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SUPPORTING EARLY DESIGN PHASES BY STRUCTURING INNOVATIVE IDEAS: AN INTEGRATED APPROACH PROPOSAL

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Keywords: innovative design process, knowledge management, information management in design, decision support system, CSP solving (Constraint Satisfaction Problem techniques).

1 Introduction

It is now a well-established fact that the development of a new design project is complex and takes place within conflicting contexts consisting of technical, economical, organizational and social aspects. Today, the generation of innovative products is a key issue for companies' development and competitiveness. However, experiences in practice highlight the difficulties and the weaknesses of the cooperation processes in the context of the early design phases, especially when a new concept or an idea is proposed for consideration. During these early phases, exploring new alternatives (new technical concepts, technologies…) can prove very difficult and off-putting as the actors find themselves devoid of knowledge in certain areas and tend to remain faithful to traditional solutions that are already proven to be stable and reliable. Various industrial fieldworks [12] suggest that before launching a new project, an important amount of work is required in order to convince the participants and the management that the new idea is worthy of consideration for the given application. At this time, the goal is to legitimise the proposed idea but also to organize (and to invent) the necessary management processes in order to prepare for the launch of the future project. Therefore, designers sometimes have to work during informal pre-project periods to disseminate new ideas or concepts in order to introduce them as new product design innovations. In this context of early design phases, actors discuss the new ideas, drafts of solutions and exchange preliminary information that may be partially validated, incomplete, uncertain and ambiguous or even risky. Cooperation processes [5] are quite unstructured and the confrontation of the different actors' points of view leads to informal and unofficial information exchanges. These phases of investigation and negotiation are not formalized design phases but participate in the new concepts emergence process. Moreover, they sometimes lead to the construction of official project development plans. Indeed, at the same time the work carried out during these phases widely determines the success of some the innovative projects. If a proper work is carried out, the arguments developed at this stage should lead to the definition of proper specifications (technical, organisational and economical), providing the input for an official development project.

This paper presents the results of a pluri-disciplinary research into the context of early design stages carried out jointly by engineering design researchers, specialists of design computing and numerical engineering, and industrial sociologists.

A socio-technical study was the opportunity to closely observe the practices of actors faced with a proposal for an innovative technical solution. We were thus able to observe and characterize the difficulties involved in integrating a material, different from the ones traditionally used, in an informal context where the actors did not hold a minimum of shared knowledge. This first study enabled us to precisely characterize the problem of innovation during the early design stage outlined in section 2. In this paper a global approach dedicated to the early design phases is presented. This approach is combining:

- a collaborative tool named ID² to promote interactions between designers in order to elicit and consolidate new innovative ideas, which is what we shall look at in section 3,
- a methodology that assists analysis and structuring of design problem and that supports first steps of design problem solving by using Artificial Intelligence techniques.

2 The innovation process in the preparatory phases: an informal context

It is today a well known fact that innovation is a key issue in any company's development and competitiveness. In this paper we propose to focus on innovation in the early design phases of projects. Our first approach is based on intervention research [2]. In this case the researcher is involved in the design process as a designer and uses this position for his/her fieldwork. For over 12 months we took part in the development of a project within a large company specializing in industrial vehicles.

Following our field study concerning innovative development [12], we were able to extend our research in the field by accompanying actors playing very specific and strategic roles in product/process innovation, i.e. the materials experts. Indeed, these people sometimes have to work during informal pre-project periods, often with the help of several other actors, in order to explore, imagine and assess alternatives to the potential applications of a new idea or a new concept. Ideas for associating technology and application are thus developed during periods of negotiation and research, which are often informal and non contractual and which are referred to as the preparatory phases. At this level the official project has not been launched and the goal of these phases is first of all to be able to bring together a certain amount of data and information in order to justify and consolidate the idea put forward creating a configuration in which it is possible to launch a project. Within these processes the material actor has a very important and strategic role: first as a "pilot actor" and second by managing informal exchanges at interfaces according to [7]. The process of innovation adoption relies on informal networks managed by a pilot actor and involving several actors from different departments and with different skills. By the way the confrontation between the different points of view implies large processes of informal exchanges. During these periods, the actors work during an informal context on the technical, economic, and strategic elements relating to their new ideas in order to define and start a new formal project.

