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INNOVATIVE DESIGN METHODS IN THE FOOD PROCESSING INDUSTRY: DISCUSSION ON C-K AND TRIZ

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ABSTRACT
The food processing industry has been an innovation intensive domain for a long time. However, when analyzing the nature of the industrial organization of this industry we surprisingly noticed that there was an important gap between R&D and marketing activities, on one side and industrial developments activities on the other side particularly in the SMEs. We believe that the latest developments in engineering design research may bring some benefits to the food processing industry. TRIZ and C-K are two very different approaches that have already been successfully used in the food industry. In this paper we present an attempt to combine the two methods in order to provide a methodological framework that allows a more efficient use of the two methods. We propose a theoretical reflection on the use of these two very different approaches and propose an original interpretation of TRIZ within the paradigm of the C-K theory.

Keywords: innovative design, design methodology, C-K theory, TRIZ, food processing industry

1. INTRODUCTION
The food processing industry can be defined as “a set of activities associated to the transformation of agricultural products into food products or any other kind of activity producing edible matter”.
Most of these industries are situated in the developed countries with a growing internationalization of the bigger ones (Nestlé, Kraftfood, Unilever, Danone, etc.). In fact an increasingly important number of populations wish to access to transformed food products. Developing countries are offering today the most important growth perspectives for the major industrial groups [1]. On the very competitive market of the food processing industry very different types of companies are living side by side. Even in our developed countries big groups (Nestlé, Kraftfood, etc.) which have big research teams working on new molecules or new synthetic products are living side by side with small businesses operating on very small and local niches. Both kinds of companies are facing the same challenges but with very different capabilities. According the report mentioned previously [1], the main challenges are:

- Improving the quality of the product (safety, traceability, etc.)
- Growing on international highly competitive markets
- Proposing products that are closer to the customer needs
- Proposing innovative products for reaching new markets

Innovation is certainly a major success factor for facing these challenges. It’s only to look at the communication campaigns of the major food companies.
It is interesting to notice that the food industry is facing very similar challenges to manufacturing industry. The common points are the mass production, the quality and cost challenges, the innovation and newness necessity, etc. The differences rely however on the characteristics of the products themselves which are “living” products with a short life time and an important biological cycle. Besides, the products are directly linked to the people health which has a huge social impact. This industry is close to the process industry where chemical transformations are prevalent. But on the other hand, the food industry provides final products directly to the consumer. We believe this is a very interesting field of study for engineering design research that deserves more attention than it has received up to now.

The first part of this paper is dedicated to a brief presentation of some attempts to introduce some methods from the manufacturing industry into the food industry. We then introduce some elements of TRIZ and C-K that we will use in the next sections.
The second part of the paper is dedicated to the case study and shows how the two methods have been used in that specific case.
The last part of the paper is dedicated to a more theoretical discussion which is a first attempt to sketch out a methodological framework integrating the two methods.

2. DESIGNING FOOD PRODUCTS

Surprisingly when studying the dominant terminology of the companies through their websites and articles we found few references to the word *design*. Most companies make reference to innovation, research and development, development, industrial processes, etc. The organizations we analyzed are very classical in the sense that they put a great emphasize on the upstream activities (i.e. marketing, R&D) and on the quality issues of the downstream ones which are critical issues for this industry. The literature is very clear on that point. The methodologies applied today are "quality oriented" such as QFD [3][4] or information oriented [5] which emphasize the systematic turn of a product development process after the preliminary phases.

