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Management of «Systematic Innovation»: A kind of quest for the Holy Grail!

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A B S T R A C T

In this paper, authors propose a contribution for improving the open innovation processes. It shows the necessity to get an efficient methodology for open innovation in order to build a computer aided tool for inventive design in Process Systems Engineering (PSE). The proposed methodology will be evocated to be fully used in the context of the "revolutionary" concepts around the so-called factory for the future, also called integrated digital factory, innovative factory. . . As a result the main contribution of this paper is to propose a software prototype for an Open Computer Aided Innovation 2.0. By definition this open innovation relies on collaboration. This collaboration should enable a community, with a very broad spectrum of skills, to share data, information, knowledge and ideas. As a consequence, a first sub objective is to create a methodological framework that takes advantages of collaboration and collective intelligence (with its capacity to join intelligence and knowledge). Furthermore, the raise of the digital company and more particularly the breakthroughs in information technologies is a powerful enabler to extend and improve the potential of collective intelligence. The second sub objective is to propose a problem resolution process to impel creativity of expert but also to develop, validate and select innovative solutions. After dealing with the importance of Process Innovation and Problem solving investigation in PSE, the proposed approach originally based on an extension of the TRIZ theory (Russian acronym for Theory of Inventive Problem Solving), has been improved by using approach such as case-based reasoning, in order to tackle and revisit problems encountered in the PSE. A case study on biomass is used to illustrate the capabilities of the methodology and the tool.

1. Introduction

The question of the Factory of the Future (FoF) is a major issue that is described in both national research strategies of many countries and also in the European Commission roadmap (European Commission, EFFRA, 2013). Among the common objectives of these proposals, the FoF allows the innervation of the industry with scientific and technological innovations on products, processes and production systems as a whole, and by the strengthening of an ever more effective collaboration among stakeholders to impel innovation. The FoF will be at the heart of its ecosystem sustainability, human-centered, and agile (able to reconfigure quickly according to demand). This factory is a response to multiple simultaneous transitions: energy, ecological, digital, organizational and societal. Each of these transitions requires many new technologies and modes of organization. Indeed, the FoF must operate in networks to easily reword the value chain to adapt to market and technologies changes. As a result, the FoF must be innovative, competitive, efficient and attractive. Therefore it must be a technological and societal response to the current factory, claiming a systematic reduction and optimization of all costs, and where the issues of competitiveness allow limited space for technological innovation. In the future the major part of the competitiveness will be based more on product intrinsic quality, the fullness of the associated services and the innovation degrees which will become the main differentiators. The purpose is to support the implementation of new paradigms on the role of individuals in the plant (operators, management . . .), in its organization but also its role in the ecosystem. In this context of deep changes, innovation appears as a crucial feature, therefore it should be made more systematic, needs to be accelerated but also the quality of the inventive ideas generated should be raised.

In the same time, the deployment of new digital technologies must speed up, facilitate, and change the links between the different partners of the value chain. This vision of the extended enterprise gives way to a new inter-companies business model around common projects to enable the sharing of knowledge,

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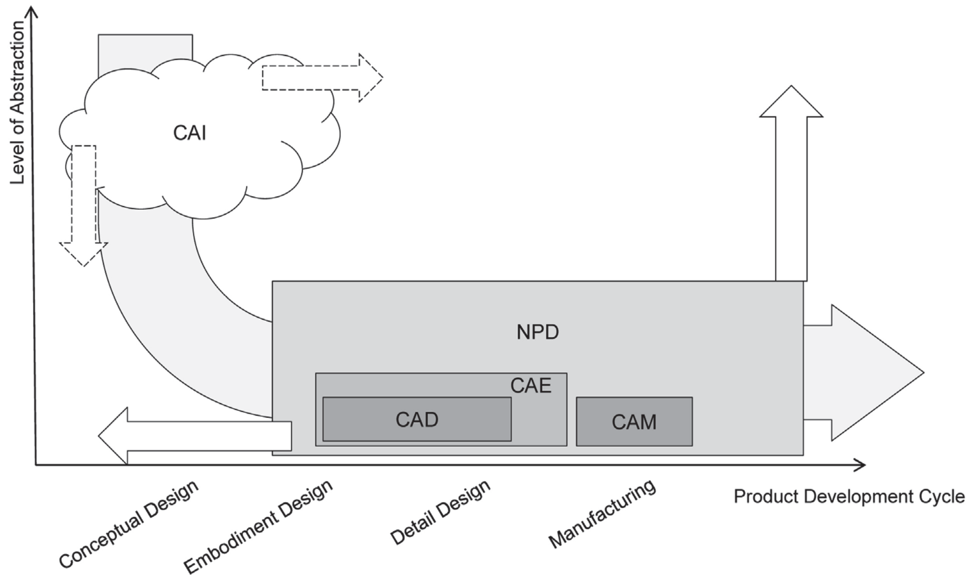

Fig. 1. Application of CAI in NPD according to (Becattini et al., 2011).

skills and experiences. Another challenge is, therefore, to invent new patterns of collaboration between these partners. Indeed, the collaboration is at the heart of the innovation process. It concerns social networks dedicated to technical problems resolution allowing information sharing, management and ranking of ideas, management of product portfolio, resolution of problem locks... Consequently the approach to innovation must go beyond the current model turned within the company to be deployed outside the company boundaries for a more open innovation. This new way of collaboration concerns both the design process and the operation of the factory. Therefore, the FoF must take into account the modifications generated by these new collaborative practices and in particular it must propose new organization to foster collaboration between people across the globe and with different cultures.

In this context, the Process System Engineering (PSE) community has to propose new methods and tools that integrate all previous dimensions, which must be adapted to the new organization to foster innovation and to ensure this transition to the factory of the future. Furthermore as Ten Kate (2016) underlines, the application of computer aided formulation design is particularly attractive in the early design stages, but it needs specific methods and tools as in this stage the level of detailed information is typically low. Thus the use of Computer Aided Innovation (CAI) is part of the strategy to address this transition. For Leon (2009) CAI is the research field that leads the efforts to develop a new category of computers aided solutions in order to support and automate the different activities of the innovation process for a new product or process development. Hüsig and Kohn (2009) and Leon (2009) present an overview on the CAI concept, its main components approaches and perspectives. In the array of computer-aided tools, the initial studies on CAI aimed to assist process engineers during the creative stage of the design process, also called the fuzzy front end. Subsequently, the scope was extended such that the general goal of CAI is to effectively support the entire innovation process, from the fuzzy front end with the generation of ideas, through detailed design and development, up to the withdrawal or recycling. As Dereli and Altun (2011) demonstrate, the perception of CAI in literature is associated with three pillars: design (e.g. computer aided design), problem solving techniques (e.g. TRIZ, Russian acronym for Theory of Inventive Problem Solving), and optimization (e.g. evolutionary algorithms, genetic algorithm). Besides CAI, the development of other computational tools have progressively

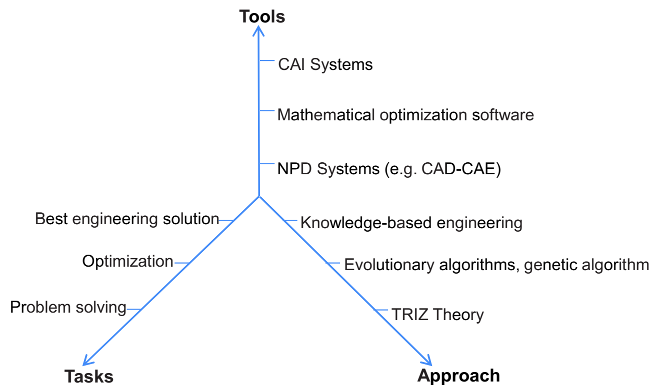

Fig. 2. Comparison of product or process development methods and tools. Adapted from (Cascini et al., 2009).

extended to enhance product development cycles. Computer Aided Design and Engineering (CAD/E), and Computer Aided Manufacturing (CAM) are the leading solutions for an efficient design process and high quality representation of products (Zeng and Horváth, 2012). Fig. 1 illustrates the positioning of CAI related to some other computational tools used within New Product Development (NPD). The figure identifies the abstraction level corresponding to CAI, it also shows how CAI are positioned in preliminary design phase.

To go deeper on the comparison of methods and tools to support the tasks of product or process development, Fig. 2 makes the relationship between the specific approaches for design with the tasks and tools associated. From the PSE point of view, Fig. 2 raises the question CAI versus Optimization. Indeed Innovation and Optimization are sometimes perceived as conflicting activities or on the contrary for some people they represent the same scientific problem. Optimization, in design, means translating the design problem into a mathematical model where it is possible to identify: the objective(s) function(s), the decision variables and the constraints. As a consequence, this approach assumes that there is enough knowledge on the system studied to identify the three aforementioned entities but also a certain experience in the design process. The optimal solution is often a compromise since improving one performance of a process may result in the degradation of another. Despite recent significant efforts on the optimization methods (e.g. multi objective optimization), the generation of the objective function or the choice of the optimal solution is based on a subjective assumption of the designer on the relative importance of the objectives. In some case this best compromise is not satisfying which means that we must seek solutions beyond what can achieve the optimization, i.e. go beyond the Pareto front. In this case, the decision variables, the definition domains and the constraints have to be questioned. As the problem has never been faced before, there is no experience on how to solve it. As a result the designer needs methods and tools to change the representation space of the problem, the solution space but also to have guidelines to avoid exploring theses spaces randomly. This is one objective of the CAI to deal with these categories of problems and to support their analyze, modeling and resolution. To continue our comparison with optimization, CAI enable to review the constraints, to expand the definition domains of variables, but also to redefine new design variables. To prove the complementary between previous approaches, Cascini et al. (2009) present an attempt to set up a framework for integrating optimization and CAI to increase the effectiveness of some design activities.

