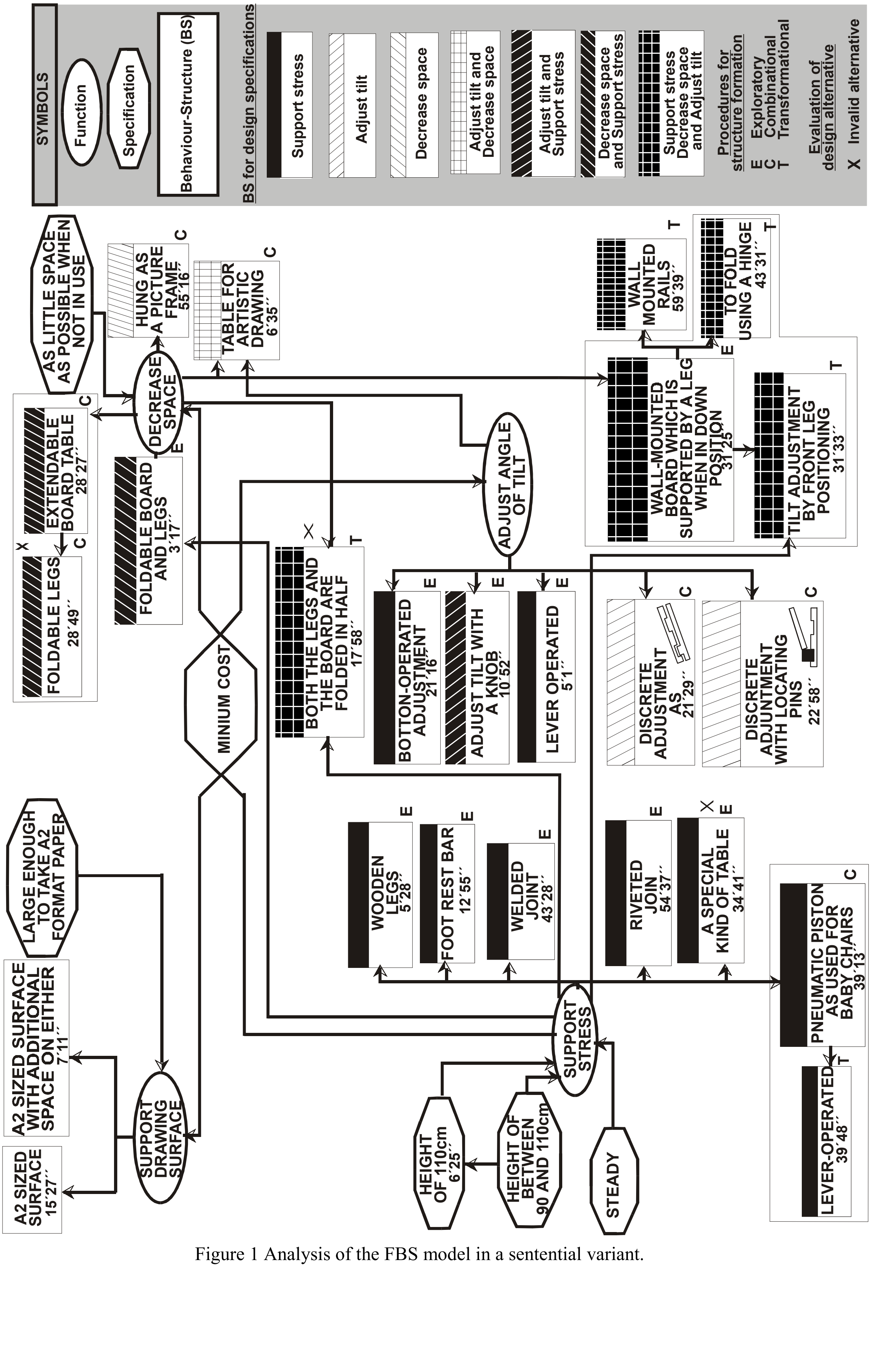

Figure 1 Analysis of the FBS model in a sentential variant.