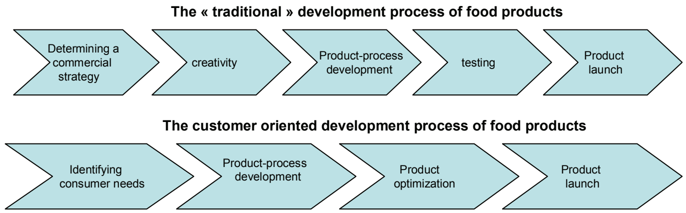

Figure 1: examples of product development processes in the food industry

2.1. Design process models

In the literature of the food processing industry we find two distinct approaches (see figure 1): a "classical" development process, and a "customer oriented" process. The first model, which is close to other industrial domains, highlights the necessity to develop the product and the fabrication process in close relation [6][7]. The second model is more product centric and insists on the identification of the customer needs [8][9][10]. Today the researches focus on a better identification of the customers needs, such as the "collages" method [11] or the means-end theory [12] to only cite these two. These authors argue that if the products are close to the customers expectations the introduction of new innovative products is obviously facilitated [13][11][14]. This assumption needs however to be verified even if this appears to be obvious.

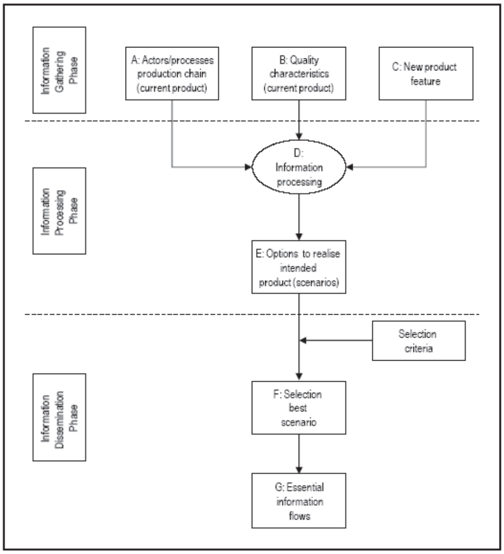

Figure 2: the chain information model [5]

2.2. QFD and the Chain information model

This is only in the early 90s that QFD has been implemented in the food industry [4]. This very well known method which is currently used in a great number of industrial companies over the world has been adapted to the specific domain of the food industry. Various products have been developed with this method example includes biscuits, chocolate cakes, ham, ketchup, etc. [3]. The method must be adapted because, contrary to manufactured products which are made of a set of assembled parts, food products are the result of combinations of various ingredients which produce chemical reactions under certain conditions. QFD does not allow the easily elicitation of these biochemical interactions. Besides the method supports innovation in an indirect way, it is more oriented toward the management of the development process than toward the support to innovation.

Another model has been developed specifically for this type of product considering the flow of information along the development process. The Chain Information Model (CIM) [5] focuses on the articulation between new products and the fabrication process. The method proposes to develop various production scenarios regarding the specificities of the domain. This method has been tested in the development of a new ketchup that incorporates a new element known for reducing cancer risks. This product could then be classified in the emerging category of food "alicaments". This method really supports new product developments but is poorly equipped for supporting the creative process of designing a new product.

We will see in the following sections how we can use other methods for supporting the upstream creative aspect of innovative design.

2.3. TRIZ method

We will not present here the now well known TRIZ method. This very original innovative approach has been extensively used across various domains for many years up to now and the reader can find numerous references and text books presenting the method in the international literature. However in TRIZ journal we find interesting case studies involving the use of TRIZ in the food industry. It gives a good state of the art of the method as it is used today and some references give interesting examples of the work required in order to apply TRIZ to the particular domain of the food industry. Man and al. [15] [16] show for example that a work is necessary at the level of the 40 principles in order to complement the examples data base. The 40 principles appear to be relatively stable across the various industrial (and non industrial) domains where they have been experimented, however, in order to improve the usability by non specialists a better exemplification appears necessary. This work is an attempt to enlarge the scope of use by a better inclusion of non TRIZ specialists.

