INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITÉ DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

TOWARDS A MULTI-INPUT MODEL AND METHOD TOOL IN EARLY DESIGN PHASES OF THE INNOVATION PROCESS

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ABSTRACT
This paper focuses on the early design phases of innovative projects. More precisely, the question of the innovation opportunities development and management is addressed here, starting from a theoretical model and methodology, until precise tool perspectives. The key elements of our approach are the PTC multi-input model and the C-K theory, and we provide a detailed background on them. Our model is based on three dimensions (*concept, technology* and *potential*) and highlights the need of interactions between them regarding strategic and operational levels. Starting from the analysis of the three dimensions of the PTC model, different opportunities for the innovation are identified. In order to develop every identified opportunity, the three dimensions have to be explored with the C-K theory and two specific workshops resulting in a tree diagram. After a case study, the paper presents also tool perspectives dedicated to structure the preliminary exchanges among all stakeholders using criteria. This tool is mainly oriented towards the consolidation and the diffusion of new ideas.

Keywords: Early design phases, Innovation process, PTC model, C-K theory, Design spaces.

1 INTRODUCTION
This paper focuses on the early design phases of innovative projects that are one of the important challenges for industrial companies. Indeed, innovation contains complex socio-technical phenomena and processes especially when new ideas of innovative concepts (such as products or services) are proposed. These innovation processes are complex because the first operations of innovative product developments are not well-defined phases of the design activity. Indeed, they are not well-known and combine different aspects such as creativity aspects but also socio-technical negotiation among different stakeholders (i.e. design, marketing, supplier, R&D, and others). In this paper, we propose a model to support innovation in early design phases combined with a methodological approach. A new tool is also proposed to provide a support for collaboration to foster innovation opportunities.
This paper is organized as follows. In Section 2, we review the existing models for innovation and early design phases, and we provide a detailed background on the PTC multi-input model and the C-K theory since they are the key elements of our approach. In Section 3, we show how to exploit the PTC model for innovation by dividing its three dimensions into design spaces. Section 4 shows how to use our approach at the example of the innovation process of a heated surfing wetsuit. In Section 5, we present tool perspectives with respect to mobilized criteria in innovative design process, before we conclude in Section 6.

2 EXISTING INNOVATION MODELS AND APPROACHES
In the economical field, there are a variety of different innovation theories that have been proposed in the literature. In general, one can distinguish between two principal innovation models: the "science push" model (innovation pushed by the science), and the "demand pull" model (innovation pulled by the demand). These two models are mainly based on the two classical concepts in economy: the offer and the demand. However, they cannot be regarded separately since the offer *and* the demand have to be taken into account in order to understand and manage the innovation process [1], [2].
Early design phases have a high impact on the innovation process efficiency. The difficulties and weaknesses of the involved cooperation processes have been extensively studied [3], especially when

a new concept or a new idea is taken into consideration. During these early phases, exploring new alternatives, such as new technical concepts or technologies, is 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.

The innovation process is a complex phenomenon that is difficult to model. In fact, in the hierarchy model [4] (sometimes also called "step by step" model), the innovation process is considered as a linear progression towards increasingly practical solutions. The Roozenburg and Eckels model [5] follows the same idea, but integrates many parallel components (production, product, and marketing). Kline and Rosenberg consider the innovation as a central chain of design with iterative feedback loops that is interconnected with the knowledge sphere [6].

In the following paragraphs, we provide a detailed background on the PTC multi-input and the C-K theory since they are the key elements of our approach.

2.1 The PTC multi-input model that supports innovation in early design phases

In 2006, we proposed the PTC multi-input model (*potential technology concept* multi-input model) for the early phases of innovation processes [7]. Our model integrates both the technological dimension and the market dimension via the potential. The PTC model is illustrated in Figure 1.