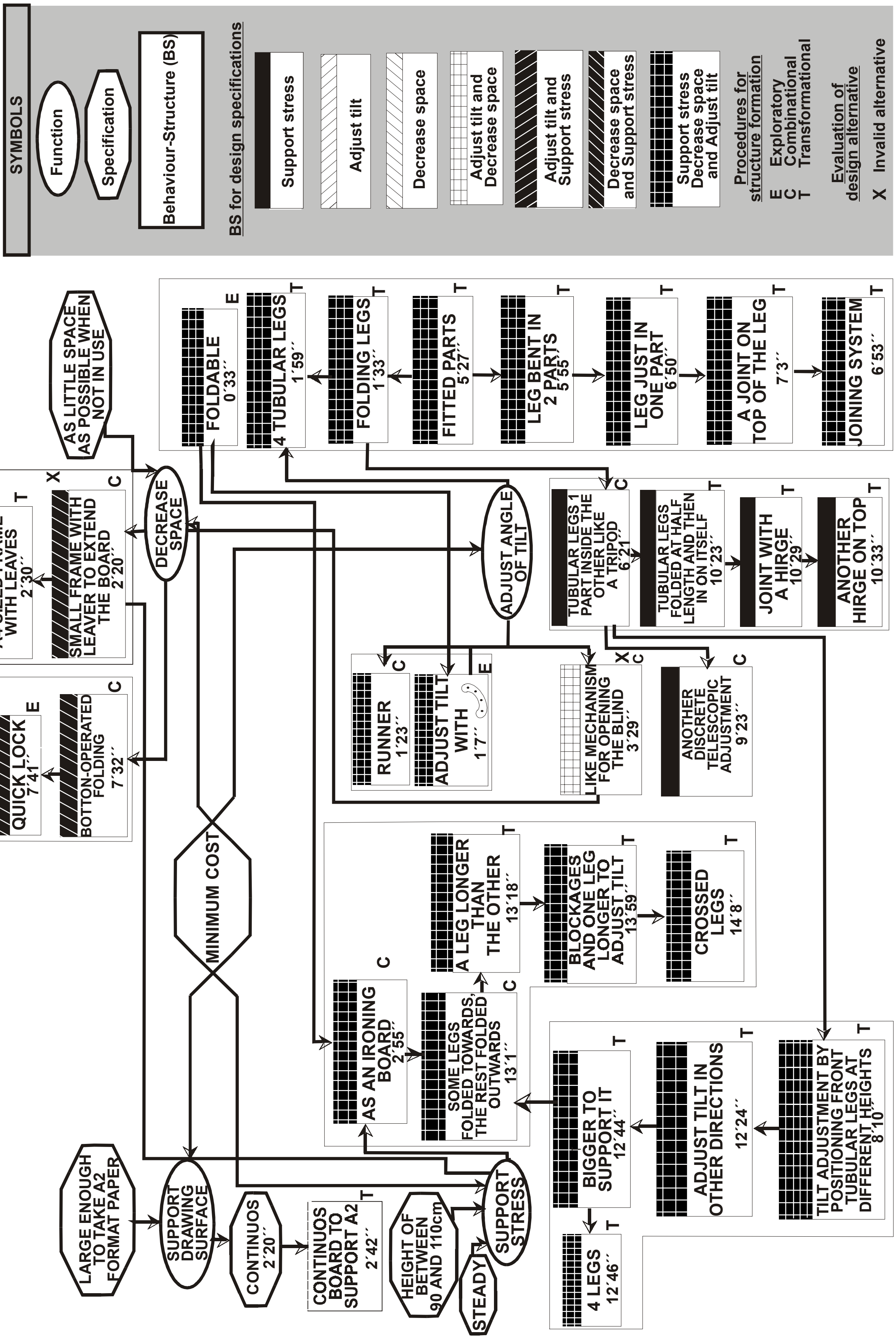

Figure 2 Analysis of the FBS model in an objectual variant.

This hypothesis is confirmed by the considerable differences in the occurrence of operations when both representations are compared (Table 2). As it can be seen in Table 2, the amount of behaviour-structures that were generated to accomplish the initial functions in the objectual brainstorming is considerably higher than in the sentential variant because the amount of transformation-based procedures is much higher in the objectual brainstorming. However the presence of searching-based and combination-based procedures is similar in both cases. Paying attention to the proportion of procedures in both variants, it can be seen that in the sentential brainstorming the amount of exploratory and transformational procedures is equally distributed. At the same time, in the objectual variation most of the procedures applied are transformation-based.

Table 2. Procedures employed

	Exploratory (E)	%E	Combinational (C)	% C	Transformational (T)	% T	Total
Objectual	7.5	12%	6.5	11%	47	77%	61
Sentential	10.5	42%	4	16%	10.5	42%	25

Similarly to the previous analysis, the assessment of design effectiveness shows differences depending on the creative procedures used. Table 3 indicates the quantitative and qualitative evaluation of the design alternatives obtained to satisfy the initial functions.

Total alternatives are those that fulfil for the four initial functions, while partial alternatives fulfil for only some of the initial functions. The first observation is that the number of design alternatives is similar in both variants, but in the objectual variant most of the design alternatives are total alternatives while in the sentential one most of them are partial alternatives. It can be concluded from this that in the objectual variant the degree of convergence of the design alternatives is higher than in the sentential one.

The evaluation has also considered the validity of the design alternatives in a qualitative way, resulting in a higher number of total valid alternatives when physical parts are used. Finally, it has been observed that in the execution of the sentential variant, the amount of functions added is higher than in the objectual brainstorming, increasing the divergence of the design process.