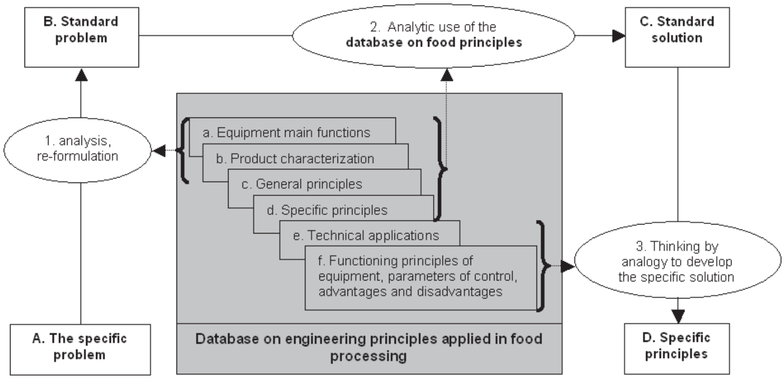

Figure 3: specific data base for helping TRIZ abstraction mechanism in the food industry [17].

Following the same idea in the even more sensitive context of the developing countries, Totobesola-Barbier and al. [17] proposed a deep analysis of the basic functions of a food equipment and the main product properties and process parameters of the food products. This approach is of great importance in the specific domain of the food industry where the products are not physically and biologically stable, which is very different from classical manufacturing products. Figure 3 shows the proposed method. One can notice that the assistance is provided at the most critical points of the method, i.e. the problem abstraction and the solution deriving. The proposed database is an interesting attempt to facilitate the work of the designers in the context of the developing countries. Despite this work cannot be directly applied in the developed countries this is an interesting base for future work applied to the developing countries.

The two examples briefly presented above were related to the main TRIZ method (the contradiction matrix) however we think that other TRIZ tools may also be studied in the same way. For example, the S-U fields may take advantage in being added new types of fields or effects in line with the product specific biological or chemical properties but this point is out of scope of the paper and requires future work.

2.4. C-K theory

This new design theory has been proposed by Hatchuel and Weil in the early year 2000 and introduced at ICED 2003 for the first time in our community [18]. This theory aims at proposing a general framework for understanding innovative design. This theory proposes to leave aside the classical decomposition and dynamic mapping of functional and structural spaces we find in most of the other theoretical approaches. The C-K approach prefers to concentrate on the design reasoning aspects and proposes to model the mapping structure between a knowledge space (K space) and a concept space (C space). This approach appears to be new in the sense that it is the first time that a theory proposes a unified formulation of the cognitive dimension (i.e. knowledge, concept, design reasoning, etc.) of design. When the other classical theories concentrate on the dynamic of the transforming artifact, C-K concentrates on the dynamic of the design reasoning. In that sense C-K is closer to Gero's FBS than to Suh's Axiomatic Design.

In C-K a "concept" (C element) is a proposition with an undecided logical status (true or false) [19]. This is typically the case when a designer makes a proposition. For example in the case we will see later we can formulate "a bread without crumb" with no idea whether there is a solution or not to this proposition (a true or false status to the proposition). A "knowledge" element (K element) is at the opposite a proposition with a known logical status. In the food industry there is a corpus of knowledge on how to manufacture bread for example. In a specific domain one can make a knowledge map of what is known as possible or impossible or what knowledge is accessible (what I know that I know and what I know that I don't know). The two spaces are expanding spaces where each new element of C may trigger new element of K and vice versa. The expansion is twofold and simultaneous and the convergence is achieved when an element of *C* meets an element of *K* giving a positive conjunction and a solution candidate (figure 4).

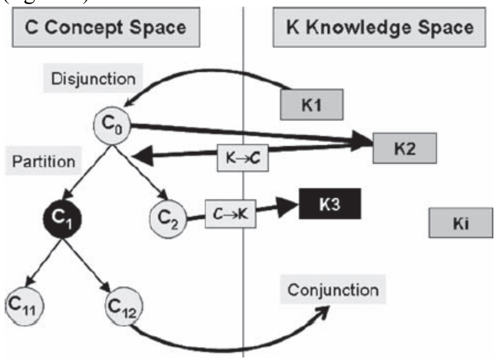

Figure 4: asymmetric structure of C and K [19]