As most of the CAI are TRIZ based, Leon (2009) has discussed the possibility to connect TRIZ capabilities with other concepts and techniques used in conceptual design such as: optimization and evolution algorithms, integration in product lifecycle management, semantic web and data mining. To go further on the last point, the joint advances in the information and communication technologies possibilities commonly referred to Web 2.0 and the strategic paradigm shift from closed to open innovation lead to the next generation of CAI defined by Hüsig and Kohn (2011) as Open CAI 2.0.

In this context, the main contribution of this paper is to propose a software prototype for an Open CAI 2.0 for improving the innovation process in the context of the FoF. To our knowledge, it is one of the first attempts for an Open CAI 2.0 in PSE. Thus, this numerical tool must allow to various experts (inside or outside the boundaries of a firm) to work together and to simultaneously interact on an innovation project. As a consequence, a first sub objective is to create a methodological framework that takes advantages of collaboration and collective intelligence, and that can be implemented in the prototype through recent advances in information technology. The second sub objective is to propose a problem resolution process to impel creativity of expert but also to develop, validate and select innovative solutions in the context of open innovation. The main difficulties are to ensure a shared vision on the nature and the formulation of the problem but also a sharing and a transfer of knowledge between experts in different scientific domains.

The remainder of this article is organized as follows. Like in other engineering domains, in process engineering TRIZ is one core component of the resolution process in CAI, thus the next section gives the theoretical backgrounds concerning TRIZ, its benefits in PSE in general and in CAI in particular. The paradigm of open innovation and the way to implement in a CAI is also discussed. Section 3 describes the concept of Open CAI 2.0 and details the main elements of our methodology and the tool architecture. It also highlights some capabilities of the problem resolution process. Before to draw conclusion, the framework and the tool prototype are illustrated through a case study on heat integration in biomass gasification.

2. Theoretical backgrounds

2.1. TRIZ

TRIZ, developed by Altshuller (1996), is one of the most articulated and effective theory for supporting the initial stage of engineering design and more particularly the innovation fuzzy front-end stage. The main goal of TRIZ is to enhance ideation and problem solving performance by making the ideation step more systematic. As a result TRIZ is a knowledge based systematic theory for effective problem solving whatever the technical domain of appearance of the problem. The premise of TRIZ is that the evolution of technical systems, scientific discoveries, and the way the inventions are generated, do not follow a random process, but conversely they are predictable and governed by certain patterns (called laws in TRIZ). The research on TRIZ has produced three major findings: (i) problems and solutions are repeated across industries and sciences, (ii) patterns of evolution are also repeated across industries and sciences, (iii) inventive solutions often used scientific effects and phenomenon outside the domain in which they were found. TRIZ provides also algorithms for the application of its set of methods, tools and meta knowledge bases for analyzing and investigating the problem, for identifying the root cause of the problem, for formulating the problem, and finally to give access to knowledge bases leading to inventive solutions. As a result, in the literature, TRIZ is largely acknowledged as one of the most powerful method for creativity, ideation and for solving design and operational problems inventively.

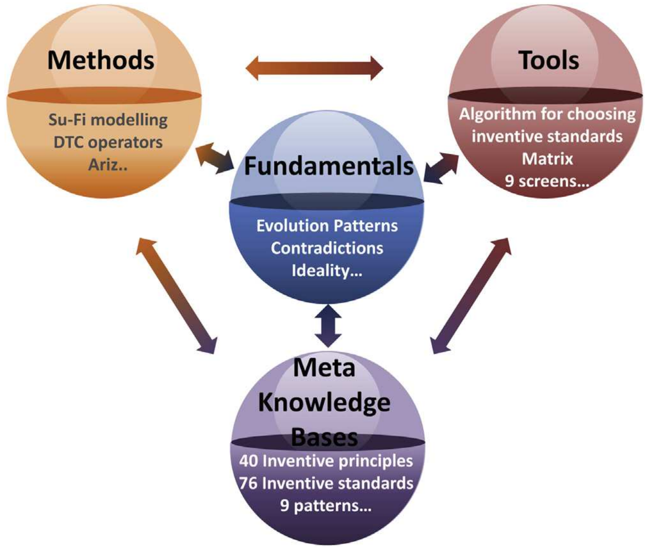

Fig. 3. Overview of TRIZ (Inspired from Cavallucci, 2013).

2.1.1. *TRIZ fundamentals, tools and methods*

Fig. 3 gives an overview of TRIZ. The theory is based on fundamentals that are used, at least one of them, in any TRIZ problem solving process.

2.1.1.1. Contradiction. In TRIZ, the heart of some inventive problems is modeled as a contradiction which arises from the incompatibility between two or more desired features or design parameters. There are two major types of contradiction: technical or physical. A technical contradiction arises when improving one feature of a system will result in worsening another feature. During the analysis of patents, Altshuller identified 39 generic engineering parameters that are commonly used to formulate a technical contradiction: incompatibility between two of the 39 engineering parameters. The technical contradictions are solved with the contradiction matrix (matrix with the 39 engineering parameters that are both on the rows and columns), which is used to extract the most relevant inventive principles among 40 (conceptual solutions) that could be applied to solve it. On the other side, physical contradictions express two inconsistent requirements to the physical condition that may both be desired in the same system. As

(Chechurin and Borgianni, 2016) have underlined, the preponderance of problem solving orientation can be inferred by the popularity of contradiction due to its apparent simplicity. But it is worth noticing that these most popular tools are not the most powerful belonging to TRIZ, as a result one perspective would be to apply these most outstanding tools in the process engineering domain.

2.1.1.2. Ideality. During its development, each system evolves towards ideality: a kind of Holy Grail, i.e. system that maximizes the benefits while at the same time minimizing its costs, energy and substance consumption, and harmful effects. The definition of this ideal final result is crucial because it provides a guideline for researching inventive solutions. It also helps in identifying the optimum resources to use in delivering inventive solutions. Ideality of a system is often expressed with the mathematical formula:

$$\text{Ideality} = \frac{\sum (\text{Benefits} + \text{Useful Functions})}{\sum (\text{Costs} + \text{Harmful Functions})}$$

Where the functions are defined as the activities, actions, processes, operations related to the system. Useful functions include the purpose for which the system was designed (primary function), other useful outputs that the system provides in addition to the primary function (secondary functions), and functions that support or contribute to the execution of the system primary function (auxiliary functions), e.g. control function. Harmful functions gather all harmful factors such as: space occupied by the system, pollution emission, energy consumption, resources needed etc.

2.1.1.3. Patterns of evolution. The evolution patterns are another fundamental; they indicate that technical systems generally follow regularities in their developments. As revealed through patent analysis and other sources describing technological achievement, technological systems evolve according to certain statistically-proven patterns. These eight patterns (or nine it depends of the school of thought) form a common thread to predict how systems would evolve.

In addition to these fundamentals, TRIZ supports the resolution process by proposing methods and tools to analyze problem, to identify the root cause, to model the problem, to formulate and solve the problem and it also gives access to the knowledge bases such as: *the 40 inventive principles, contradiction matrix, patterns of evolution, separation principles, effects database, substance field (Su-Fi) analysis, 76 standard solutions, analyze of resource, nine windows, function analysis, creativity tools, ARIZ algorithm*...

2.1.2. Strengths and weaknesses

For TRIZ non practitioners, the main difficulty lies in the understanding of all the methods and tools due to the level of abstraction required (necessary to maintain transdisciplinary knowledge exchange and especially to fit a large panel of problematic situations but which in return gives a certain rigidity). This understanding often requires some practical experiences before producing effective solutions. This remark explains the popularity of contradictions, inventive principles and the matrix which are the most affordable tools. This required learning time is often incompatible with the current industrial context where the aim is to reduce the time to market. As a result this difficulty of acquisition and/or application results in its seldom used into product and process development practices, in a part of skepticism for some people, but also in an oversimplification of its methods and tools.

To our knowledge, within the TRIZ community the main drawback is the difficulty for TRIZ to tackle complex problem appropriately. Indeed, in classical TRIZ even the most complex situation should be restricted to one and only one problem or to a succession of problems to solve. However it is not always obvious to restrain the problematic situation to its root cause problem, i.e. one contradiction for example. Furthermore, classical TRIZ does not propose method to support the ranking of problem, likewise in the case of several simultaneous sub-problems they must be solved successfully and not globally which is not adequate to ensure a consistent solution.

Another claim is that TRIZ is often seen as an unstructured collection of methods and tools for problem solving and not a unified theory. This is due to the lack of a standardized guide to identify the most appropriate tools for a situation, how the different tools can be and should be linked, and for a specific tool how best to apply it. ARIZ is an attempt for this purpose, unfortunately it is commonly acknowledged that it has failed because of its inherent complexity.

These main identified drawbacks confirm the results presented by (Ilevbare et al., 2013). In their survey they also trace other disadvantages: inordinate time requirements, organizational issues, cultural issues. As a consequence, it is often assumed that TRIZ allows to reach significant results, but just when designers master the theory proficiently. Moreover, despite a large number of industrial successes, the widespread diffusion of TRIZ in the industrial world remains insufficient. To go further, Chechurin and Borgianni (2016) have demonstrated and explained in details that the development of TRIZ had not followed the usual pattern of scientific validation required by engineering methods.