The preparatory data helps to provide the first data that will go some way to rationalising the decision to launch a new project by providing the elements for comparing the available alternatives. This means that even if these phases are not clearly identified today in the development process traditionally presented by companies, they nevertheless constitute in themselves a real design work which is sometimes necessary in the development of innovative solutions.

We think that informal work context sharing is one key point to foster interactions and collaboration among actors. Our work therefore consists in providing a tool for these preparatory phases in order to develop and share new ideas within informal contexts.

3 A new tool for the early design phases

3.1 General objectives

The main objective is to foster multidisciplinary collaboration among actors who have different points of view and build different representations of the product during informal phases. This point implies to develop new way of interaction between them and taking into account of their differences of culture due to their domain of expertise (design, manufacturing, marketing, sales, etc.).

As our analyses show up a certain lack of tools offering help during these preparatory phases, we have developed a web-based tool named ID² (Innovation Development & Diffusion) designed to be used with a view to improving the following points:

– Building a common representation of the new ideas,

– Setting up a network of actors,

– Distributing information in informal context,

– Fostering interactions between participants for ideas consolidation,

– Providing a project guide,

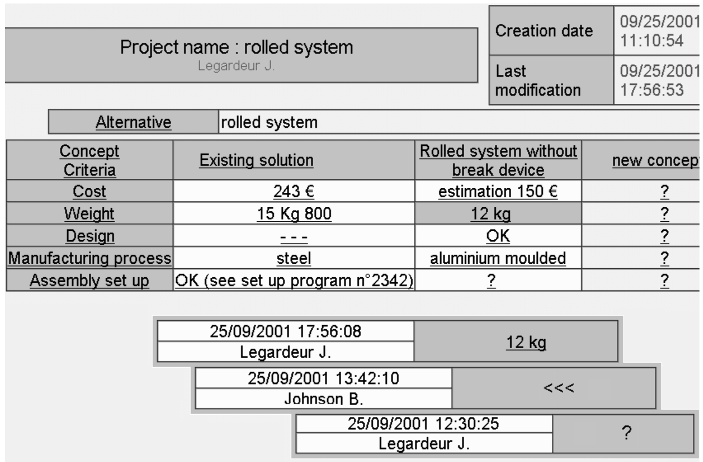
– Learning and capitalising on experience during the project.

The general objective of this tool is to propose a support to the diffusion of innovation within the organisation. More precisely we propose a tool dedicated to supporting the strategy of the pilot actor in order to foster the development of new ideas and concepts. Our tool is not oriented towards the generation of new ideas but its use is complementary to creativity methods such as TRIZ [1]. ID² is rather oriented toward the synthesis and the sharing of information about new proposed concepts and provides a support for new ideas developments by proposing a platform for negotiation. To this aim we propose a new web tool to provide to a pilot actor with assistance in his/her strategy by taking into account the different points of view, rationale and reasoning of the other actors involved.

3.2 Sharing information in early design phase with the Concept/Criteria Table

We propose in this section to describe the main aspects of our new tool dedicated to the early design phase [13].

First of all, the heart of a project on ID² is based on the Concepts and Criteria Table (CCT), see figure 1. This table displays a summary of all the information concerning the project. The existing solution, in the first column, is compared with the innovative proposals, in the following columns, against a number of evolving design criteria (rows). The pilot actor can invite a number of network actors with different expertise to help provide the data to validate the innovative proposal, so that the different points of view and areas of expertise can be compared. The idea is to provide a shared support tool enabling each actor to specify and explain his/her assessment criteria for the solutions. Thus, the structure of the table is dynamic and each actor can put forward new criteria (and thus new lines) as the project progresses. The criteria and information are therefore open to public viewing and discussion throughout the network.



Project name : rolled system Legardeur J.	Creation date	09/25/2001 11:10:54
	Last modification	09/25/2001 17:56:53

Alternative	rolled system

Concept Criteria	Existing solution	Rolled system without break device	new concep
Cost	243 €	estimation 150 €	?
Weight	15 Kg 800	12 kg	?
Design	- - -	OK	?
Manufacturing process	steel	aluminium moulded	?
Assembly set up	OK (see set up program n°2342)	?	?