Starting from these two spaces the authors define 4 operators that allow the mapping from one space to another. The authors show that the design process begins with a proposition in the *C* space. This clearly translates the hypothetical value of a proposal, an idea, etc. even if it relies on a comprehensive marketing study the designer always starts with a conjecture, a solution that *may* reach the market requirements. In C-K terms it is called a "semantic disjunction" in *C* (e.g. "crumbless bread" is a semantic disjunction). The other operators are more extensively defined in [19] we will not detail them, we simply mention here:

- C->K: Search Knowledge element for C attributes, trigger new knowledge search.
- K->C: trigger new concepts by assigning new attributes
- C->C: Concept tree expansion, new concept derivation (i.e. fostered by creativity methods)
- K->K: Knowledge expansion, refinement, technology development (e.g. classical R&D activity)

In K space the intrinsic stable nature of the K elements remains until a paradox appears in the C space. We reach here an interesting parallel with TRIZ where a contradiction is in fact a paradox that we introduce in order to trigger new knowledge elements. We will develop this point in the third part of the paper, before it is necessary to present our case study in more details.

3. RESEARCH METHODOLOGY

3.1. Industrial survey

This research has been carried out using two distinct methods. First we made an industrial survey starting from our first literature study. Our aim was to, first observe the design activity of food products, second analyze the needs of this specific domain and third collect data for building case studies of innovative products. Among the 2230 companies we detected we selected 174 companies we found suitable for our study (i.e. they communicate on their innovative products). We found after a very poor level of feed back that most of these companies were using the term innovation more as a marketing argument than as a real level for improving their products (i.e. involving systematic innovative design methods). This is may be one of the most interesting and frustrating preliminary result we had. Innovation as a methodology for improving the products and the associated services through technological changes or industrial optimization is not at the centre of most of the food companies (if we exclude of course the biggest companies such as Nestlé, Kraftfood, Unilever, Danone, etc.). The bigger ones spend a lot on communication but the innovation remains mostly in the marketing and R&D departments, when the industrial aspects are left aside this process (few references to product-process innovation). The deep modification of the products and processes remain rare. Radical innovation that changes the way of consuming food, preparing it, etc. remains unusual. We think that this is partially due to the industrial culture of the sector which has not integrated existing methods especially that take into account the necessary integration of the design and the manufacturing dimensions putting forward a real integrated design method. But above all, the very culturally sensitive aspect of the products prevents from proposing too odd products, new concepts, etc..

3.2. New Bread Corp. case

This is why our second approach focused on the development of case studies that show the benefits of importing methods used in the manufacturing industry. Our reflection led us to propose two complementary methods as means to analyze and manage innovative design.

This case is a virtual case for confidential reasons. The company is specialized in the industrial fabrication of bread and bakery products. The company was founded in 1975 and is situated in the Parisian area. With a 20 billion Euros turnover last year, this company which employs 103 persons is a medium size company of the sector. The company offers fresh bread (of the day) to their clients (mainly supermarkets of the region). The plant is made of two main production lines. The first is dedicated to the fabrication of bread, and the second to the fabrication of bakery products (brioche, croissants, etc.).

Over the years the company specialized in the fabrication of baguettes and brioches. The recipes and formulas are strictly monitored and the process diagram is clear and stable. The process diagrams that are commonly used in the profession include the various stages and operations, the formula and the main time elements that are important in the overall process (we can compare that to process parameters).

The company wanted to develop its activity because of the growing competition with other companies and the evolution of the customer attitude. They decided to engage themselves in an innovative process which aims to define a new product that would be more suitable to the new consumption habits and that could give the company a new competitive advantage. In the following we will detail the use of two innovative methods and the results that came out of this study.

4. INNOVATIVE DESIGN OF A NEW FOOD PRODUCT

After a customer survey the analysts found that the consumption habits evolved toward a nomadic dimension: the customers want to eat in various places (in their cars, in the office, etc.), and they want to have fresh bread at anytime (even when they come back home quite late). In this section we will sketch out the various steps of the methodology.