As aforementioned, TRIZ is very powerful for the idea generation phase of the innovation process, because it helps to generate more inventive and qualitative ideas compared to other creativity methods. Because TRIZ refuses compromise it provides real breakthrough solutions and concepts for future development. Furthermore as TRIZ concentrates on the root cause of the problem, identifies it quickly, and relies on meta transdisciplinary knowledge, the inventive resolution of problem is achieved in shorter times. Contrary to other creativity methods which are based on a random exploration of the solution space, TRIZ proposes more structured methods and tools to clarify problems and to find more inventive solutions. The projection into the future thanks to the patterns of evolution is another benefit associated with TRIZ which enables to imagine and forecast how the technologies can evolve. The latest strength, and probably the most primordial regarding the purpose of this article, is the ability of TRIZ to improve effectiveness of teamwork often composed of participants with a very wide range of technical skills and different cultural backgrounds. First, it can be regarded as a carrier of transferable knowledge: all relevant information is condensed in a universal language. It also facilitates the analysis and the sharing of the different visions of the problem. As a consequence, the collaboration is improved because TRIZ eases the knowledge flow and transfer between the team members.

2.1.3. Discussion on TRIZ in PSE

Recently, (Chechurin and Borgianni, 2016) have explored the scientific literature about TRIZ with the aim at achieving a general overview about what is deemed relevant and agreed in the scholarly discussion rather than verifying if specific issues have been tackled. The previous authors have defined clustering criteria concerning the topics discussed in the literature (whatever the scientific domain) and finally they have identified ten separate clusters. Among them, one concerns CAI development which shows a tight connection with TRIZ. Indeed they have highlighted that CAI tries to integrate all the relevant computer based approaches with TRIZ and more than 60% of Scopus indexed papers with the research field CAI contain also TRIZ. A similar conclusion can also be drawn in chemical engineering where the ratio of computerized systems exploiting TRIZ potential can reach 90%. A short review of these tools is proposed in Lopez Flores et al. (2015a). It is worth to underline that the recent contributions on TRIZ in chemical engi-

Table 1
TRIZ application in PSE corresponding to the clusters of (Chechurin and Borgianni, 2016).

Cluster	Reference in PSE
−1- TRIZ diffusion and development	Li et al. (2001, 2002, 2003), Pokhrel et al. (2015), Sigalovsky et al. (2015)
−2- TRIZ in biomimetics	Adams et al. (2009)
−3- Computer Aided Innovation	Chechurin et al., (2015), Lopez Flores et al. 2015a,b)
−4- Studies about the benefits from using TRIZ and its use in practice	Lim et al. (2015), Poppe and Gras (2002)
−5- TRIZ in conceptual design, problem solving and ideation	Abramov et al. (2015), Berdonosov et al. (2015), Rahim et al. (2015) (all the papers of the table could be in this cluster)
−6- Conjoint use of TRIZ and other techniques for engineering design and ideation	Cortes Robles et al. (2009)
−7- TRIZ to support business innovation and to achieve customer satisfaction	Not addressed in process enginering
−8- Sustainable design using TRIZ	Barragan-Ferrer et al. (2012), Samet et al. (2010), Srinivasan and Kraslawski (2006)
−9- Decision making procedures that include TRIZ	Not addressed in process enginering
−10- TRIZ within Information processing and intellectual property	Sitarz and Kraslawski (2012), Sitarz et al. (2012), Valverde et al. (2015)

neering are in accordance with the general trends and the clusters previously identified as documented in Table 1.

In chemical engineering, TRIZ have started to be applied at the end of the 90′s, but as Kraslawski et al. (2015) have underlined while processing industries commonly use TRIZ, the chemical and process engineering journals have rarely published papers on TRIZ, and more generally dealing with methods for supporting engineering creativity. Both the complexity of problem treated the difficulty to handle TRIZ aforementioned, and the fact that TRIZ is often used for product design and less on process design can explain this difference of use. However, recently, more contributions in the chemical engineering domain appear with for example the special issue on inventive design and systematic engineering creativity (Kraslawski et al., 2015). The use of TRIZ in the process engineering for design activities covers the direct use of its tools on case studies (clusters 1, 3, 4 and 5 of Table 1), and the tuning of TRIZ to the requirements of the chemical engineering domain to improve TRIZ capabilities (clusters 2, 3, 6, 8 and 10 of Table 1). The oldest contributions have introduced TRIZ and have claimed its potential usefulness and benefits for design. Concerning further development, to our knowledge in the chemical engineering domain there is no article that deals with the development of the classical TRIZ and its toolkit. Furthermore, there is no study to expand or redefine the classical TRIZ methods and tools: new evolution laws, inventive principles. . . The attempts are more focused on the tuning of some tools such as the contradiction matrix or the inventive principles adapted to the process engineering in general (Pokhrel et al., 2015) or in specific sub-domains in particular (Li et al., 2001, 2002, 2003). But the counterpart in this domain specific tuning is that it limits the effectiveness of the method and especially leads to solution with a low level of inventiveness. However, concerning the papers of Table 1, the following general conclusions can be drawn: TRIZ is relevant and well suited for analyzing and solving problem in chemical engineering also confirmed by (Abramov et al., 2015), the increasing number of papers dealing with TRIZ in the last years reflects a growth demand for innovations, and TRIZ tools are most useful to innovate on technological devices.

As a result, in PSE, recent papers (cluster 3 and some papers of cluster 1) try to integrate the relevant computer based approach with TRIZ capabilities to create the first generation of CAI or to develop platforms that support the use of TRIZ. This is one way to foster TRIZ dissemination. But TRIZ alone is often not sufficient, thus, a new trend appears with the conjoint use of TRIZ and other techniques for engineering design and ideation. Indeed one of the first studies has hybridized TRIZ with Case Based Reasoning (CBR) (Cortes Robles et al., 2009) to accelerate the inventive design process on the one hand and to raise the level of inventiveness on the other hand. Rahim et al. (2015) have included strategic TRIZ tools in a framework for solving problem and forecasting in product development. Chechurin et al. (2015) have proposed an invention support software using function modeling, mathematical modelling and TRIZ and have demonstrated its capabilities on a cooling system of a chemical reactor. In the context of this article, Sigalovsky et al. (2015) have demonstrated how one of the main TRIZ tools, functional approach, can increase the effectiveness of open innovation with an application on centrifugal slurry pumps used under difficult conditions.

Whereas the number of annual contributions increases each year, it remains a limited industrial adoption. This is mainly due to the drawbacks aforementioned, i.e. its difficulty to tackle complex problems, extensive understanding required, lack of TRIZ standard to identify the most proper methods and tools to apply to a given problem. But another way to foster TRIZ dissemination is through the ontology proposed by (Zanni-Merk et al., 2011). As ontology can be seen as a mean to describe a domain of interest and a specification of the meaning of terms, it would be interesting to match the TRIZ ontology with domain ontology to find correspondences between semantically related entities. Ontology matching allows knowledge and data of different domain to interoperate. In the case of CAI dedicated to process engineering, the previous TRIZ ontology could be matched with Ontocape (Morbach et al., 2009) for example. Another possibility is to propose effective software application for inventive design where TRIZ is seen as a reference theory. In the context of the FoF, this is particularly true and especially due to the collaborative dimension required, and because TRIZ is well suited for that, as discussed into the following subsections.

2.2. *Open innovation: a new paradigm for innovation*

In their innovation process companies are looking for an increase of their innovation capabilities, a shorter time to market but also to minimize the risks by pooling them. In the current context where the budgets related to innovation are reduced, the importance of the previous requirements is increased. As innovation is not limited of one isolated intelligence (but instead it is the result of a multidisciplinary workgroup), the innovation process must evolve from a closed model to a more open approach that includes actor and knowledge beyond the enterprise boundaries. As a consequence, open innovation appears as a suitable solution as it will allow to multiply and leverage the ideas and also to add agility in the process of innovation.

2.2.1. *Open innovation*

Open innovation is a process of interaction between the company and its environment in order to achieve a broader spectrum of knowledge, skills, ideas and solutions. An organization adopts the open innovation paradigm when: (i) it goes beyond its boundaries to search ideas or expertise, to improve its own skills and to enhance its innovation capabilities (outside in or inbound modality), (ii) it proposes its own expertise or patents (inside out or outbound modality). For example the pharmaceutical company Pierre Fabre opens its plant library with the goal to give the opportunity to scientific actors (biotechs, pharmaceutical and food companies, academic labs, and startup) to discover innovative natural products. As a result in open innovation it is also possible to distinguish:

- the scouting: to search one existing solution to a problem, or conversely to identify new applications to one technology outside the cultural, geographical, scientific or technical boundaries.
- the crowdsourcing: to seek a more or less wide community to harvest new ideas and solutions.

In addition to the company restructuration and the redesign of its innovation process, and among the keys to success for the implementation of open innovation, the technological and the numerical aspects are primordial. The nature of the technical requirement and its formulation must be shared and clearly understood by the community. Indeed, a real complex problem must be reformulated at a higher level of abstraction in order to be focused on its root cause, but also to extract it from its technical field of appearance to withdraw any connotation that could guide the solution providers in a wrong way. The purpose is to reach the ultimate degree of the open innovation which consists in identifying a solution beyond the technical boundaries by working with a company or people with skills in another industrial sector, and for which we find common problems. The identification of these common problems requests to disregard the technical field thank to a neutral modeling as the theory TRIZ does, for example with the triplet "System-Principal Useful Function-Object" and with the four main components of a system (Engine, Transmission, Working Unit and Control Unit).

