X CONGRESO INTERNACIONAL DE INGENIERIA DE PROYECTOS

VALENCIA, 13-15 Septiembre, 2006

SEARCH AND COMBINATION CYCLES FOR AN INTERACTIVE FRAMEWORK FOR SUPPORTING CONCEPTUAL DESIGN

E. Mulet Escrig(1p), A. Chakrabarti(2), R. Vidal Nadal(1)
1 Engineering Design Group, Universitat Jaume I, Spain
2 Centre for Product Design and Manufacturing, Indian Institute of Science, India

Abstract

This work proposes the use of iterative cycles for the generation of design alternatives based on the search for design structures in a knowledge base and the consecutive application of combination and change operations to those design structures. This study shows the inclusion of these cycles in a framework for supporting conceptual design based on function-behavior-structure framework and co-evolution.

Keywords: conceptual design, synthesis, functional reasoning, FBS, interactive design.

Resumen

El presente trabajo propone la utilización de ciclos iterativos para la formación de alternativas de diseño basados en la búsqueda de estructuras de diseño en una base de conocimientos seguida de la aplicación de operaciones de combinación y modificación de las mismas. El estudio muestra la incorporación de dichos ciclos en un modelo de soporte del diseño conceptual basado en el marco FBS y en la co-evolución.

Palabras clave: diseño conceptual, síntesis, razonamiento funcional, FBS, diseño interactivo

1. Introduction

In conceptual design, designers can be aided by synthesis systems to obtain a subset of valid solutions for a given problem. To provide a better assistance to designers some advances in the generation of more creative solutions by means of computational systems have been performed by Takeda and coworkers [1-3], who defined a new model of synthesis based on abduction and other reasoning processes. Other approaches for the synthesis of creative solutions implement case-based and analogy-based-design [4], which consists in the use of known cases from other problems to find a solution for a new one. Some of these systems use analogies to produce designs even from analogous designs in different domains [5, 6].

The chance of accomplishing a computational system, capable of generating new solutions automatically is a subject of some controversy. In spite of the progress made thanks to the development of a number of computational systems, many authors claim that creative design has such an unpredictable nature that in general terms it is not possible to explain and predict the processes that give rise to it. This is the reason why they claim that computational techniques offer their greatest potential as long as they are integrated with human processes, and therefore designer and machine interact [7-9].

Further research must be conducted to develop computational systems which provide more aid to designers. This should be based, among others, on the study of the design process. In this work we present an interactive framework for supporting conceptual design that has been defined considering some guidelines observed in empirical findings about creative design.

The aim of this work is to improve the supporting of design process by the implementation of design activities that lead to successful results. A basic and gross model was defined to support conceptual design from empirical findings obtained from the analysis of design process [10]. In this work, we propose additional design activities in the framework. This framework has been defined as a part of a research project whose aim is to develop a synthesis system to support conceptual design.

2. Empirical findings

One of the objectives for conceptual computer aided design is to generate a set of design alternatives that fulfill the design requirements. Activities of design process that help to a better accomplishment of requirements have been identified by means of protocol analysis in previous works [11] like:

- More attention on previously proposed ideas (study solution).
- Mental visualization of combinations of ideas as they are generated (image context, geometry).
- Identification of related requirements.
- Initial requirements and functions are considered over a period of time (periodical repetition of the requirements).

Besides, one of the factors that have been proved to affect the success criteria is the means of expression of ideas (that is, sketches, words, diagrams, physical objects, etc), and there are several works showing the relationship between the use of sketches and objects and the generation of better ideas.

On the other hand, other design studies based on protocol analysis show that a better requirement satisfaction is related to:

- Co-evolution during design process [12].
- Application of multiple synthesis methods on a design alternative in order to develop it into a better one [13]: search, adaptation, combination, substitution, adding and changing information.
- Ideas that come up as a consequence of previous ideas acting as stimuli [14, 15].
- Partial combination of sub-solutions, that means searching and combining ideas, but where combination of ideas is not implemented in a (fully) systematic way. Figure 1 shows a simplification of the search and combination cycle.