25/09/2001 17:56:08 Legardeur J.	12 kg
25/09/2001 13:42:10 Johnson B.	<<<
25/09/2001 12:30:25 Legardeur J.	?

Figure 1. The CCT of ID²

The table is structured so that the different boxes can be gradually filled in. The most recent information is displayed in each box of the table while previous information given by the different participants is stored in a tree structure (see figure 1). Each piece of information provided can include a value and a description. Information can be modified and the history of each piece of information is accessible as well as the evolution of the CCT.

Moreover, we propose a structure with different levels of use so that actors can formulate information simply (a value, an appraisal, a word, etc.) until this information has a more complete specification (exhaustive reports, sketches, CAD files…). In this way each box in the table can be linked to additional elements (texts, images, files enclosed) providing a broader description of the solutions (figure 2).

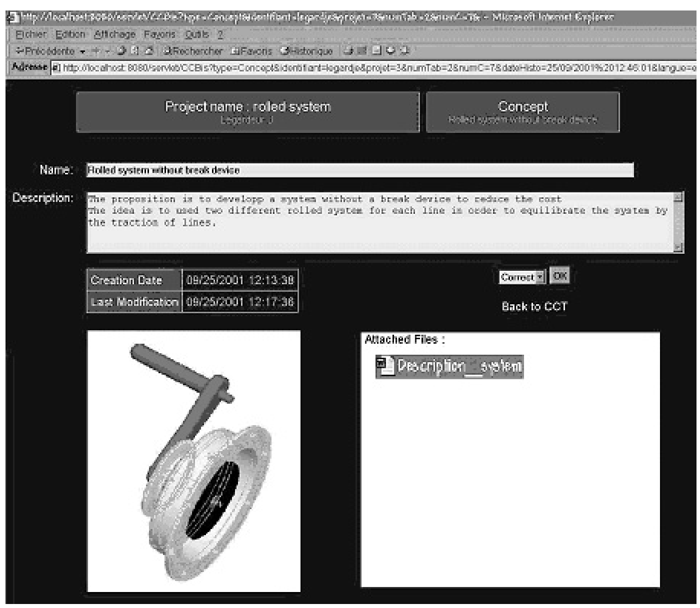


Figure 2. The different level of information in ID²

3.3 Sharing early design phase context with the annotations

We have seen that the design situations where partners were not sharing enough common representation, and more especially during the early design phases, often lead to communication and translation difficulties among the different fields of expertise and participants involved. The concepts/criteria table provides a multi-view support where each actor can react, comments on and requests explanations with regard to any aspect of the project. Additionally, annotations may be added to information including alarms, links, questions and requests for information. The tool thus provides instrumental support to guide interactions among different specialists via 4 annotation modes: links, alarms, questions and information enquiries (see figure 3).

1. The links (shown by segments on the CCT in figure 3) allow actors to link two dependent pieces of information, whose dependency is not obvious and is worth being underlined.

2. The warnings (shown by the W icons on the CCT in figure 3) indicate an actor's remark about a specific point.

3. The questions (shown by the Q icons in figure 3) show the need to look for information about a specific point and thus also help to mark the degree of un-certainty surrounding the solution.

4. The information enquiries (shown by the dI icons in figure 3) allow actors to express their interest in a specific point of the project.