Concerning the numerical aspect, numerous tools are available to support open innovation and particularly to facilitate exchanges between community members but with different purposes: (i) tools for creativity to generate, select and develop ideas relying on company's collaborators, (ii) open modeling and simulation platforms to validate the concept, (iii) platforms to make available experts or companies, (iv) inside the company social networks or collaborative platforms... Whatever the purpose, open innovation has a collaborative dimension that allows to a company to enlarge its development field to bring out, to decide and/or to realize innovation projects jointly. As a consequence collaboration is a central issue in open innovation.

2.2.2. Collaboration in open innovation

By definition, open innovation is based on a collaborative approach. For example for a firm, exchanges with its innovation ecosystem must be continuous throughout the innovation process either for the strategic and operational management of the process. At the strategic level, it is to manage projects by exploring the ideas and decide which ones will be selected to start the innovation project. Collaboration can be found in different stages such as exploitation, evaluation and decision. For the former, it is to identify potential actors, to organize and to build a community in order to redefine the needs and uses of the system with all stakeholders. The assessment phase focuses more specifically on opportunities for partnerships and the opening degree of innovation (completely open or smaller community controlled by the stakeholder) but also to identify the skills and contributions of each partner. Finally in the decision stage, it is possible to rely on the wisdom of the community to decide the innovation project to launch and what may be essential for success. However, giving away the control of project assessment can lead to a complex situation, particularly when the top-ranked projects are in contradiction with the strategies of the company.

At the operational level, open innovation can be applied to all the stages from problem investigation to solution development. Thus, we must find means to have a shared vision of the problem, focusing on the main root causes while ensuring certain neutrality with respect to the domain of occurrence of the problem, to increase the scope of possibilities and to avoid focusing on a specific scientific or technical field. It is also to execute the entire ideas management process from ideas generation to ideas evaluation. This level also needs to be linked to the detailed design. Finally this level must also integrate a knowledge capitalization phase because the numerous information and data generated during the various stages can be reusable for other future problem solving episodes in order to gain in development time.

For all these stages of the innovation process, it is crucial to implement methodologies and collaboration tools to overcome the constraints of space and time associated with open innovation. Due to the collective dimension and the will to break down barriers of the company (cultural, geographical, scientific or technical), it is interesting to study the contribution of information and communication technologies as tools to support the open innovation process. The cornerstone is the capacity to exploit the users' contributions. Nowadays, the ecosystem of participation in the Web 2.0 enables the emergence of surprising new forms of collaboration and collective intelligence.

2.2.3. Web 2.0

As the main objective of our proposal is to provide a computer aided tool to support open innovation, it must gather elements and methods for ideation (generation of inventive ideas), providing structured approach to problem analysis and problem solving, and harnessing the benefits of the collective effort of individual intelligences. In addition, such tool must propose a high degree of interactivity, connectivity and sharing. The Web 2.0 as a technological driver leads to implement, and to take advantage of collaborative workspaces. Indeed, the Web 2.0 technology supports an emerging form of collaboration that can be beneficial for open innovation, based on the many-to-many form of communication. Web technologies offer new possible ways to communicate and share information; from the use of the e-mail up to the incorporation of the "architecture of participation". Build on the Web 2.0 technologies, Social Network Services create new forms of communication, interaction, information sharing and collaboration by impelling the creation of relationships between community members. For (Caseau, 2011), there is an emerging way to organize collaborative work in the industry, leading to what is known as "Enterprise 2.0" or even to extend it to Enterprise 3.0 as proposed by (Carbone et al., 2012) in order to increase collaboration and interoperability.

Profiles diversity in collaboration environments is another element to take into account in the creativity driver. Indeed, to have an efficient collaboration, the community must gather members with various domains of expertise, consequently, it is important to bridge the gap between their different backgrounds. While TRIZ is an appropriate tool for reconciling concrete and abstract visions of the problem and to facilitate exchanges, these exchanges between the community members can also be improved by incorporating semantic web technology. Indeed it can give a meaning and a semantic contextualization to the contents in order to have a computer readable and reusable representation of contents which can help to create interaction, relation and to ensure continuous information and knowledge flows between community members.

3. Computer aided innovation 2.0

Open CAI 2.0 is based on the combination between an open model to manage the innovation process and the advantages provided by the advances in Web technologies. Hüsig and Kohn (2011) have defined the Open CAI 2.0 concept as "*a category of CAI-tools that use technologies following the Web 2.0 paradigm to facilitate open innovation methods in order to open access of organizations to a large audience of external actors and enable them to interact in different activities*". It is expected that the implementation of the open innovation paradigm will be supported by the use of CAI methods and tools; consequently, it is necessary to use new information technologies and computational methods. With Open CAI 2.0, it is possible to develop a platform that facilitates the sharing of problems, problem investigation, problem formulation, ideation, idea analysis, idea evaluation and knowledge transfer between different domains, thereby leading to deeper collaboration. However, the use of new information technologies is not only a matter of integrating information technologies; the in-depth focalization on the outgoing of methodologies and concepts for supporting innovation teams more effectively and efficiently is also indispensable (Leon 2009). Consequently, the challenge is also to develop new theoretical methodology frameworks to integrate the new requirements of open innovation.

3.1. Conceptual framework

Build on the idea that it is possible to overcome the randomness in the problem resolution process while using the collective intelligence; this work proposes a framework to develop creativity following a systematic approach. The conceptual elements of our proposition for an Open CAI 2.0 solution can be decomposed into three dimensions, namely; the creative dimension, the knowledge management dimension and the collective intelligence dimension. Each conceptual element requires specific theoretical development. For example in the creative dimension, new methods and tools are proposed to support problem analysis, problem reformulation with the extension of TRIZ (details are given in Section 3.4), but also we have to implement a collaboration support to impel ideation. Thus the conceptual and theoretical elements must be organized and linked with the goal to configure a flexible conceptual framework, i.e. the previous elements can be easily replaced or the configuration can be easily scaled. As a result, the core elements of each dimension are organized into three levels depicted in Fig. 4., namely (from the upper to the lower level):

- Collective intelligence: based on the work of (Geiger et al., 2011), we identifie a sequence of three important steps to implement a crowdsourcing process: crowdsourcing configuration, accessibility of peer contributions, and aggregation of contributions. The capacity to gather the resulting intelligence from the collective effort requires also techniques and practices related to Web 2.0 application in order to improve the innovation process. Among the practices, the framework includes the implementation of rating, tagging and building user profiles to extract the tacit knowledge that arises from the user's interaction.
- Collaboration support: this level gives the four basic operations for the organization of activities to support collaboration: i) preselection of the community members (with a created tool based on the graph theory to analyze networks of documents, e.g. patents, to extract and qualify the expertise of potential members); ii) coordination of users' activities by defining the collaboration pattern in terms of rules (work rules, norms, constraints), of times (synchronous, asynchronous, multi synchronous) and space (locally, distributed); iii) organization of the collaboration, i.e. centralized, decentralized or distributed; and iv) control processes to ensure integrity. The control is performed through the mutual exclusion pattern.
- Innovation process: it starts when a new problem is faced in a voluntarily sought evolution of a system, or when a new idea of evolution emerges but its practical implementation faces a technological lock. Then, the problem is formulated using the TRIZ concepts (Contradiction, Su-Fi Analysis etc.). This level encompasses the following elements to assist the community members in the process of inventive problem resolution: problem description and analysis, problem formulation, and the hybrid TRIZ-CBR (merely presented in part 3.4) method for searching solution concepts, solution proposition(s).

In this work, the new information and communication technologies are also considered as enabler for virtual collaboration. In the next sections are presented the details about the integration of the core components to develop a collaborative application in order to implement collective intelligence techniques.

3.2. Collective intelligence

The use of purposive inflows of knowledge in the phase of conceptual design makes necessary the incorporation of new technologies to enable the interaction between different sources during innovation activities. Collaborative technologies facilitate the aggregation of multiple intelligences for the search of new ideas and innovative solutions. According to (Zara, 2012), the challenge of collective intelligence and knowledge management is how to improve the collective efforts in order to be better than individual efforts. Zara (2012) defines collective intelligence as "*the capacity to join intelligence and knowledge to achieve a common objective*". The study on the intelligence emerging from community of people is not recent, but it has received special attention with the raise of the digital company and more particularly with Web 2.0 applications (Leimeister, 2010). The Web 2.0 helps to improve and optimize the potential of the collective intelligence due to its architecture centered on the user participation while simultaneously enhances connectivity (Adebanjo and Michaelides, 2010). The use of the Web 2.0 technology for collaboration in innovation activities is not directly correlated with an implementation of collective intelligence. However, the opportunities related to Web 2.0 applications (e.g. recommendation system, user review, user profile, tagging) promote and increase the possibilities to harness the collective intelligence in a collaborative application (Alag, 2008; O'Reilly, 2006). The application should aggregate the content in models, and the aggregation allows learning from users contributions. Finally, the user rates or recommends relevant content. According to (Alag, 2008) this architecture is useful to get three forms of intelligence: explicit, implicit, and derived. The cornerstone of applications is the capacity to exploit the users' contributions.