4.1. C-K for structuring design reasoning

As shown in section 2.4 C-K theory provides theoretical foundations for describing creative reasoning mechanisms relying on the latest mathematical finding in the set theory [19]. But C-K provides also a method for structuring design reasoning and has proved to be useful in numerous occasions [20]. Our survey showed a lack in methods (mostly in the SMEs) for this kind of activities, at the boundary of R&D, product usage and industrial development. Being able to explore and build a map of the design space, in relation with the knowledge resources available proved to be an interesting tool in our study.
The starting point, also called "semantic disjunction" is: "a crumbless bread" (i.e. a bread without crumbs). Regarding the new customers habits, especially the fact that a large number of young people do not eat at home or in places dedicated to food (i.e. a restaurant), providing a bread that could be eaten everywhere could be an interesting value added for the customers.

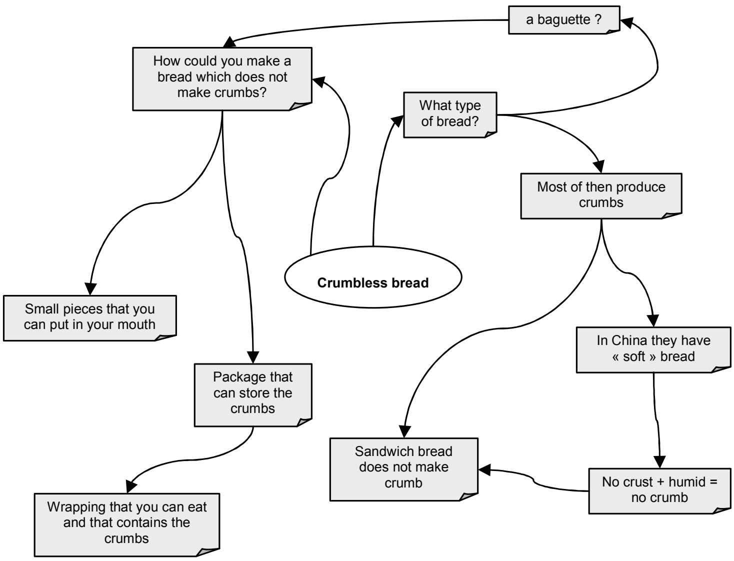

Figure 5: result of the brainstorming

Step 2: From this logical proposition with no true or false logical status at the moment, we made a brainstorming session involving potential users (figure 5). This allowed to randomly explore the concept space and to produce some interesting ideas.

Step 3: From this first exploration, we mapped the reasoning process by constructing a C-K map. This is obviously a reconstruction and does not reflect the "actual" cognitive process of the designers. However, the connections between the concepts are logical connections. For example the concept of "pre cutting" (figure 6) is logically linked to the concept of "cutting" in the sense that there is a cognitive dependency between the two concepts. We can now build a tree with four expanding partitions (C-C operators) that summarizes our exploration of the design space at that stage of the innovation process. From this we can deepen the exploration and make the tree grow in order to refine our decomposition. All those links are logical links that represent in a way the cognitive links we make during design reasoning. Therefore we have here a good tool for supporting design reasoning and structuring at the conceptual level. Note that all the branches have not been explored systematically. This tree is the "picture" of the stage of reflection the team has reached at that point of the project. It is supposed to evolve and may be change drastically in future stages.
The Knowledge side has been developed in the same way, looking for knowledge spaces that were present in the company, widely shared among the community, or missing, or even to be constructed, requiring research developments (K-K operators). For the *Lego brick-like* bread the state-of-the-art does not allow to fabricate such bread in an industrial way. The process needs to be developed and validated. Therefore there is a technological gap to fill if the company wants to develop this kind of product. In other words, there is no semantic conjunction at that stage that allows this proposal to be a candidate solution to our problem.