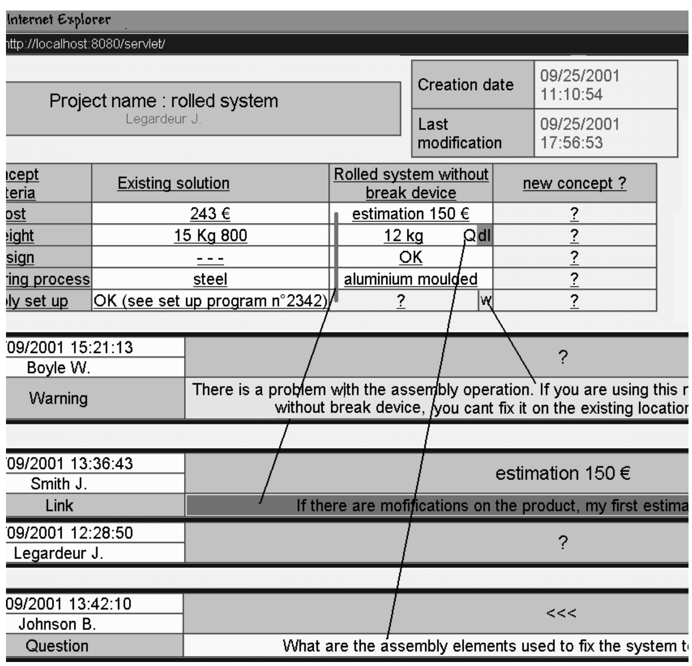


Figure 3: The annotations functionality of ID²

Our aim is to propose an adaptable information sharing support where the actors can modify annotations according to the unpredictable context of project developments. Every link, question or warning can be discussed and completed by various actors. The result of this interaction is synthesised in a thread. The CCT appears as a multi-actor forum of the preparatory phase where we propose to store two levels of information: information concerning technical solutions (blueprints, price estimations, material data, etc.) and information concerning design rationale (remarks on design decisions, initial context of the project, different possible choices). The criteria and information progressively shared with the tool are therefore open to public viewing and discussion throughout the network.

3.4 The information management in informal context

The tool we are offering is a tool designed to be used mainly by the actor who is promoting the innovative solution (the pilot actor). One of the main difficulties is to take into account the different strategies used by actors during the preparatory phases and generally in the early design phases. However, the need to mobilise a wide variety of skills during the prospective phases has led us to propose a tool that is open to other participants operating in the network.

This tool leads to build and to share in real time an informal context of a project development. However, the information flow management and the access control [18] are key points during the early design phase. At this moment, the project is very fragile as we saw in introduction: for example, an estimation price showing an additional cost of the innovative solution can stop the new product development process. However, this additional cost often due to a lack of knowledge can be temporary masked until it will be renegotiated and acceptable for the network of actors. We think that information sharing in the early design phase implies specific and adapted protocol. In this way, the information within the CCT must be adapted according to the involved participants of the project. Using the ID² tool the co-ordinator can define project access rights at different levels for the different actors in the company (and, if necessary, for the actors in external companies).

We propose also to summarise the different contacts on a "map of the network" in order to mutually inform the actors that have been involved directly or indirectly in the early design phases. Each participant must give his/her identity before being able to consult and act on the projects in the database for which he/she has been given authorised access by the co-ordinator. Thus, following the identification procedure all information entered is linked to the author's name and any cell of the table is connected to the actor that has evaluated the criteria. Thereby, the actions regarding any aspects of the product can be discussed between the participants. The different communication supports between the actors proposed in the tool facilitate the propagation of the information within the network.

However, any new information must be validated by the pilot actor before being updated in the data base. The co-ordinator must check each declared participant's access by defining the read accesses to the project for all information or just a certain number of specific points. The co-ordinator also checks the modifications put forward by the actors by validating or putting on hold information entered by the other project participants.

3.5 Re-use information of informal context

Context information structuring is nonsense if it is not oriented toward knowledge creation and the improvement of the actors' competencies. Our proposition [13] includes a search engine and functionalities to assist in the re-use of information available in ID². With a "knowledge asset" page we aim to structure and choose the information necessary to provide the greatest support for learning and re-use, and present it in the most accessible way. Consequently, each project now includes a "knowledge asset" page, on which the pilot actor can record the key elements and knowledge mobilized or gained from the project. Our study leads us to select the capitalisation of the following elements generated automatically from the data of the CCT: the actors involved, the design criteria used, the proposed concepts and a calendar of the project evolution.

The others requiring some 'human review' by the pilot actor of the project: a project summary, the general context of the project, the principal results and current state of the project, the key decisions made, the main obstacles and problems encountered.

The element of "human review" guarantees the pertinence and validity of the information recorded, yet the fairly formalized process ensures that it is not significant extra work. The sole fact of having reflected on the outcome of an action is useful, and if any useful lessons can be recorded to minimize future duplication and maximize sharing then it is especially worthwhile.