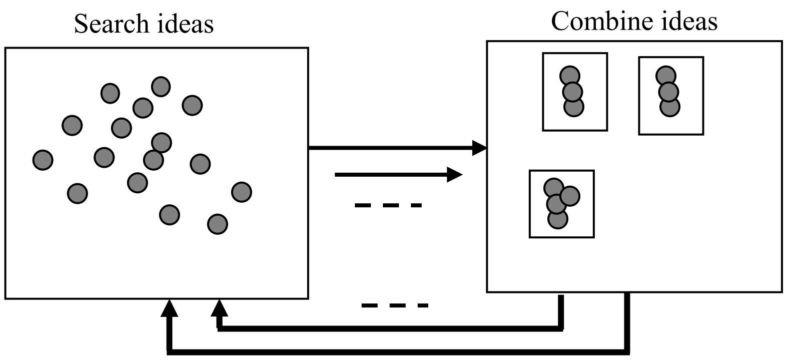

Figure 1. Search and combination cycles for generation of design alternatives.

- During design process, designers consider more than one design alternative simultaneously. Indeed, they usually change from working on one alternative to work on another one, varying from one to another during the combination of alternatives.
- Ideas searched are sometimes ideas for more than one function of the design problem, because our knowledge is composed not only of single ideas but also of complete solutions.

3. Prescriptive framework

This section shows a conceptual prescriptive framework for supporting conceptual design in which several operations for supporting new empirical findings on design process are added. FBS framework has been selected for representing design knowledge because it is a representation strongly related to design process. Consequently design operations have been adapted from the more general ones defined in [10] to a set of operations related to FBS representation.

A number of design elements and operations are defined for this framework, in a way that design operations are applied on design elements in order to generate design alternatives. Many of these operations could be implemented automatically as well as by the designer in order to allow for a high degree of interaction.

3.1 Design elements in the framework

Design elements will be represented using the FBS (Function-Behavior-Structure) model [16, 17]. Function represents the functions that an element performs, structure represents the physical elements of a solution and behavior acts as a link between F and S, so that:

- In synthesis, behavior is derived from an intended functionality to arrive at a structure (solution).
- When a structure (solution) is defined its behavior is deduced in order to evaluate how well the solution achieves the intended functionality.

Many synthesis systems use FBS to represent the knowledge needed to apply search and exploration procedures, as in FuncSION [18], Schemebuilder [19], DIICAD [20, 21] and A-Design [22].

Functions are used to represent the design problem. Different syntactic and semantic representations of function are considered in terms of Purpose Functions and Action Functions as defined by Deng [23]. Purpose functions (PF) are a description of the designer's intention or the purpose of a design and they are human-oriented functions. Action functions (AF) are an abstraction of intended and useful behavior that an artifact exhibits and they usually cannot be represented in a solution-independent way.

Three working spaces are defined in the framework; each one containing and managing several design elements and operations:

- The Problem Definition Working Space (PDWS) manages design problem functions.
- The Searching Working Space (SWS) manages all the structures and alternatives retrieved to solve the problem from the knowledge base.
- The Combining and Modifying Working Space (CMWS) contains and manages all the alternatives generated by the application of design operations on the retrieved structures and alternatives.

The three working spaces are related to each other, but a partition can be made based on the large increase in the amount of information that takes place during the design process.

A knowledge base could be created to contain the following design elements:

- Overall Purpose Functions (OPF) represents designers' intention, for example in the design of a drawing table, the OPF would be "to support a person's drawing action". OPF are achieved by a number of purpose functions.
- Constraints (C). For example, "the board cannot be larger than a particular size".
- Purpose Functions (PF) represent independent tasks in which an overall function is decomposed. For example, "decrease occupied volume".
- Principles (P). Principles categorize behavioral concepts and act as supporting knowledge to search for action functions or behaviors. For example, for the purpose

function “decrease occupied volume”, a principle could be “disassemble components” [24].

- Action Functions (AF), that represent an abstraction of useful behavior in a solution-dependent way and provide a supporting knowledge for those purpose functions that can not be mapped to any structure.
- Behavior (B) describes physical interactions between the components of a design and between design and its environment. So, it includes intended and non-intended behaviors.
- Structures (S),that describe geometrical and physical properties of a component or subassembly.