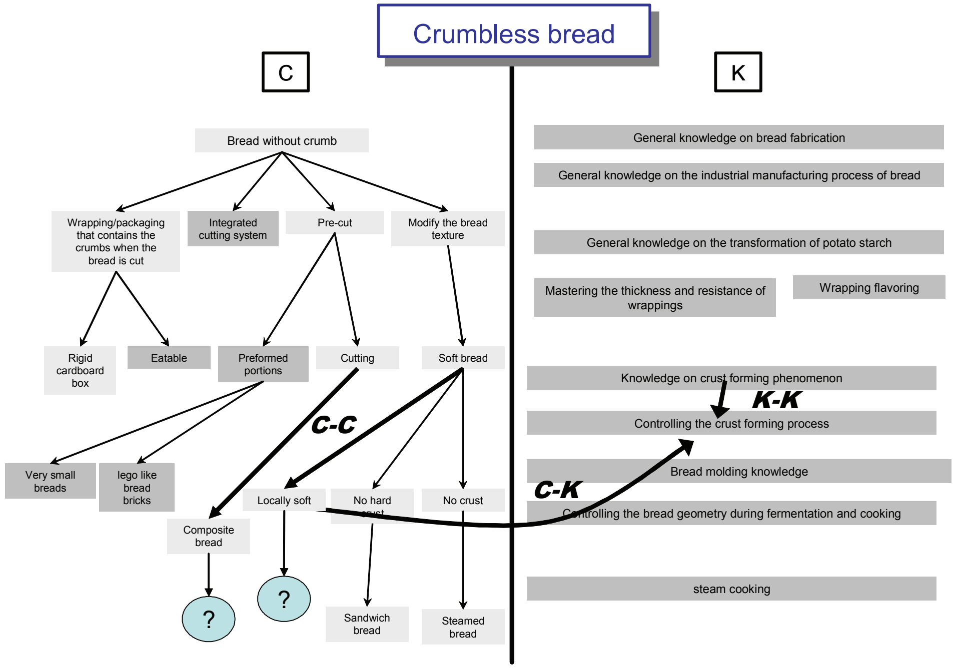

Figure 6: C-K map of the "crumbless bread".

4.2. Formulate/refine design problems with TRIZ contradictions

As we have seen in section 2.3 the TRIZ principles database does not suit very well to our domain and the examples sometimes remain too far to be useful for generating new ideas despite the works mentioned before [15] [16]. However we show that we can use this method under certain conditions and sometimes examples that are very far from the domain of application may help to create some surprising creative connections.

The design problem can be formulated as follows: *"make a bread that one can cut everywhere without producing crumbs and that keeps the flavor and consistency of a "French baguette""*. From this formulation we can draw some contradictions relying on the exploration of the design space formalized in the C-K diagram presented before (figure 6). Four branches can be explored: the soft bread, the cutting system, the eatable package, the Lego brick-like bread. Just to remind us that the four proposals are actually design conjectures in the C-K theory sense as they have no logical status at the moment. Let's pay attention to the *soft bread* conjecture. In order to solve it we will make an hypothesis regarding the solution to this problem and identify a contradiction (one or more depending on the question can be considered). Given the known elements of K space the solution "suppress crust" raises the following contradiction:

"If we suppress or reduce crust the bread become too soft".

The design parameter we improve is the loss of crumbs. We can translate it in the TRIZ formalism as a *"loss of substance"*. The design parameter we deteriorate is the crusty effect we can translate as *"loss of strength"* of the crust. If we introduce the parameters in the TRIZ contradiction matrix we get the principles and standard solutions presented in figure 7.