We cannot formalize and capitalize all the knowledge that is mobilized throughout the design process. Because of time and resource, only a few of explicit knowledge can be stored in a searchable database for re-use. Moreover tacit knowledge [16], that is highly contextual and linked to the actors involved, cannot be easily formalized. This being the case one must therefore provide other methods in order to foster tacit knowledge sharing and enhance the learning process.

Meetings and informal discussions between actors can represent highly productive occasions for knowledge exchange. Furthermore, to concur with the idea developed in [4], we consider that invisible and tacit networks exist within companies that are specific to each person and that connect people. Such networks are built according to "weak ties" that are established among designers during throughout their professional or even extra-professional life. Industrial organisations are a place where tacit agreements among people develop and are linked to several parameters such as: collective success on a project, attendance at high schools, similar interests, former colleagues, neighbours, etc. In practical terms these "weak ties" enable somebody to get information and answers or to gather skills to accomplish their own activities by involving people from their informal network, even if they do not belong to the formal project group.

As others past works such as [15] based on mining semantic associations from email communications, we think that actors networking can be foster by new functionality of CSCW system. It is therefore beneficial to promote this type of interaction by the implementation of a "Who Knows What?" function within ID2. This functionality enables the research of an expert within a company by a number of search criteria: research field, participation in previous projects, problems encountered. Furthermore, we propose to promote the interactions between actors and the creation of "weak ties" by the means of a personalised profile of each actor.

Accordingly, each actor owns a page upon which they can optionally provide some information regarding their professional activities: some keywords describing their activities, their position, their expertise both general and concerning ID² projects, their links to Internet resources (companies, databases...) and equally, personal information, their interests (hobbies, passions).

We believe this functionality of "Who Knows What?" will, in this way, facilitate the creation of new networks of actors, or "communities of practice" [20], linked by common interests. It aims to address the personalization approach, where knowledge is not easily stored, by assisting and encouraging contact between the actors involved.

As we saw in section 3.2, ID² stores information of several different natures. Consequently we have implemented a search function within the tool's databases. Our study of existing search engines, based on data mining or predefined key words, led us to the conclusion that the search method most suitable for ID² is a basic search capability able to display results that contains the user's search words. However, the search is performed on the different types of information stored within ID² and displays the results of each separately. The results also include a percentage of affinity with the research in addition to links to the relevant information, the actor's profile and the "knowledge assets" of the project. This is to say that the search improves the efficiency of the learning before the action phase, by utilising stored knowledge, and during action by assisting the process of problem solving.

3.6 Conclusions on ID²

We propose through ID² a tool dedicated to formalize the non-structured information concerning new ideas and new innovative projects. The "open" structure of the tool allows capitalizing every kind of data concerning the project.

The features used in ID² (Concepts, Criteria, Warnings, Questions, Links, and Information Requests) are useful to build a common representation of the new ideas and also of the associated projects under construction. Therefore we think that this tool act as a "medium" between the participants and their "three worlds" (external, interpreted, and expected) according to [10] [11]. We propose this tool as a support for the processes between to foster collective cognitive processes.

In this way we think that this tool leads to provide the input data of the requirement definition step and also participate in the conceptual design phase.

In the following section we describe a methodology dedicated to the analysis, the structuring and the modeling of design problem that are enhanced through ID². This methodology allows designers to easily use Artificial Intelligence tools in order to sort out preliminary design solutions.

4 A methodology for supporting preliminary design solution identification

4.1 Introduction

We propose to implement after ID² an approach that supports embodiment design step and really extends the conceptual design stage. Our approach fosters creativity and innovation

We provide a systematic methodology that allows designers to build a declarative model of the design problem.

This methodology consists in:

- analyzing and structuring the design problem,
- implementing a constraint based representation of the design problem,
- identifying preliminary embodiment design solutions by using a Numeric-CSP solver.

The following sections describe the three main levels of our approach.

4.2 Analysis, structuring and modelling of the design problem

The knowledge associated to design project is currently organized in four classes:

- the structural knowledge: knowledge about product components and their arrangement within the whole architecture,

– the behavioural knowledge: knowledge about the behaviour of the product in its environment,

– the teleological knowledge: knowledge defining the purpose and the aims of the design project,

– the functional knowledge: knowledge about how system behaviour is employed to achieve an expected use.