The particular characteristic of the PTC model is the association of a *concept* to a *potential* of added value of one or more *technologies*. Its main objective is the synthesis and confrontation of the data coming from the technological survey, the market survey, and the different concepts of solution coming from the idea's portfolio of the company. Furthermore, the PTC model claims (i) to provide a framework in the very early phases for an evaluation of the innovative opportunities and their associated risks, and (ii) to propose a flexible methodology for the exploration of innovation opportunities based on multiple inputs: the *potential* of added value identification, the *technological* opportunities emergence, and the innovative *concept* generation or collection.

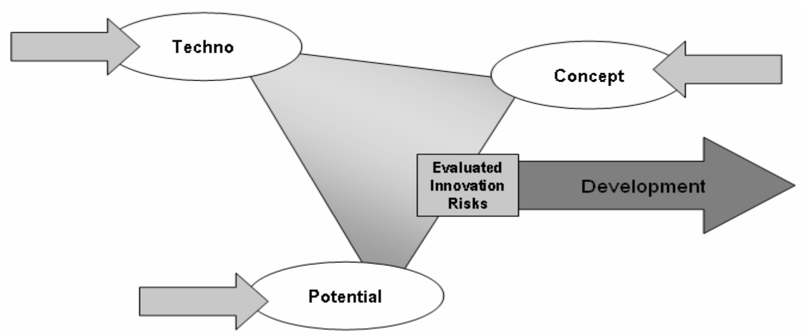

Figure 1. "Potential-Technology-Concept" model [7]

In the following, we define the three dimensions of the PTC model.

The *potential* of added value dimension models the existing gap between the product and the current or future customer expectation. The *potential* should take into account not only the approaches concerning the analysis of the customer's need, but also its change dimension. Therefore, the clear identification of the product added value induced by the *potential* is not only integrated in the analysis of the current need, but also in the analysis of the changes (e.g. usage, way of life).

The *technology* dimension encompasses the technologies (e.g. material, physical principle) and the production techniques for the new product development. The aim is to identify the opportunities offered by the technology (e.g. mechanical, electronic, and magnetic) that can open the domain of "the possible".

The *concept* dimension is related to the different ideas of the new concept of solution issued from any creativity method, from a tools or ideas box, and from the portfolio of the company.

It is very difficult to characterize and structure the innovation process phases in order to present the complex dynamics of informal exchanges that the different actors' encounter. Moreover, it is quite hard to structure the richness (but randomness) of the existing creativity methods. The contribution of the PTC model is to highlight the complex character and the need of combinations and confrontations of "multi-input" opportunities for innovation. The multi-input aspect for the innovation regroups the *potential*, *technology* and *concept* dimensions. Their exploration provides many innovation

opportunities to the company, and the PTC model's architecture corresponds to the different opportunity origins that exist in reality. For example, every stakeholder in the company can identify a problem or a change (*potential* dimension), identify the use of another material or a different process (*technology* dimension) or have a new idea of solution (*concept* dimension).
In the PTC model, the three dimensions are linked and aim to foster the networking between them. In fact, every new input proposition is analysed regarding the three dimensions of the model. The main objective is to select and analyse the different ideas regarding its three dimensions during early design phases (Figure 1). This approach provides a framework for a first evaluation of innovative opportunities and allows the limitation of the risks related to a future innovation (in order to understand the risks related to innovation, see [8]).
During early design phases, every dimension is not stabilized and changes occur at any time. These changes must be quickly propagated to the other dimensions during the early development to foster decision-making with the most appropriate information and knowledge. The main goal is to propose a multi-dimensional analysis in order to foster point of view confrontations in the very early design phases. This model can also be used as a mapping tool in order to manage the innovation strategy of the company.

2.2 The C-K theory for a conceptual exploration and development of the solution space

The C-K theory, initially proposed by Hatchuel in 1996 [9], is named "C-K theory" because its central proposition is a formal distinction between *concepts* (C) and *knowledge* (K). The starting point is an interpretable concept without any logical status, or, in other words, a comprehensible idea that cannot be directly materialized. For a better understanding, consider "Keys that cannot get lost" as an example.
The principle of the C-K theory is to progressively add properties to the concept by switching between the concept space and the knowledge space. Adding the properties supplies an interpretable "object" that can be materialized by a stakeholder. On the one hand, if the property we add to a concept is already known in the knowledge space, we have a *restricting partition*. On the other hand, if the property we add is unknown in the knowledge space involved in the concept definition, we have an *expansive partition*. Creativity and innovation are due to expansive partitions of concepts.
Figure 2 illustrates the exploration of the expansive partition "safe hammering with hammer in right and left hand doesn't hold the nail" that is involved in the innovative design of the Avanti nail holder.