TRIZ Principles	Standard solutions

Parameter change	• Change object's physical state • Change the concentration and consistency • ***Change the degree of flexibility*** • Change temperature
Mechanisms substitution	• Replace a mechanical system with sensory means • Use electric, magnetic, electromagnetic fields to interact with the object • Use fields in conjunction with fields activated materials • Change from static to movable fields
Porous Materials	• Make an object porous or add a porous element • If an object is already porous use the pores to introduce a new substance
Composite materials	• ***Change from uniform to composite materials***

Figure 7: result of the contradiction strength vs. loss of substance

We have selected the principle "parameter change" and focus on the standard solution "change the degree of flexibility". If the bread is too hard (or stiff) it breaks into small pieces (the crumbs) and on the other hand if it is too soft (or flexible) the crispy effect is missing. We see here appearing a physical contradiction. The bread must be soft for avoiding crumbs and hard for remaining crusty. Therefore the bread must be soft and hard at the same time, which reveals a *physical contradiction* in the TRIZ sense. In order to solve this contradiction we have some separation principals. For example we do not need to have the opposite characteristics in all along the bread. We only need soft bread in the very exact place we need to cut it. So we can imagine a bread with a varying crust alternatively soft and hard. We can then enrich the branch of the concept tree (C-C operator) and add another alternative (locally soft bread figure 6). This alternative will trigger in return the knowledge space "control the crust forming process" (C-K operator figure 5).
In the same way if we take the "composite material" principle, we can imagine a bread made of slices separated with a specific material allowing an easy partitioning of the bread. This material can also be bread but in another physical state (i.e. harder for example). We can have "composite bread" that can enrich the "pre-cut" branch of the concept tree (figure 6).

5. DISCUSSION

From our analysis and the presentation of both TRIZ and C-K we propose to sketch out a methodology for structuring innovative problems and design reasoning through an intelligent use of C-K and TRIZ.

5.1. TRIZ contradiction mechanism: heuristics in the K space

Through this case study we show that we can navigate in the design space, mainly at the concept level, but with an interesting link to knowledge requirements. In fact the Concepts of solutions are far to be transformed into solutions and they require engineering knowledge and research efforts to be eventually validated.
At this stage of the study we can raise some interesting issues regarding the methodology. Our starting question was: are we able to use innovation methods from the domain of engineering into the food design domain? The answer is obviously yes at this stage of the study. We found similar cognitive mechanisms that can easily be described in the C-K and TRIZ languages.

If we consider that C-K, as a method, does not provide tools for supporting the creative process, we find in TRIZ an interesting complementary method. Notwithstanding the fact that the theoretical foundations of TRIZ have never been rigorously explored, TRIZ nevertheless provides interesting tools for fostering creativity. Contrary to the authors of [21] we consider that TRIZ provides a support to design reasoning. If we only consider that TRIZ is an intelligent search method in a database we miss the most important part of the method. Indeed, in order to be able to formulate a contradiction, the designer must build an abstraction of his problem, which is, in itself a reformulation and a refinement of the design problem. The second step, the search in the database often gives standard solutions that are absolutely not understandable in the grammar of the specific design problem. The transformation between the standard solutions and the new concept is more than a translation it requires creativity. The TRIZ tools use various abstraction mechanisms to help the designers to formulate progressively a problem in more abstract terms (contradiction formulation, S-U fields formulations, etc.). This obviously helps to create unknown semantic connections and explore the concept space with new surprising propositions. From this point of view, the standard abstract solutions do not need to be close to the considered expert domain. This may even be an obstacle to innovation. Standard solutions can be considered as cognitive triggers that foster semantic disjunctions in the concept space. We think there is an interesting research program between cognitive sciences and design sciences on that point.