Performing creativity, we propose to model previous knowledge as a declarative form in order to improve design problem solving by simultaneous satisfaction of all the knowledge.

First, we propose to model as soon as possible the product by implementing a structural and physical description of the product being designed. The Technical Chart (TC) is a suitable and a modular model to represent the global architecture of a system. The TC can evolve if the system is not completely defined and, so, it always supplies a way to represent the product.

In fact, the TC provides a representation of the system by highlighting the different component groups, the components and the sub-components of the product. It shows also the interactions between them. The component groups, the components and the sub-components constitute different systemic level of the product that appears on the TC (see figure 4).

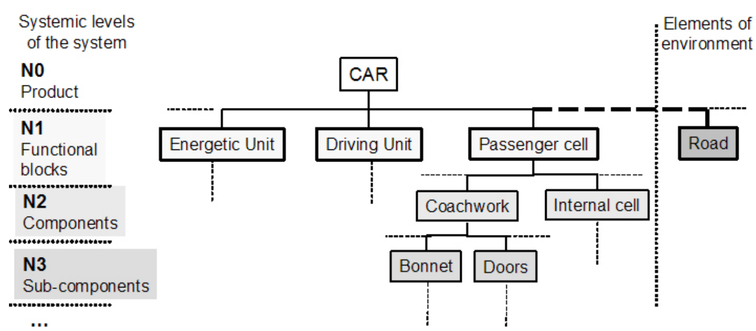


Figure 4: A Technical Chart; the example of a car

The level 1 of a TC represents the component groups of the product, also named functional blocks. Each Functional Block (FB) is described by the function that the component-group has to realized (i.e. “Energetic unit” FB does not describe the design solution but the function of the block).

The sub-levels of the TC present the components of FBs. According to the progress of the design project, a TC may include more or less levels. Usually, during the preliminary stages, only the first levels occur in the TC and the FBs are really described by the functions that are realized.

Our industrial implementations have demonstrated that the TC is a relevant mean to represent conceptual solutions. It supplies a sharing view of the design problem, offering also a way to formalize the concepts that are presented by ID^2.

Furthermore, the TC underlines the classes of components:

– the known standard elements,

– the non-pre-defined standard elements that designers have to dimension,

– the non-standard elements that designers specifically have to design.

So, the design process aims at identifying components and to define solutions to guarantee their interaction.

Secondly, from the TC, we suggest to develop a design problem model based on available knowledge for each systemic level of the diagram.

Each element (component) of the TC is usually characterized by specific knowledge that aims at describing its behaviour, manufacturing conditions, constraints of using, costs, maintenance points of view, etc. Our approach consists in building a Component Model (CM) by defining [19]:

– variables being able used to describe a component,

– available domains of values for each variable,

– relations that link variables of the component.

We suggest using only three classes of variables to describe a component of the product:

– the Design Variables (DV): they allow designers to distinguish different configurations of the element,

– the Criteria Variables (CV): they are extracted from ID^2 and they enable designers to value the performance level of design choices for an element,

– the Intermediate Variables (IV): they are not necessary to describe an element, but they have a meaning for designers.

From the TC of a product, we propose to identify variables that intend to describe each component, and subsequently the product (see figure 5).

Next, for each variable, we define the domain of available values. Those domains may be discrete (catalogues, qualitative, enumerate values, etc.) or continuous (intervals). If a domain may not be immediately determined, the description is not sufficiently exhaustive. It usually requires considering the models of the sub-elements. Indeed, the MCs of sub-components will finally lead to the model of directly linked upper element in the TC. We consider that the definition of value domains as being relationships: as a matter of fact, it comes down to equality definition.