3.2 Operations to support the design process

Using the proposed framework, a designer should start a session with an overall purpose function or a subset of purpose functions and apply several operations. The end should arrive when the designer considers terminating the session, which is usually when an undetermined number of potential alternatives for the intended overall purpose function is achieved. There are two types of operations defined: operations for modifying the knowledge base and operations for supporting the design process. The first kind/ones are usually done by the designer, except in those cases where an automatic checking of knowledge coherence is implied.

Operations for supporting the design process are conformed by operations that the designer does, the operations automatically done by the computer, and the operations that can be done by both. In this way, the creativity and participation of the designer is allowed, being also assisted with help of the computer. Table 1 shows these operations.

In Figure 2 a diagram is shown outlining the knowledge base and the three working spaces. A flow diagram of the operations to support conceptual design is shown in Figure 3. One of the main characteristics of the framework is an undetermined number of cycles taking place within operations I5, I6, I7 and I8 each time that a set of functions is selected in the Problem Definition Working Space.

Operations for supporting the design process start with the designer’s selection of an OPF and requirements, which would be displayed in the PDWS (I0). Next step is a decomposition of OPF into several PF (I1), which would be usually made automatically, although manual addition of functions is also possible. Then, a number of PFs are selected (I2) and an automatic mapping is done between PF to P (I3) or AF (I4). In this phase the map could be done from PF to P and then to AF (PF →P→AF), from PF to AF (PF→AF) or combinations of both. Then, a number of AFs are selected and automatic retrieval of design structures for achieving these AFs is done (I5, I6). After retrieval of some structures, combinations would be done, generating a number of partial (uncompleted and unfinished) design alternatives (I7). Several iterative cycles I5, I6 and I7 should be done. While designer is working on one alternative for some time, a suggestion message would encourage the designer to change from working on one alternative to work with another (I8). Later on, the designer may come back with the previous or start with a new alternative and so on. At any moment, the designer can select an alternative and evaluate it (I9, I10, I11). The last operation to support design process is to review the problem definition, which can be done at any moment during the design process.

Table 1. Operations for the interactive framework to support conceptual design.

Knowledge base operations	Design process operations
D1: add/change an overall purpose function and its decomposition D2: add/change a purpose function, an action function or a principle D3: add/change structures D4: add/change an alternative in the knowledge base D5: add/change constraints D6: check knowledge coherence to avoid any contradiction between constraints	Operations for functional decomposition I0: Select an overall purpose function I1: Decompose the OPF in several purpose functions I2: Select a small number of purpose functions I3: Map and select among alternative principles I4: Map and select among alternative action functions Operations for search and combination cycles I5: Search for structures that achieve the selected functions in the knowledge base I6: Retrieve and represent selected structures in the retrieving working space for each function I7: Combine structures from different functions. The designer chooses the structures and creates alternatives I8: Suggest the designer to look for other alternatives and to change from working with one alternative to work with other one Operations for evaluation and co-evolution I9: Verify the alternative with the problem definition (functions and requirements) I10: Verify against constraints I11: Correct what is wrong I12: Review the problem definition

This framework should support the design process, providing a high level of interaction with the designer and considering multiple operations for the synthesis of design alternatives. The potential benefits expected with this framework are:

- Generate a set of design alternatives at conceptual phase that fulfill functional purposes avoiding an excessive expansion of the search space. Then, it is expected that designer obtains a set of varied design alternatives in less time.
- Support conceptual design in a way that it does not act as an obstacle to designer's creativity, but even encouraging it.