While in literature the terms collective intelligence, crowdsourcing and brokering services are often used as synonyms, there are some minimal differences. Collective intelligence is presented by (Alag, 2008) as a research field that groups scientists from different domains to create software solutions that benefits from the "network effect": they get better the more people use them. Crowdsourcing is a form of service that makes use of the collective intelligence for completing a task (Yankelevich and Volkov, 2013), in this sense crowdsourcing is a mechanism to implement collective intelligence (Rouse, 2010) and more specifically the Open Innovation process (Enkel et al., 2009). Finally, the broker is the technological element that makes the link between an innovation-seeker and the community that provides solutions (Nunez and Perez, 2007). Despite the limitation in the operation model of crowdsourcing services, different companies are using collective intelligence to solve problems, but the lack of systematization

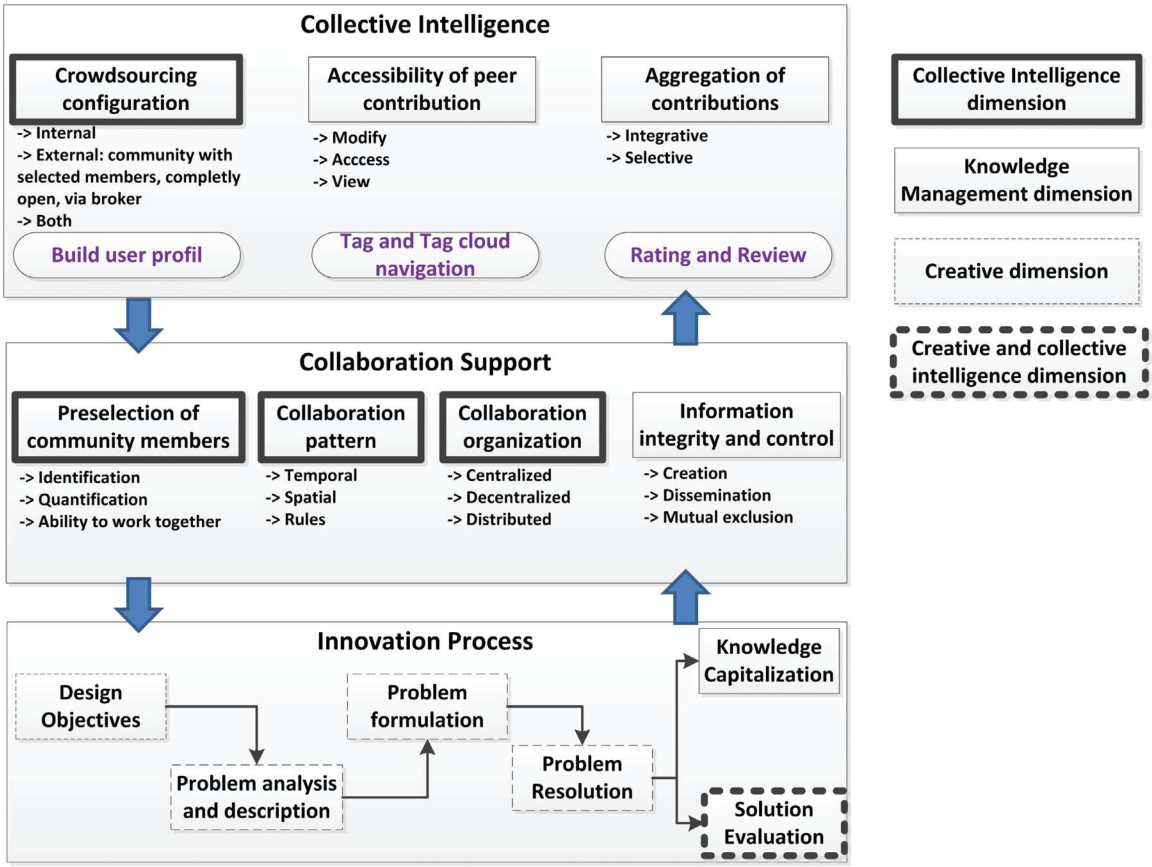

Fig. 4. Conceptual framework.

makes the use of collective intelligence an unpredicted process (Georgi and Jung, 2012). Currently, the innovation process in existing platforms that gather the collective intelligence is chaotic and not structured. For (Majchrzak and Malhotra, 2013) the problems with existing architectures of participation are: minimal collaboration, minimal feedback on idea evolution, and isolated efforts to develop new ideas. Consequently, an organization is required to aggregate the collective intelligence to complete, improve and implement an idea that seems innovative (Christofol et al., 2004).

In a distributed architecture for collaboration, participants can express their creativity in a more open way. Nevertheless, if not handle correctly, there is a risk of losing the produced information and knowledge. Fig. 5 details the nesting of these three concepts and their place in the Open Innovation practice. To operate the human creative effort in a community in combination with the power of computer algorithms we introduce the algorithms and techniques currently used to develop the collective intelligence concept in Web 2.0 based solutions. These algorithms are oriented to self-organized communities for organizing collaboration for an Open CAI 2.0 solution. The choice for the collective intelligence functions is performed by taking into account that most of the user-generated content is unstructured information. In the architecture of participation, it is possible to combine this user-generated content with sophisticated algorithms to exploit explicit and implicit information, such as Tag and tag cloud navigation, Building user profiles, Harness external content, and Review. They are classified, but not limited to, as techniques to gather data for intelligence in web applications according to (Alag, 2008). The use of collective intelligence for inventive problem solving in the context of an open CAI is detailed in (Lopez Flores et al., 2015b).

3.3. *Collaboration process*

The goal of the collaboration process is to facilitate the participation of different actors in the activities related to reach a common objective, e.g. solving an inventive problem, designing a new product or process. Whatever the purpose of collaboration, the generic model for conducting collaboration activities must gather the following crucial elements: (i) identification of the situation that requires collaboration; (ii) identification of members to form a collaboration team; (iii) collect, process and analyze information and knowledge; and (iv) give the tools and patterns to support the collaboration process.

In our approach the collaboration activities are centered around the TRIZ-CBR process in order to propose a collaborative resolution process based on a systematic approach. The operation of the collaborative resolution process is introduced in Fig. 6. The rationale of the collaborative resolution process consists in orienting the interactions of the involved participants in such process with a common language to communicate the problem formulation (Ilevbare et al., 2013), specifically the logic approach of TRIZ.

The description of the operation of this approach is such as:

I Following the generic collaboration model specification, the first activity –identification of a situation- corresponds to the description of the problematic situation.

II The stakeholder invites other participants, it is highly recommended to have at least the participation of one TRIZ practitioner. The main challenge of this part is how to create this community with relevant skills for the problem at hand? Collaborators discovering through documents such as research articles or patents appear relevant because they contain scien-

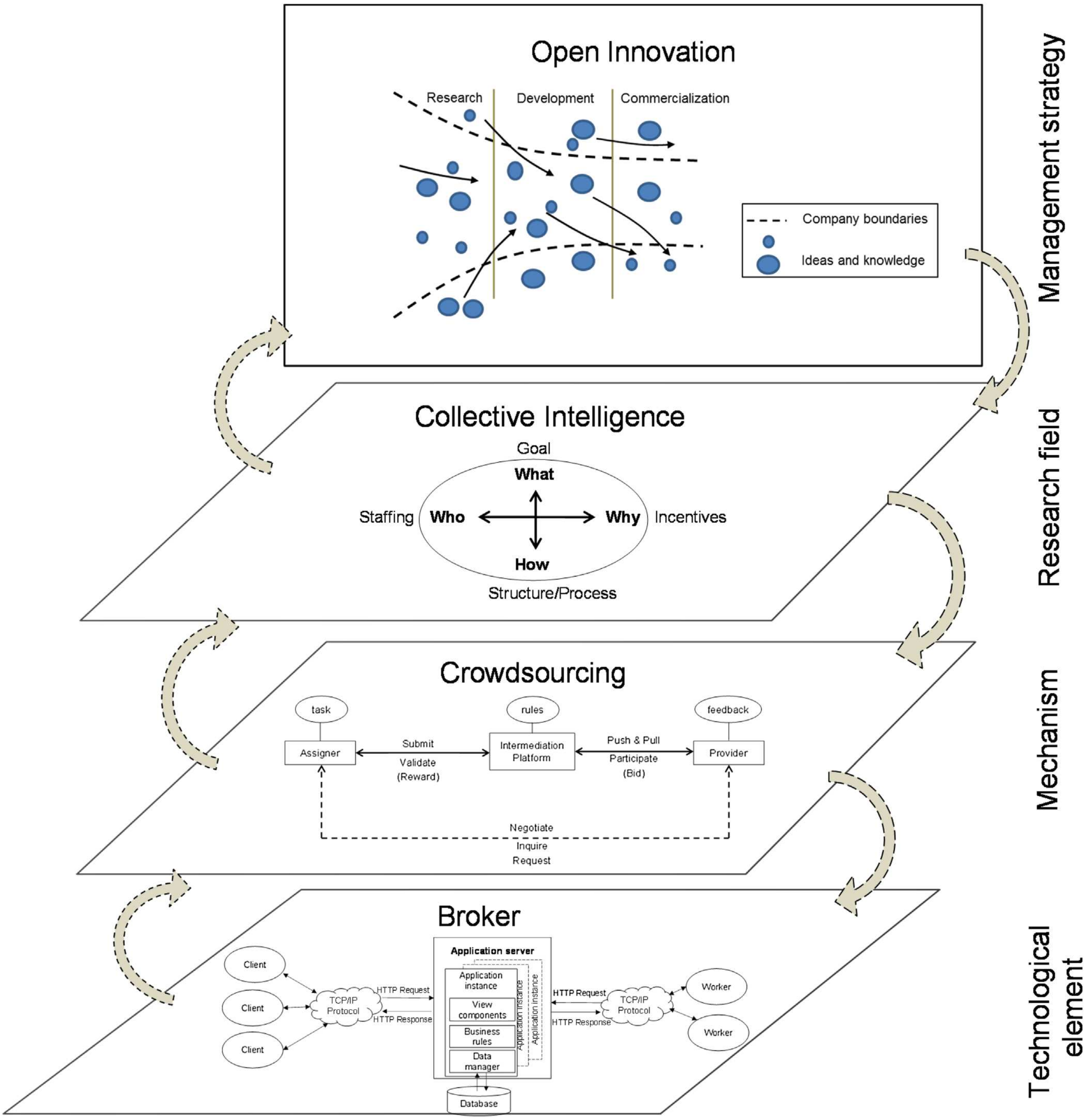

Fig. 5. Implementation of collective intelligence in open innovation.