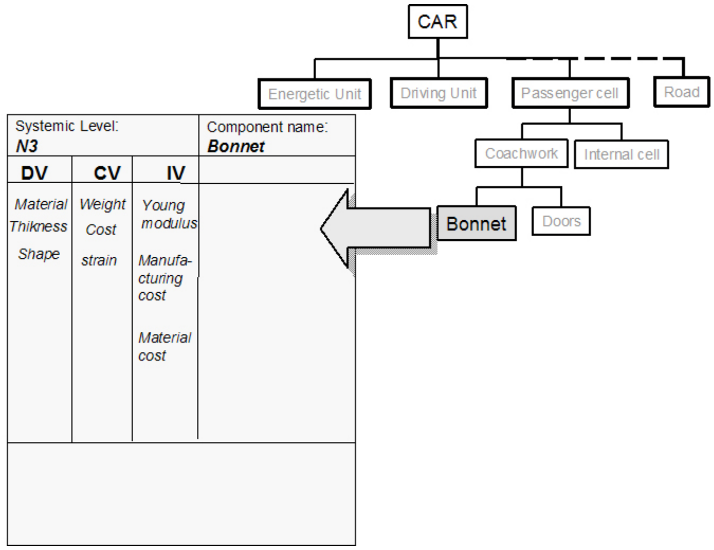


Figure 5: Variables of a CM; non exhaustive example for a car

As we have previously presented, a CM includes variables and value domains. Next, we commonly have to add the relationships linking variables: those relationships result from a capitalization of the knowledge required for design-problem-solving.

The main objective of those relationships is to aid decision-making during preliminary design. So, the whole CM must be significant.

In order to measure the relevance of a CM, we supply a method enabling designers to qualify models. The PEPS (Parsimony, Exactitude, Precision and Specialization) of a CM allows designers to value the using cost of the model and its relevance for decision-making assistance. The qualification is based on four criteria [17]:

- the Parsimony: measurement of number of variables and couplings between those variables.
- the Exactitude: evaluation of the adequacy between the results provided by the model and a reference case (real case or other),
- the Precision: measurement of the domain size on which each variable can take its value satisfying the model,
- the Specialization: measurement of quantity and level of the information introduced in the model; the specialization is higher when the model belongs to a component that appears to a low systemic level.

Finally, for each element of TC systemic level, we obtain a CM summarized in a specific sheet (see figure 6).

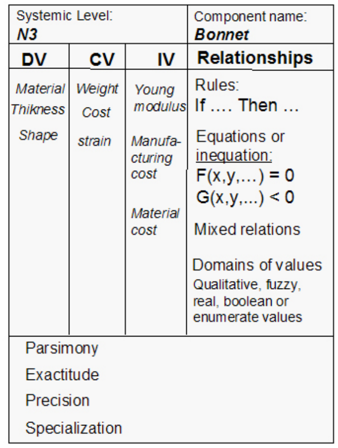


Figure 6: A qualified Component Model

Thirdly, when CMs are defined, we built the interaction models. An Interaction Model (IM) is based on constraints (declarative relationships) describing the coupling between elements of one systemic level of the system. For each IM we supply an IM sheet including the constraints and terms for model qualification (see figure 7).

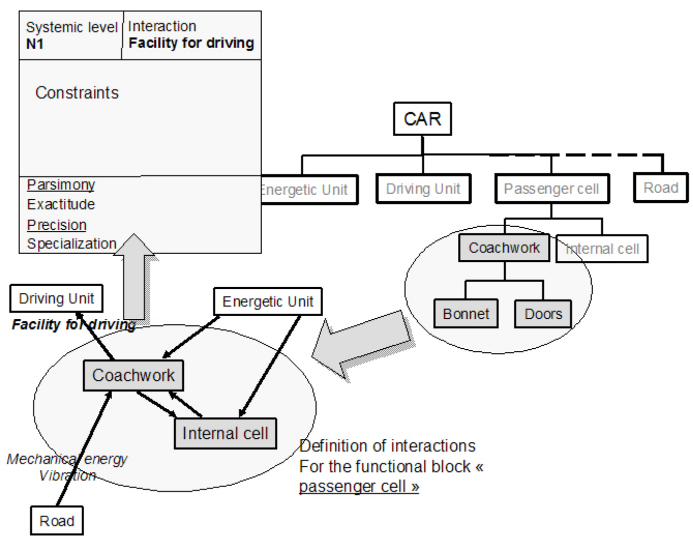


Figure 7: highlighting of interactions between components

We have emphasized a systematic methodology that aims at structuring and modelling a design problem based on innovative ideas. Using simple, modular and dynamic representation of preliminary design choices (the TC) our approach facilitates the sharing of knowledge. It makes every design actor aware to describe simply own knowledge involved in decision making. So, we propose a way to gather required knowledge for design problem solving. CM and CI sheets define the architectural design problem, including all innovative points of view defined earlier.