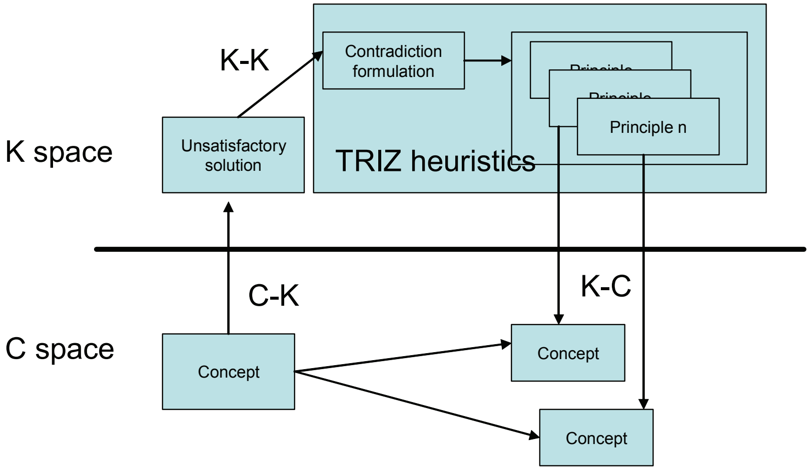

Figure 8: TRIZ abstraction mechanism within C-K the framework

In fact TRIZ principles combined in the contradiction matrix can be seen as design heuristics that have been formalized by altshuller and that aim at fostering the creative potential of the designers. If we adopt that point of view in the C-K theoretical framework, TRIZ contradiction mechanism becomes a powerful heuristic in the K-Space (figure 8). Besides, if we consider that the first concept generation (C space) leads to an unsatisfactory solution (K space) we have a C-K operator. The contradiction formulation is a K-K operator and the K-C operator becomes concept formulation from the TRIZ principles database (remember the composite bread concept).

5.2. Using TRIZ contradictions and principles for finding C-C partitions

What has been shown all along this paper appears to be eventually a way to find C-C partitions in a more efficient, systematic and creative way. The methodology we sketch out here is a summary of what we have seen along the paper (figure 9).

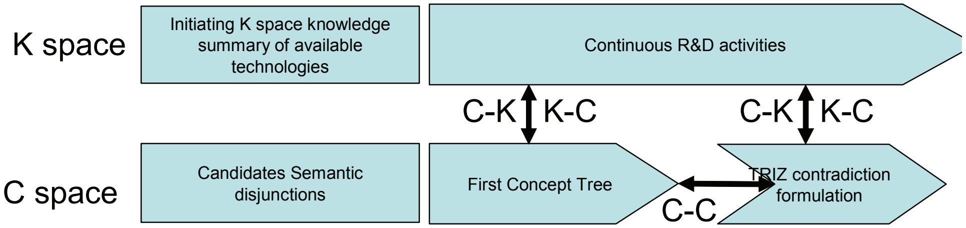

Figure 9: A proposition for embedding TRIZ contradiction mechanism within C-K framework

The first step of the methodology relies in the initialization of the K space through the systematic identification of the knowledge elements available at the time. This work is usually done by R&D departments and is often linked to knowledge management approaches. The C space can be initialised by the output of marketing studies, competitors benchmarking, etc. This side may also be populated by previous concepts which have been left aside in the past for contextual reasons.
Step 2 (C-C phase): building a concept tree using classical creativity tools.
Step 3 (C-K phase): selecting candidate concepts and elaborating candidate solutions within the K space framework.
Step 4 (K-K phase): if the solutions are satisfactory they become candidate solutions, if not, they can serve as a basis for a TRIZ contradiction formulation.
Step 5 (K-K phase): Appling TRIZ contradiction matrix and select principles.
Step 6 (K-C phase): from the selected principles generate new expanding partitions in the concept tree.
Figure 9 shows a synopsis including the basic C-K TRIZ loop. The process can iterate until a satisfactory solution is reached.

6. CONCLUSION

This paper shows a successful attempt to use innovative design methods that have mainly been designed in the context of the manufacturing industry in the food industry, our study proved that the methods can easily be used and can produce interesting results. In order to generalize our approach we proposed a theoretical reflection based on our empirical analysis of the use of the two methods. From the theoretical point of view, C-K is today a leading edge theory in the domain of innovative design. However, as a method, it appears to require other developments in order to be commonly used. Particularly we lack support at the reasoning level and creativity methods are not implemented in C-K. TRIZ, as a creative problem solving method provides a specific framework for feeding part of the identified need. Unfortunately the poor theoretical foundation of TRIZ is an important limitation to the extension of the method. We believe that TRIZ has interesting cognitive links which could be valuable to study more extensively.

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