tific knowledge and information also useful for point III. For documents analysis, the network analysis, a branch of graph theory, provides intuitive methods to link under the form of a network and to analyze them. As the importance of a document is not limited to its number of links (citation or cocitation) with other documents, the network analysis offers different mathematical indicators for assessing the importance of a document in a graph such as closeness centrality, betweenness centrality, and eigenvector centrality etc. Furthermore, the documents network is not the only significant network to analyze. For instance, the inventors network is also relevant for community creation to identify whether some inventors used to work together or whether they had previously exchanged some knowledge in the past. In (Lopez Flores et al., 2015a), the potential collaborator discovering workflow based on patents network is detailed.

III Collect relevant information helps to provide details to clarify the problematic situation.

IV The collaboration process uses an asynchronous pattern to coordinate the participations in order to ensure information integrity. In this phase, it is the TRIZ-CBR model which drives the collaboration activities. With ICT evolution, new forms of collaboration have emerged through the phenomenon known as the network effect. Moreover, these technologies provide the network services to join, create social links, search for specific user, and share information and objectives and to divide the work in a virtual community. In addition, social network services are

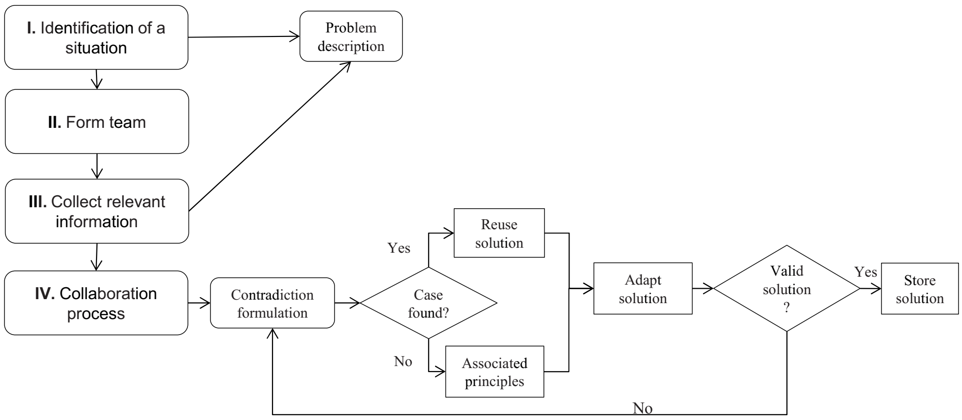

Fig. 6. Collaborative resolution process.

an emerging way of organizing collaboration in the industry, leading to what is known as Enterprise 3.0.

The best way to create the so-called "weak-links" and promote the emergence of a collective intelligence behavior is having a distributed architecture between the participants. In the case of this framework, stakeholder selects the participants involved in the collaboration activities. But it is possible to share the problem with the a completely open community via an open-call, as crowdsourcing platforms work.

3.4. *Inventive problem resolution method and knowledge management*

The two crucial steps on the resolution process illustrated on Fig. 6 are the "Contradiction formulation" and "case found?". Consequently, the proposition of a framework for the problem definition and for knowledge acquisition and reuse, is the key cornerstone for this issue. Because of the high abstract level of TRIZ as it is based on meta knowledge on the one side, and due to open innovation foundations where the amount of knowledge to manage is sharply increasing on the other side, we have proposed a method to improve the efficiency and quality of the ideas generated, and to organize domain knowledge to assist users in formulating and solving of problems. This method relies on a previous work on the synergy between TRIZ and a knowledge management approach, i.e. CBR (Cortes Robles et al., 2009). To deeper exploit this effective hybridization, the proposed method was improved with two major evolutions: reduction of the abstraction level (Negny et al., 2012) and consideration of the environmental aspect for technological eco-innovation (Barragan-Ferrer et al., 2012). As a result a more structured knowledge driven environment is implemented with a three steps workflow as illustrated in Fig. 7. The workflow follows the main classical stages for finding solutions to an inventive problem: problem definition, problem formulation and problem resolution. For each step, some existing methods and tools were adapted to process engineering, and some tools of TRIZ were modified and improved to deal with the increasing technological complexity. The goal of the first step is to share a common vision of the design issue between community members, by establishing the objectives, requirements, constraints and bottlenecks. In the second step, we try to establish a shared formulation of the encountered problem. Finally, last step is dedicated to idea generation by solving the problem using the TRIZ Case Based Reasoning method and to idea ranking to identify the best ideas based on the wisdom of the community.

The key feature of the open innovation paradigm is that knowledge must be exploited in a collaborative way, flowing not only inside the company, but also among external collaborators. During collaboration the community members exchange a large amount of knowledge that must be stored and exploited. But, we must be able to distinguish between specific knowledge only valid for the problem under studied and the general knowledge that can be transferred to other solving episode. Of course the former must be stored for a future reused and to improve the TRIZ-CBR system skills. From the knowledge management point of view, the goal is to improve the knowledge elicitation during the three steps of the resolution method. Elicitation allows to formulate the expert reasoning in an inference engine, thus giving the possibility to reproduce the situation analysis and the decision making by focusing on the useful knowledge. In knowledge management, the goal of elicitation is to help the expert to formalize his knowledge in order to save and share it. Another important objective is to evaluate the quality and usefulness of the acquired knowledge in order to increase the skills of the system. Thus, in our TRIZ-CBR method the traditional CBR cycle was transformed to introduce flexibility and agility necessary to manage the large amount of knowledge. An interactive process with the expert is added in the reuse step (where the knowledge exchanges are tremendous) through an additional loop to create online knowledge acquisition. Furthermore, in our knowledge based system, we assume that the knowledge can be decomposed into a finite number of elementary knowledge containers. This allows to formulate knowledge and to have an accurate and sharp description of the knowledge added. For each single container, it will be possible to enclose comments to explain it, and thus to add confidence to the knowledge acquired. Besides it would be easier to distinguish specific knowledge to general one. This distinction enables to facilitate knowledge maintenance. The details of the classical CBR cycle modification with the new loop and the knowledge decomposition can be read in (Roldan Reyes et al., 2015).

3.5. *Human machine interaction*

The emergence of social networks services has changed the way people interact through virtual spaces. Indeed, the immediacy and feedback capabilities offered by new technologies allow also to improve information exchange through a friendly and easy visual interface. This structure must have a functional design focused on facilitating collaborative means and ideation, but also to be adapted to any potential user. On the first screen of the interface the principal sections including the elements and tools to promote collaboration and communication are directly accessible. The hier-