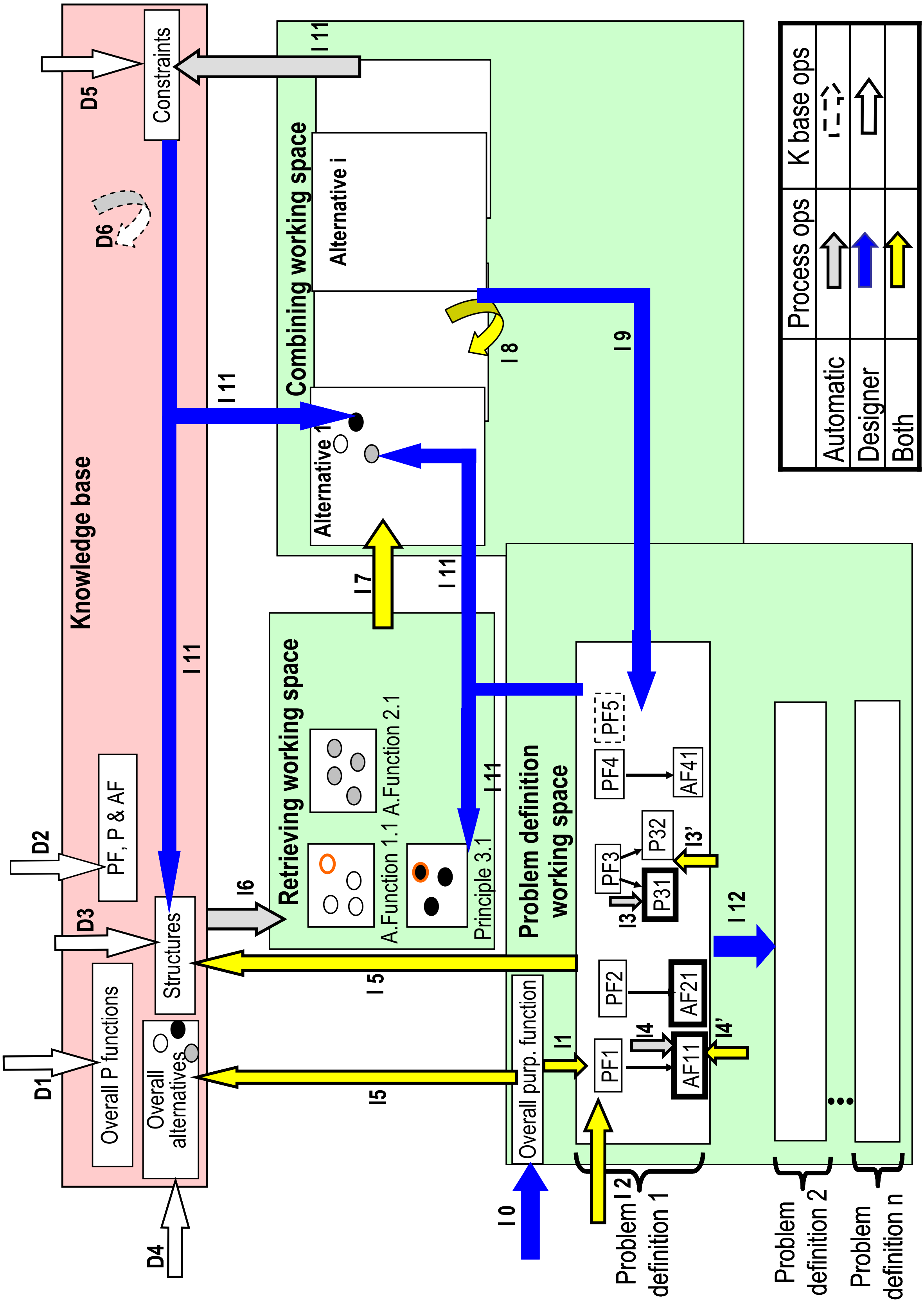

Figure 2. Proposed framework

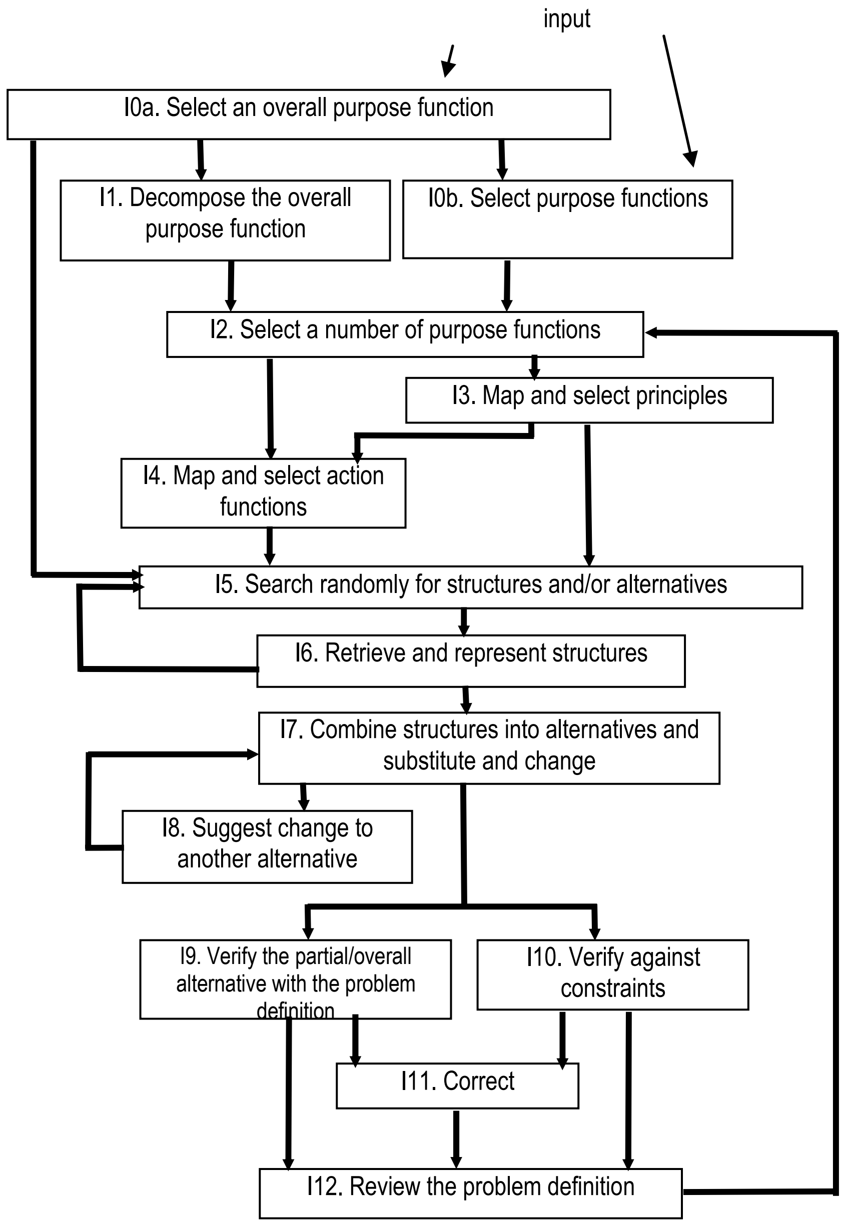

Figure 3. Design process operations

Conclusions

This work shows a design framework that has been defined considering design activities that have proved to be related to generation of better design alternatives. The main characteristics of this framework are:

- Multiple search and combination cycles since the beginning of the design process
- Stimuli from previous alternatives to generate new ones
- FBS representation
- High degree of interaction with the designer

Implementation and further development of this framework is in progress.

Acknowledgments

This research was made in the Innovation, Design Study and Sustainability Laboratory (IDeAS lab), Centre for Product Design and Manufacturing, Indian Institute of Science, Bangalore, and it was possible thanks to grant E-2004-22 from Bancaixa and Universitat Jaume I, Castellón, SPAIN.

Correspondence

Dr. Elena Mulet. Engineering Design Group.

Department of Mechanical Engineering and Construction. Universitat Jaume I. Avda Sos Baynat s/n. 12007 Castellón. SPAIN.

Telf. +34 96 472 9252. Fax: +34 96 472 8106. E-mail: emulet@tec.uji.es URL: www.gid.uji.es

References

[1] Yoshioka M. and Tomiyama T., "Model-based abduction for synthesis", *2000 ASME,DETC2000*, 2000, pp.103-111.

[2] Tomiyama T., Takeda H., Yoshioka M. and Shimomura Y., "Abduction for creative design", Liption H., Antonsson E.K. and Koza J.R., ed., Working notes for aaai-2003 spring symposium series on computational synthesis: From basic building blocks to high level functionality. Aaai, 2003,

[3] Takeda H., Sasaki H., Nomaguchi Y., Yoshioka M., Shimomura Y. and Tomiyama T., "Universal abduction studio—proposal of a design support environment for creative thinking in design—", *International Conference on Engineering Design, ICED 03*, Stockholm, Sweden,

2003,

[4] Kolodner J. and Wills L., "Case-based creative design", *AAAI Spring Symposium on AI and Creativity*, 1993,

[5] Maher M. and Zhao F., "Dynamic associations for creative engineering design", Gero J. and Maher M., ed., Modeling creativity and knowledge-based creative design, Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1993, 329 - 351.