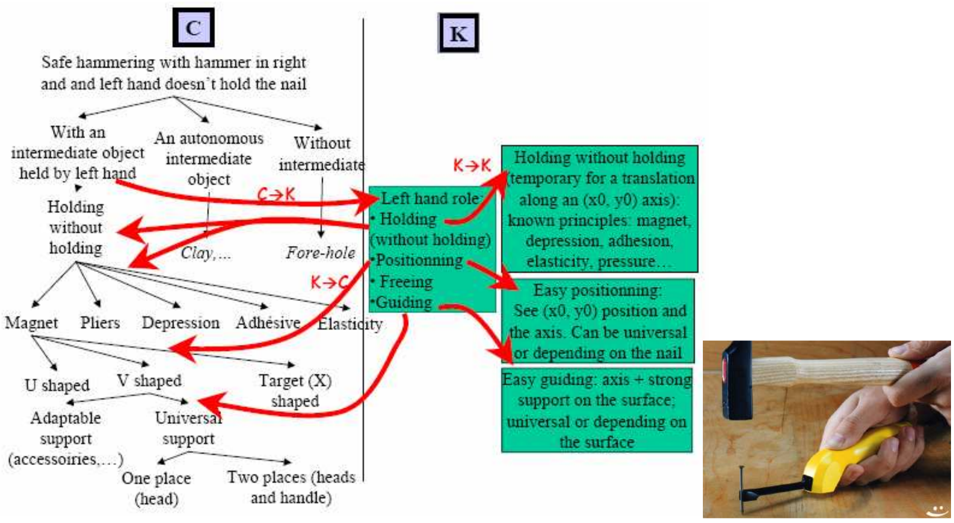

Figure 2. An application of the C-K theory at the example of the Avanti nail holder [10]

The resulting tree diagram of the development of the initial concept highlights the exploratory character of the C-K theory. Some branches of the tree are cancelled, others further developed. This formalism supports the exploration by a conscious and progressive development of the different solution concepts starting from the initial concept. In this point, the C-K theory differs from the "classical" creativity methods where first several concepts are generated arbitrarily before evaluating them. Moreover, the C-K theory keeps in memory not only the paths that have been followed, but also the mobilized knowledge and the concept expansions. For further details on the C-K theory, we refer the reader to [11].

3 FROM THE PTC MODEL TO A METHODOLOGICAL APPROACH TO INNOVATE

Starting from the analysis of the three dimensions of the PTC model (*potential, technology, concept)*, different opportunities for the innovation are identified. In order to develop every identified opportunity, each dimension has to be explored in order to confront the point of views, and thus to innovate.

However, the three dimensions of the PTC model cannot be considered in the same way regarding the role of Innovation in RID organization defined by Hatchuel et al. in 2004 [11]:

1. The *potential* of added value and the *technology* can be evaluated for future innovation. On the other hand, a *concept* cannot be evaluated since, beforehand, a *concept* is neither good nor bad when the relationship to the *potential* of added value and to the *technology* in the innovation is ignored. When developing the *concept* to one or more solutions, the dimensions *potential* of added value and *technology* have to be explored and confronted to the dimension of the concept.
2. The *concept* dimension has to be explored (transversal process) and developed (vertical process). Indeed, it is necessary to pass from an abstract *concept* to one or more solutions. In order to explore the field of *concepts* and to develop them, we propose to use the C-K theory.

We show how to realize the exploration in the *concept*, *potential* and *technology* dimensions. The multiple innovation opportunities coming from each of the three dimensions are the starting point.