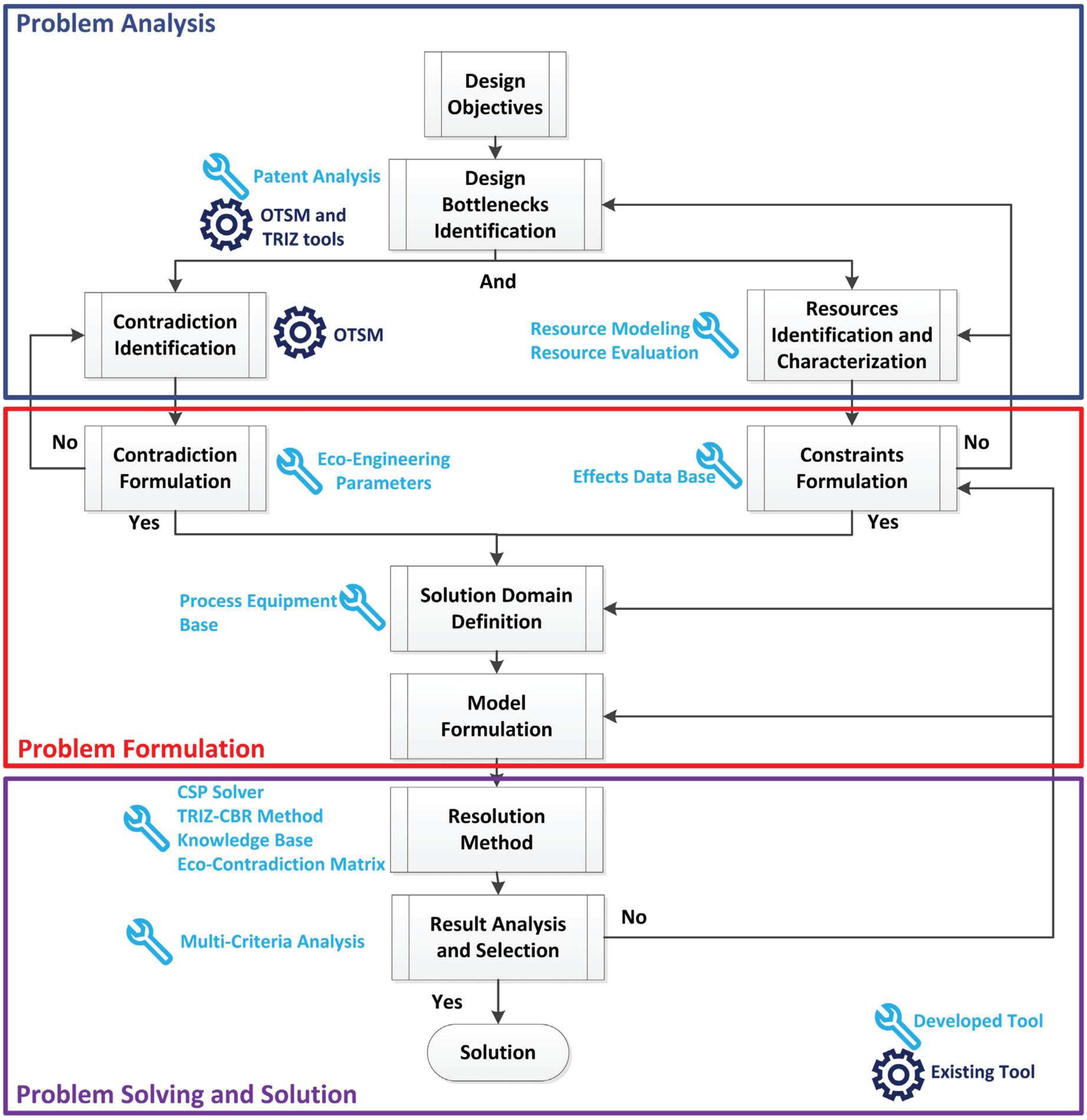

Fig. 7. Workflow for the inventive problem resolution method.

archy of all the elements was determined to provide the structure needed by the users in order to understand the system functionalities in an organized environment. This system design allows the user to access all content on the first screen and also presents all the components arranged according its nature. For examples the community members have access to the following sections:

- My projects: space with the option to create, edit or modify the projects that include the problems to solve.
- Collaborations: space where the user accesses to its current projects and communities.
- Latest updates: space specifying the last updates on collaborations or in projects in which the user has hand in.
- Information exchange components: These components enable the information exchange and the knowledge flow at different levels. These components facilitate the collaborative practices by affording the possibility for each user to understand the proposals and contributions from the other members within the team or the community. The components that compose this section are mainly composed of statistics and instant messaging that offers real-time text transmission.
- Workspace: Space where the user accesses to all the information related to a project and the resolution process. It includes a marker of progress and indicators on the current section the user is working on.
- Components to reduce communication errors: These components allow users to make contributions in all the phases of the resolution process. The components interacting in this section are the tags and online comments.

4. Case study

4.1. Presentation

Biomass is the resulting photosynthesis derived from the reaction between CO_2, air, water and sunlight to produce carbohydrates. The chemical bonds of structural components of biomass store the solar energy. According to (McKendry, 2002), the value of a particular type of biomass depends on these chemical bonds. Common sources for biomass are woody and herbaceous species with the following properties:

- Moisture content (intrinsic and extrinsic).
- Calorific value.
- Proportions of fixed carbon and volatiles.
- Ash/residue content.
- Alkali metal content.
- Cellulose/lignin ratio.

Biomass gasification involves three principal thermochemical conversions: combustion, pyrolysis and gasification. For thermochemical reactors design, the configuration depends on the type of transport of feedstock through the reactor; whereas two mainly configurations exist: fixed and fluidized bed (Warnecke, 2000). Hereafter, in this work the case study focuses on the fluidized bed process because it has good heat and material transfer, as well as the capacity to tolerate wide variations on fuel quality. Specifically, the study is about the circulating fluidized bed process. This process is composed of a gasification chamber, a combustion chamber, an upper and lower stream between both chambers, and outlet stream in the combustion chamber to withdraw the combustion gases, and an outlet stream in the gasification chamber for the produced syngas. The dried biomass is fed in the lower part of the gasification chamber and then flows to the combustion chamber. In the combustion chamber gases produced by pyrolysis react with oxygen to produce CO_2 and H_2O with an exothermic reaction. This energy is transferred (through the upper stream) in gasification chamber where the biomass is converted in solid residues (char) and the previous compounds react to produce syngas and tars with an endothermic reaction.

The three major drawbacks of circulating fluidized bed reactors for biomass gasification are: (i) the production of ashes and tars in the outflow syngas, (ii) low heat recovery, and (iii) difficulty to operate with different biomass moistures. The first weakness was treated in the work of (Barragan-Ferrer et al., 2012). The goal of this case study is to find a technical solution to remove the two previous drawbacks. As a consequence the two main design objectives are: to improve the thermal performance by improving the heat recovery and to facilitate the operation of this unit by treating biomass with moisture greater than 20%.

In traditional gasifier, the heat recovery between the combustion chamber (exothermic) and the gasification chamber (endothermic) is ensured by solid grains media (due to the high temperature reached in both chambers), i.e. solid olivine (as a consequence the process also contains a cyclone to eliminate solid olivine in the outlet stream). To reduce the temperature difference between chambers and to optimize the heat recovery, both chambers and the canalizations must be insulated to improve the heat transfer through the solid flow. In a first configuration, the combustion chamber can be directly in contact (common wall) with the gasification chamber to improve the heat transfer by thermal conduction. Concerning biomass moisture, depending on the biomass source a drying pretreatment can be added in the process to reach the operating threshold for moisture.

Furthermore this process is subjected to several constraints on the level of temperature. First for security reason, the temperature in the drying operation does not exceed 150 °C to avoid risk of ignition of the biomass. There are also operational limits to the temperature in both chambers. In the gasification chamber the temperature is constrained due to a balance between heat exchanged with the combustion chamber, the endothermic reaction and with heat loses. Besides the temperature of the combustion chamber cannot be upper than 1000 °C in order to not reach the melting point of ashes and also for economical reason. Indeed increasing the temperature means a greater consumption of biomass in this operation and as a result a lower production of syngas and consequently a decrease of the cash return of the process.

Table 2
Biomass sources properties (McKendry, 2002).

Biomass	Moisture (%)	VM (%)	FC (%)	Ash (%)	LHV (MJ/kg)
Wood	20	82	17	1	18.6
Wheat straw	16	59	21	4	17.3
Barley straw	30	46	18	6	16.1
Lignite	34	29	31	6	26.8
Bituminous coal	11	35	45	9	34

Regarding the moisture, in biomass two contents are observed: intrinsic and extrinsic. The intrinsic moisture is the moisture content of the material without the influence of weather effects. The other kind (extrinsic) is observed only under laboratory conditions. According to (McKendry, 2002) the typical intrinsic moisture contents of different biomass sources are listed in Table 2.

For (McKendry, 2002), thermal conversion technologies require raw material with a moisture content lower than 50%. As observed in previous table, biomass sources have different intrinsic moisture contents. Therefore, the gasification process needs to adapt to the different moisture values. As the problem context has been exposed, the following step is to describe the process of collective resolution used our approach.

4.2. Problem resolution

Once the collaboration support established, i.e. preselection of the community members, collaboration pattern and collaboration organization chosen (not presented here, further details are available in (Lopez Flores et al., 2015a), the next step is to follow the resolution process presented on Fig. 7. In this part, only the crucial phases and sub phases are presented in details. The attention is focused on the input data necessary for the problem analysis, formulation, the resolution and the description of the retained idea.

The methods and tools (developed or existing) illustrated on Fig. 7 afford to have a deep and detailed analysis of each step of the resolution method to reach the following problem features necessary as input information for the resolution. All this information is detailed in Tables 3–5 .

In the created tool, details about problem description, analysis, problem resolution are documented in Graphic User Interfaces (GUI) like the one illustrated in Fig. 8. As observed the different components are organized according to the guidelines for human-computer interactions specifically created to facilitate interactions and information sharing between community members.

Several ideas were generated but only the retained one is presented here. This concept was chosen based on the wisdom of the community members, as they expressed their opinion in a numerical way (this process is detailed in Lopez Flores et al., 2015b), i.e. rating, which is also useful as an input to the algorithms for a recommendation system. This recommendation process takes into account the potential flaw due to self judgement bias; a member could be naturally attracted to give a higher score to his ideas. When the resolution process is deployed, the geometrical effect “Put a system inside another” is one of the preferential ways of solution to explore in order to transform it into a concrete concept. The first direction explored was to increase heat exchange by increasing the gas residence time in the combustion chamber. But this leads to an increase in the size of the apparatus, this is not going in the trend of process intensification. Furthermore, this configuration has two major drawbacks: the enhancement of the size of the combustion chamber increased thermal losses, and the more the residence time is increased, the more the energy flux towards the gasification

Table 3
Project Details.

Project name	Improved design for a fluidized bed gasifier
Design objectives:	To improve heat recovery, and to extend the operating conditions; with biomass moisture greater than 20% in a circulating fluidized bed reactor.
User generated tags	fluidized bed; gasifier; heat recovery; moisture; biomass
System generated tags	biomass gasification; fluidized bed; fluidized bed reactor; combustion chamber; gasification chamber; drying process

Table 4
Problem Analysis.