4.3 Design problem solving with Constraint explorer

In our approach, design consists in managing knowledge and achieving a preliminary design solution by rapidly satisfying every relationships extracted from CMs and IMs. In order to realize such a process, we suggest to use a specific numeric-CSP solver (Constraint Satisfaction Problem) named Constraint Explorer (CE). In this article we do not focus on techniques that aim at leading to relationships having constraint form and high-level of qualification. We have developed some metamodelling techniques in order to obtain reduced and accurate constraint based models of the design problem. Those techniques imply fuzzy approach, rules based representation, and the management of intervals of Real [8] [9]. They aid engineers to obtain relevant models of knowledge being able solved by a CSP solver.

Next, in order to solve the design problem, we use CE tool (figure 8). CE is a CSP tool dedicated to design problem solving. Linked to classical devices for creativity, requirement definition and also associated to the previous modeling methodology, it rapidly leads to field of solutions. Those solutions define consistent dimensions for components and also characterize the interactions. We do not detail CE within this article and propose to read [21].

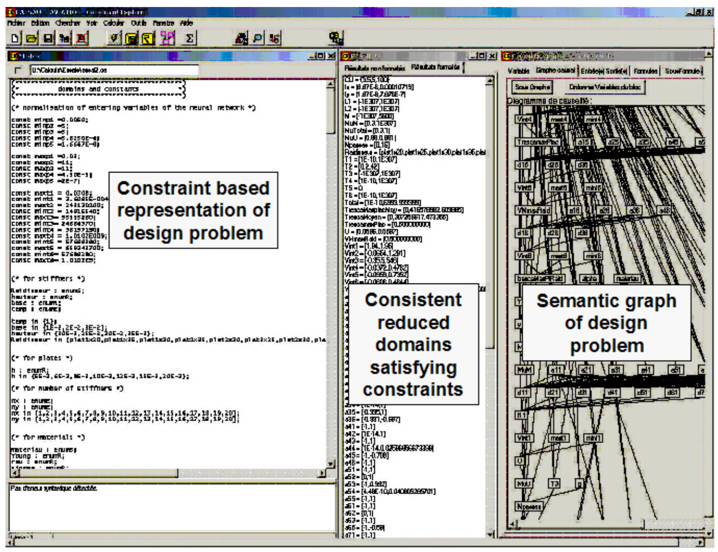


Figure 8: CE tool

5 Conclusion

Sharing the project of the early design phase is one key point to foster cooperation among designers. During theses phases, actors discuss of new ideas, drafts of solutions and exchange preliminary information that may be no-validated, incomplete, uncertain and ambiguous [6]. This information is partially true, and has to be updated often. The natures of information and of the context are then different from the traditional design process. Exchanges are sometimes performed verbally face-to-face or on the phone or by e-mail. Information is therefore poorly controlled, the sharing of the context is not really managed and there is no capitalisation of problems treated during the design. In this situation we think that Concept/Criteria Table and annotations functionality can help to structure design activities and collective cognitive processes. They are used to clarify and compare opposing or convergent points of view, thereby creating a meaning that can be understood by everyone. However, few of methods and tools dedicated to this problem are now available. We propose here the tool ID² which is structured to encourage actors to formulate and explain their own criteria thus facilitating discussion within the network. Each new actor adds his or her vision of the solution, which may be positive, neutral or negative, resulting in a certain number of assessment criteria. In innovation situations, the goal of design work above all consists in managing a certain amount of knowledge extracted from different engineering cultures. We associate to ID² a specific methodology dedicated to structuring and constraint based modeling design problem. Our methodology relies on structural and dynamic representation of design solutions, leading to the well-qualified models of knowledge involved for design problem solving. The innovation is the result of an adaptation process, the success of which depends on the actors who will be progressively involved in the design procedure [3]. Thus, improves the preliminary design process by fostering knowledge sharing and consideration. Our approach provides all the actors with the context of different views of the project enabling them to learn and to integrate in their own process about the specialised field of the other actors.

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