Concerning the exploration of the *concept* dimension, we propose to use the C-K theory: a reasoning about an innovative conception is done by starting from the initial *concept* and exchanging between the concept space and the knowledge space. During the reasoning, Hatchuel et al. propose to use *design spaces*. A design space is a limited working context that allows learning within the design process. This restriction of the reasoning, or, in other words, localized workshop, is realized for a particular issue and the conclusions are then reintegrated in the principal reasoning.

Complementary to this reasoning about an innovative conception relative to the *concept* dimension, we propose to explore the two other dimensions of the PTC multi-input model, i.e. *potential* and *technology*, by opening for each dimension a specific *workshop*. The workshops related to the *potential* and *technology* are used throughout the entire design process and "feed" the principal reasoning continuously. Figure 3 illustrates how these two particular workshops refer to the principal reasoning that is itself related to the concept *dimension.*

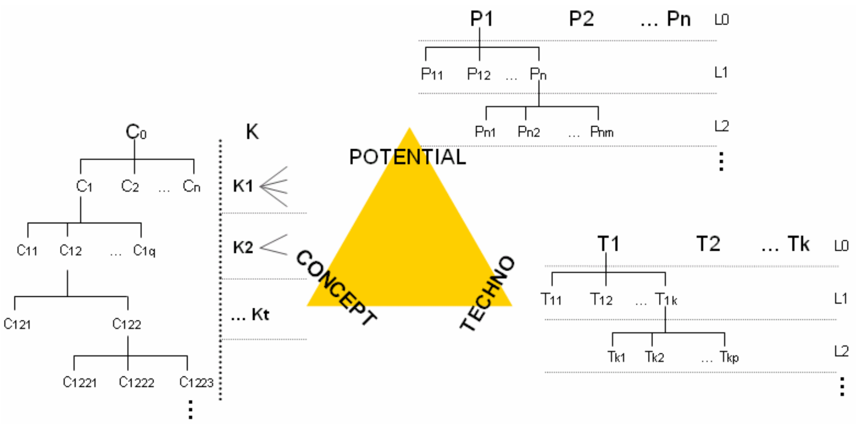

Figure 3. C-K reasoning related to the concept dimension and the design spaces related to the potential and technology dimensions.

A limitation of the C-K theory is that the innovation must be concept driven. In our multi-input approach, the innovation can also be technology driven or potential driven. Indeed, innovation opportunities are based on multiple inputs: the *potential* of added value identification, the *technological* opportunities emergence, and the innovative *concept* generation or collection. Each of these three workshops allows all the stakeholders to work in the way they are used to, while being the most inspired. For example, ergonomist and marketing people are used to work in the design space

potential – they are concerned by the demand and the usage of the clients, and they are especially interested by the added values.
The existence of the three workshops throughout the entire process enforces the continuous exploitation of all the three dimensions. We are convinced that this is a prerequisite for innovation. Consequently, the obtained knowledge and information is rich and accurate in order to better orientate the choices in the early design phases of the innovation process.

4 APPLICATION TO A CASE STUDY

So far, we have presented a new exploration method that integrates the three necessary dimensions that have to be considered for innovation. The theoretical results have been tested on different examples, and we present here a student's case study of the imagination of a "heated surfing wetsuit".
More precisely, we show the results from the exploration of the *potential* of added value and the *technologies*, followed by the reflections on the *concept* dimension.
Figure 4 shows an extract of our reflections on the exploration of the design space of the *potential* of added value for the client. We started by the identification of various categories of clients that could be potentially interested in the heated surfing wetsuit. For each potential client, the usage value has been analyzed by exploring the different situations that are involved in the given sport.
The case study has been restricted to the design space on diving wetsuits that have been studied extensively in order to understand the thermal behaviour. The result of this study allows the identification of the design criteria of the wetsuits. Note that from now on, the design spaces are indicated by a red frame in the Figures 4, 5, and 6.