[6] Qian L. and Gero J., "Function-behaviour-structure paths and their role in analogy-based design", *AIEDAM 1996,* Vol.Vol.10 1996, pp.289-312

[7] Parmee I. and Bonham C., "Towards the support of innovative conceptual design through interactive designer/evolutionary computing strategies", *Artificial Intelligence for Engineering Design, Analysis and Manufacturing (AIEDAM),* Vol.14 2000, pp.3 -16

[8] Boden M., "Computer models of creativity", Sternberg R., ed., Handbook of creativity, Cambridge University Press, 1999, 351-372.

[9] Candy L. and Edmonds E., "Creativity enhancement with emerging technologies", *Communications of the ACM,* Vol.43 (8), 2000, pp.62 - 65

[10] Mulet E. and Vidal R., "Modelo del proceso de diseño para el desarrollo de un sistema computacional de asistencia al diseño", *AEIPRO - VIII Congreso Internacional de Ingeniería de Proyectos*, Bilbao, Spain, 2004,

[11] Chakrabarti A., Morgenstern S. and Knaab H., "Identification and application of requirements and their impact on the design process: A protocol study", *Research in engineering design,* Vol.15 2004, pp.22-39

[12] Nidamarthi S., Chakrabarti A. and Bligh T.P., "Improving requirement satisfaction ability of the designer", *International Conference in Engineering Design, ICED*, Vol.1, Imeche, Glasgow, U.K, 2001, pp.237-244.

[13] Mulet E., Vidal R. and Gomez E., "Experimental research on creative models", *VI International Congress on Project Engineering*, Barcelona, 2002,

[14] López-Mesa B., Mulet E., Vidal R., Bellés M.J. and Thompson G., "Creativity in people vs in methods", *AEIPRO - IX Congreso Internacional de Ingeniería de Proyectos*, Málaga, España, 2005,

[15] Mulet E., Análisis experimental y modelización descriptiva del proceso de diseño (phd), Departamento de Proyectos, Universidad Politécnica de Valencia, Valencia, 2003.

[16] Umeda Y., Ishii M., Yoshioka M., Shimomura Y. and Tomiyama T., "Supporting conceptual design based on the function-behavior-state modeler", *Ai Edam-Artificial Intelligence for Engineering Design Analysis and Manufacturing,* Vol.10 (4), 1996, pp.275-288

[17] Gero J., "Design prototypes: A knowledge representation schema for design", *AI magazine,* Vol.11 (4), 1990, pp.26 - 36

[18] Ying-Chieh L., Chakrabarti A. and Bligh T., "A computational framework for concept generation and exploration in mechanical design", *Artificial Intelligence in Design'00*, 2000,

[19] Bracewell R. and Sharpe J., "Functional descriptions used in computer support for qualitative scheme generation-"schemebuilder"", *e* Vol.10 (4), 1996, pp.333-346

[20] Lossack R.S., Umeda Y. and Tomiyama T., "Requirement, function and physical principle modelling as the basis for a model of synthesis", *Computer Aided Conceptual Design'98*, 1998,

[21] Lossack R., "Design process and context for the support of design synthesis", Chakrabarti A., ed., Engineering design synthesis. Understanding, approaches and tools, Springer-Verlag, London, 2002, 213 - 227.

[22] Campbell M., Cagan J. and Kotovsky K., "The a-design approach to managing automated design synthesis", *Research in Engineering Design,* Vol.14 2003, pp.12 - 24

[23] Deng Y., "Function and behavior representation in conceptual mechanical design", *Artificial intelligence for engineering design, analysis and manufacturing (AIEDAM),* Vol.16 2002, pp.343-362

[24] Mulet E. and Vidal R., "Integración de principios inventivos de triz en sistemas de diseño conceptual asistido por ordenador (cacd)", *AEIPRO - Congreso Internacional de Ingeniería de Proyectos*, Málaga, España, 2005,