Table 3. Evaluation of the design alternatives

	Design Alternatives	Total alternatives	Total valid alternatives	Partial alternatives
Objectual	17	11	10	3.5
Sentential	18	2.5	1.5	10

Figure 3 graphically shows the differences in the number of exploratory and combinational structures applied in each alternative in relation to the means of expression employed. Each symbol illustrates how many design alternatives make use of the number of exploratory and combinational structures that are indicated in the horizontal axis. In this manner, one alternative is represented by the symbol ; the symbol means two alternatives and an additional line jutting out the circle means one more alternative.

As can be seen, in the sentential variant, almost all of the alternatives proceed from only one exploratory or combinational structure, while in the objectual one, there are some alternatives which proceed from more than one.

Frequency of design alternatives per number of E and C structures used

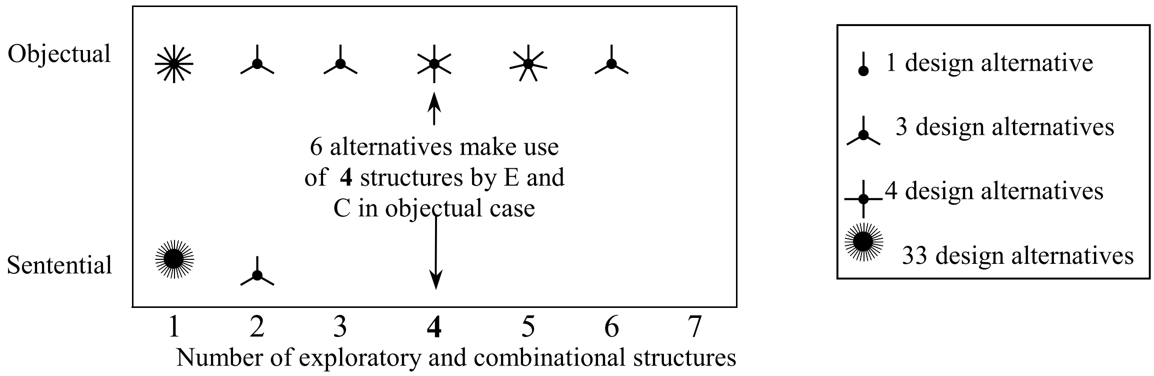

Figure 3 Utilization of exploratory and combinational structures in relation to the means of expression

Figure 4 shows the differences in the number of transformational structures generated from an exploratory or combinational structure in relation to the means of expression employed. Each symbol illustrates how many exploratory or combinational structures produce the number of transformational structures that are indicated in the horizontal axis.

Frequency of E and C structures in relation to the T structures produced

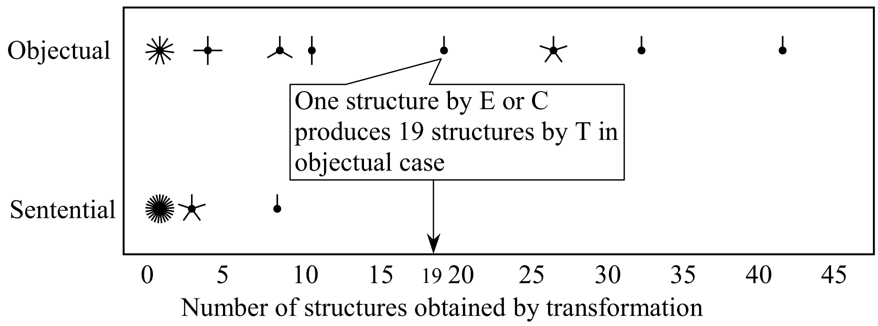

Figure 4 Generation of transformational structures in relation to the means of expression

In the sentential variant, almost all of the exploratory and combinational structures produce no additional transformational structures and only few ones produce a low number of transformational structures. Contrarily, in the objectual variant, there are quite structures from which a higher and variable number of transformational structures is generated.

4. Conclusions

The study demonstrates that design representations play a significant role in the design process as they influence qualitatively the solutions obtained by means of the procedures used. The results of this research have revealed the presence of procedures used in the design process that are linked to exploratory, combinational and transformational methods. All these procedures should be used together during design in order to get suitable designs in a more effective way than applying only one of them in a design. So, the use of these procedures together is a promising way to support the development of computational algorithms for creative design.

The way to combine them into a computational model is related to the demands of each particular case. The study presented in this work shows that when the aim is to focus and to converge on a small number of initial functions, the computational model employed should apply less operations related to exploratory creativity and more transformational operations. From this preliminary results a research area is launched and new findings are needed about how to combine these procedures for improving effectiveness for a particular design strategy.

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