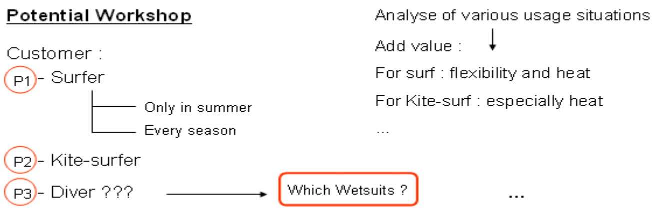

Figure 4. An extract of the design space of the potential of added value dimension

For the *technology* dimension, a flowchart of the potential technologies has been first created. The aim was to analyze if an existing technology could be used, and to discuss the advantages and drawbacks of every technology. Then, an expert group familiar with the textile industry has been consulted in order to gain the most precise insight about the future of these materials. Finally, more locally, a design space on the physical contradiction between the thickness of a material and its thermal isolation has been studied by using some principles of the TRIZ method [12]. The technology catalogue associated to this method in CATIA's "Invention machine problem manager" module has been consulted as well, as shown in Figure 5. Figure 6 shows an extract of our reflections on the exploration of the *technology* dimension.

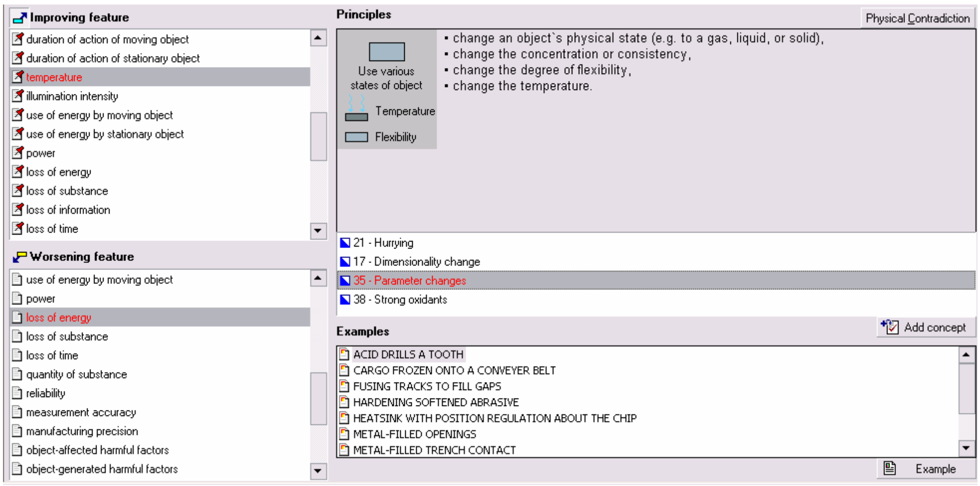

Figure 5. Screenshot of CATIA's « Invention Machine Problem Manager »

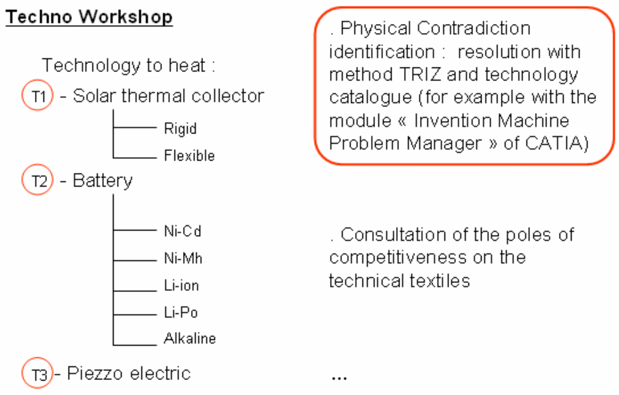

Figure 6. An extract of the design space of the technology dimension

In the concept dimension, Figure 7, some different elements have been modelled: the surfing, the role of a wetsuit, and the heat notion. These different models have brought up several questions and various problems, and several design spaces have been created. As a consequence, we acquired a lot of knowledge and many criteria have been identified.

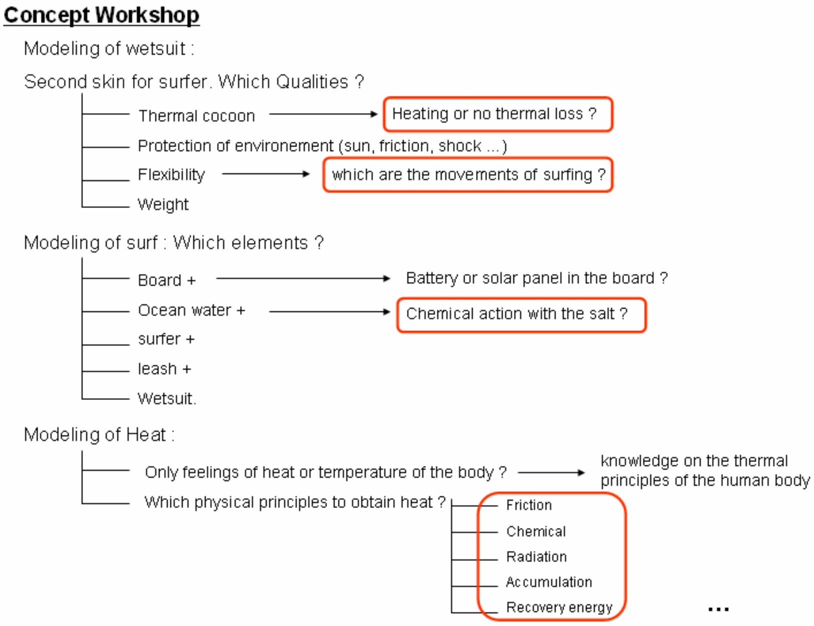

Figure 7. An extract of the design space of the concept dimension

All theses different explorations on the three dimensions allowed us to advance the reasoning about an innovative conception, and a synthesis in the form of a C-K tree structure can be seen in Figure 8.

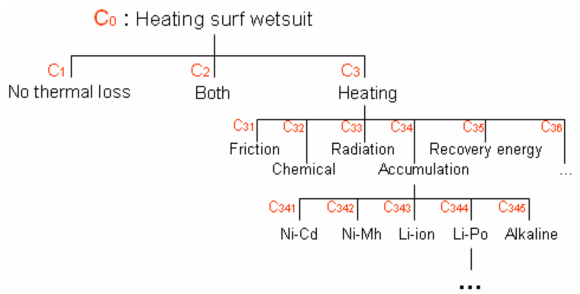

Figure 8. Reasoning in the form of a C-K structure

During the different experiments with the students, we have observed three types of activities that structure the exploration of the three dimensions:

1. The first activity consists to identify and model the constitutive and surrounding elements of a concept. In the example of our case study, the wetsuit has been modelled as a "second skin" leading to a reflection on the skin characteristics.
2. A second activity consists to enumerate and analyze the different types of solution concepts, and to compare the advantages and drawbacks for the emerging partitioning criteria. In the example of our case study of the heated surfing wetsuit, the study of different types of batteries allowed us to identify different criteria of the danger of these batteries like *radiation*, *electric shock*, or *explosion*.
3. The third activity consists in obtaining information and acquiring knowledge, in particular in order to "feed" the two first activities that require information and/or knowledge. In our case study, we can cite the example of the consultation of an expert group in order to acquire knowledge about the future techniques in the textile industry.

5 TOWARDS A TOOL FOR INNOVATIVE CONCEPTS MANAGEMENT

We have now seen how to practically apply our proposition to manage the exploration of the three dimensions on the example of a heated surfing wetsuit. We now present how to exploit certain results, and we propose to use and develop the ID² software tool proposed by Legardeur [13].
The preceding explorations allowed us to identify several criteria for the choice of the innovation. Figure 9 illustrates how the information is structured, and how the advances and its criteria are identified for each of the three dimensions. Figure 9 illustrates how the multiple criteria can be organized in the ID² software in order to structure the different evolutions and exchanges. ID² is mainly oriented towards the synthesis and the sharing of information about new proposed concepts and provides a support developing new ideas by proposing a platform for negotiation. The multidisciplinary team enriches each concept with its knowledge and criteria [14]. ID² uses a collaborative platform around a concept-criteria table: the different concepts that should be compared are spread along the columns, and the criteria along the lines of the table. At the end, the aim is to track back the mobilized criteria that lead to the definition of the chosen concept.
The interactivity between the C-K tree diagram (modelling the reasoning about conception), and the table concept-criteria, allow the identification of the mobilized criteria for any phase of the reasoning. Consequently, the concept-criteria table allows the creation of links among the mobilized criteria during the construction of the tree diagram.

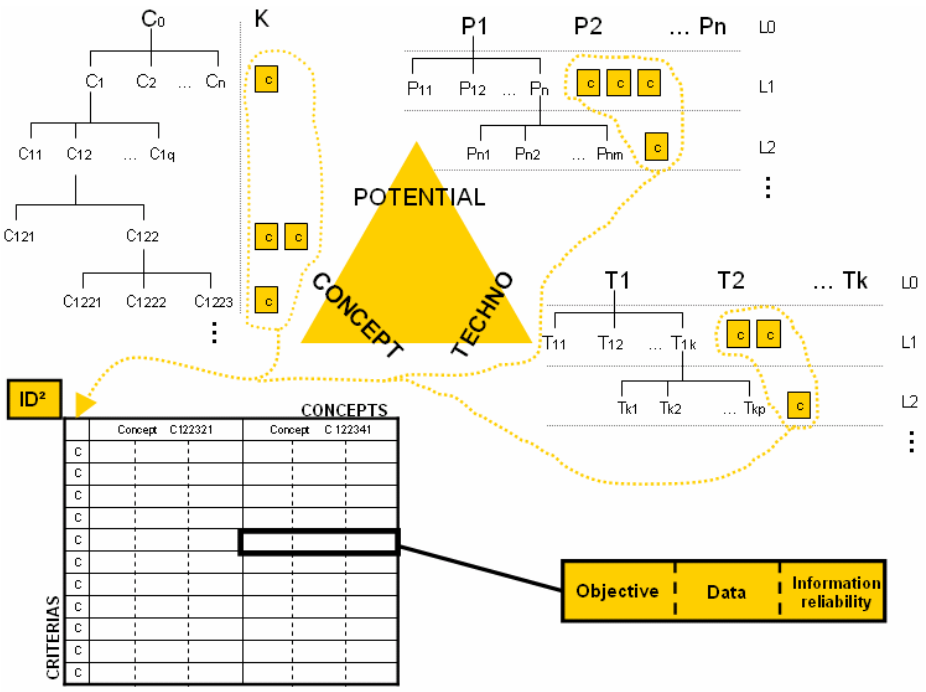

Figure 9. Mobilization of the criteria in the ID² software tool

For every criterion, we propose to define a result objective in order to have (i) an indicator that is related to the development phase of the concept, and (ii) an estimation of its reliability and maturity.

Consequently, the indicator tells us by its value whether the result comes from a formal test or a vague estimation of a stakeholder. Indeed, the mobilized criteria in innovation projects can be classified according to their reliability. This consideration takes a non-negligible importance in the early phases of innovation processes where the information is less mature and the input is often unofficial, private, or fuzzy. As a consequence, when the concept-criteria table in the ID² software tool is filled, it becomes an interactive tool for managing the innovative development concepts and provides a solid basis for choosing the right strategies.

6 CONCLUSION

New product/process ideas are thus developed during periods of negotiation and research of solution, which are often informal and unpredictable. At this level 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 while creating a configuration in which it is possible to launch an innovative project. The PTC (Potential –Technology – Concept) approach is one way to structure this complex process of emergence of a new innovative solution.

During this process, the efficiency of the method and tools implies a clear strategic vision of the product, the internal company politics, i.e. a "guide". The results issued from the field [15] reveal the importance of such internal politics during the early phases.

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