Problem statement	In its traditional configuration the circulating fluidized bed reactor is composed of a gasification chamber, a combustion chamber, an upper and lower stream between both chambers, and outlet stream in the combustion chamber to withdraw the combustion gases, and an outlet stream in the gasification chamber for the produced syngas. The dried biomass is fed in the lower part of the gasification chamber and then is entrained to the combustion chamber. In the combustion chamber an exothermic reaction transform gases produced by pyrolysis into CO_2 and H_2O. The produced energy is transferred (through the upper stream) in gasification chamber where the biomass is converted into solid residues (char) and the previous compounds react to produce syngas and tars (endothermic reaction). Except the production of ashes and tars, the two major remaining drawbacks of circulating fluidized bed reactors for biomass gasification are: (i) low heat recovery, and (ii) difficulty to operate with different biomass moistures.
Bottlenecks	Low energy efficiency, Operating conditions too restricted not allowing a great variability on the properties of the input biomass
main useful function of the technical system	Biomass gasification to produce syngas
success criteria, to consider the problem is solved	A gasifier increasing energy efficiency, and using the same device to a wide range of biomass without increasing the energy consumption (in the pretreatment stage). Intensified process.
Resources Identification and Characterization	All the substances (such as Biomass, H_2O, CO_2, O_2, Olivine. . .), Physical fields (Thermal, Pressure. . .), Geometrical spaces, Time possibilities (before, during or after the realization of one function). All the resources are characterized in terms of quantity, quality, cost, localization and recyclability.
Constraints formulation	Temperature in combustion chamber cannot be upper than 1000C Drying chamber operation does not exceed 150C to avoid risk of ignition of the biomass

Table 5
Contradiction formulation with TRIZ inventive parameters.

Positive characteristic	Negative characteristic	Associated Inventive Principles
17 Temperature	39 Productivity	- Dynamics - Mechanics substitution - Parameter changes
20 Use of energy by stationary object	39 Productivity	- Segmentation - Universality
22 Loss of energy	17 Temperature	- Periodic action - Strong oxidants - Nested doll
39 Productivity	33 Ease of operation	- Segmentation - Mechanics substitution - Nested doll - Preliminary action
22 Loss of Energy	36 Device Complexity	- Nested doll - Feedback

chamber is reduced. To go further with the proposed principle of solution, the combustion chamber could be inside the gasification chamber to reach a high exchange surface and thus expand the thermal transfer. Always with the idea of energy integration, the gasification chamber could be situated within the storage enclosure in order to value the external thermal loses and to dry the biomass before gasification to reach the accepted maximum moisture. However we must account for the temperature constraint of 150 °C. Because of the high temperature of the gasification chamber compared to the desired temperature, an insulation layer should be interposed between them. As a result the proposed device is similar as nested dolls with successive overlapping of the different chambers. Fig. 9 depicts the previous described elements about the conceptual solution for a new fluidized bed gasifier.

After this stage, the next one will be the proof of concept, with for example the comparison with other technologies and the validation of the phenomenon that could occur in the proposed device. For example in a traditional gasifier, the hydrodynamic and thermal behaviors, and the gas produced are closely related to the first reaction that occurs when the biomass is fed in the fluidized bed: devolatilization. Consequently, a detailed design must be conducted to characterize the new hydrodynamic and thermal conditions and their consequences on the transfer coefficients and thus on the conversion. It is crucial as the devolatilization phenomenon has a strong influence on the local hydrodynamic of the fluidized bed.

4.3. Discussion

The first returns on the method and tool have allowed us to identify the following positives points:

- TRIZ methods and tools must be included in the investigation and resolution method because in the one hand it is well suited to address the previous point and on the other hand it offers a common language to formulate technical problems and facilitates collaboration within a community of problem solvers.
- The use of collaborative technology opens opportunities and provides access to a broad spectrum of sources of knowledge. Consequently our method based on the coupling between TRIZ and the modified CBR cycle enables to store and to easily reuse this large amount of knowledge generated for future problem resolution episodes.
- The expected benefits of open innovation were reached: more constructive exchanges, stave off psychological inertia, accelerate ideas generation, improve the level of inventiveness of ideas generated, and beneficiate of the network effects during collaboration.

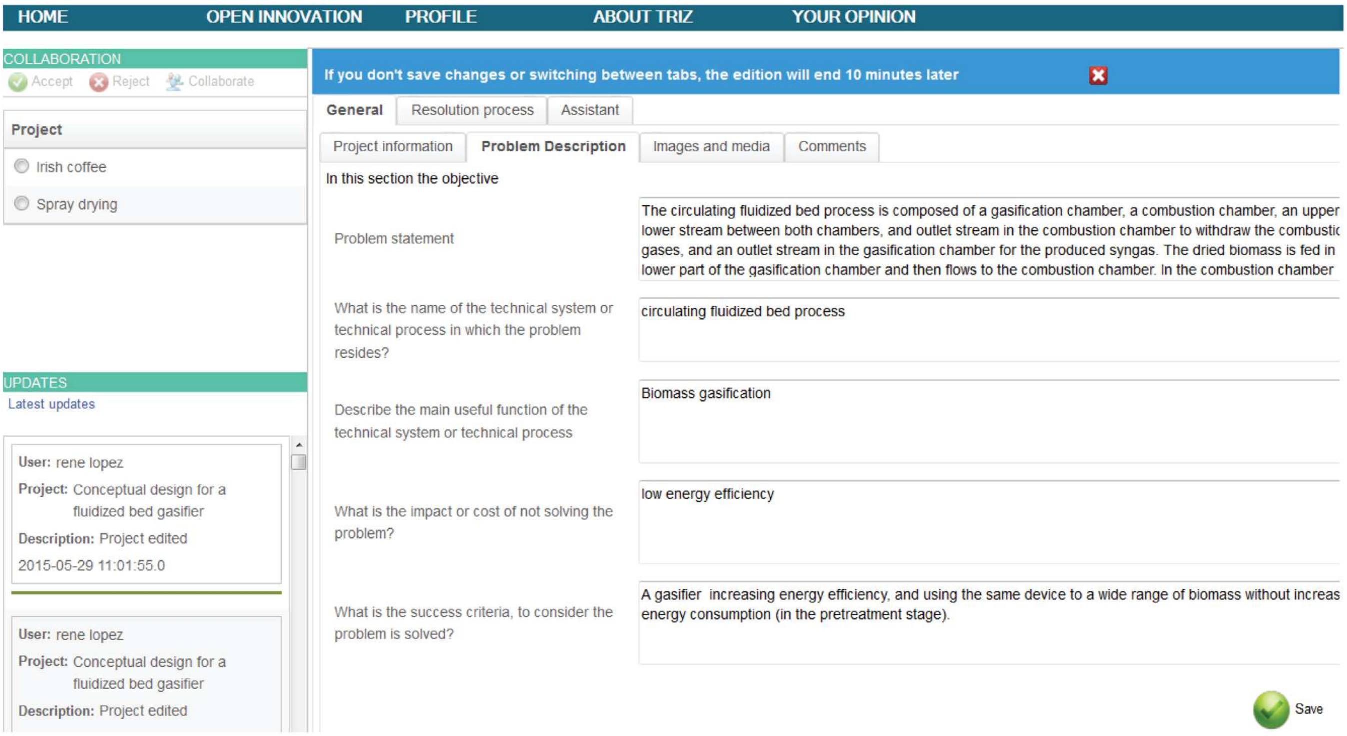

Fig. 8. Problem description GUI.

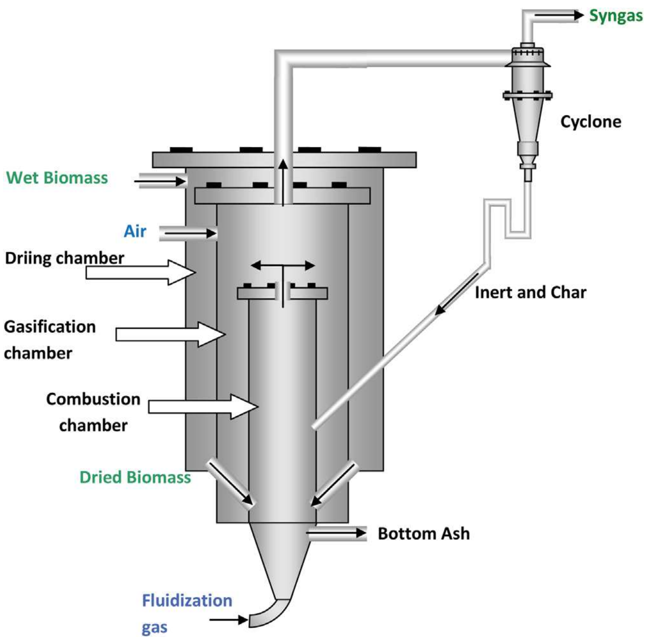

Fig. 9. Technological solution for a new gasifier.

- The social web services provide the technical means to unlock the potential of the collective intelligence, and the creative capabilities of each individual. The benefits of such tools have mainly been seen in the problem formulation and problem resolution steps where the collective intelligence was the most indispensable.

Despite the previous positive aspects, some limitations are also observed:

- The success of collaborative innovation relies mainly on the selection of the community members. Even if the documents analysis enables to identify them, the analysis is not deep enough to identify exactly the skills of each member. Worse, we can not a priori anticipate whether the members of this community will be able to work together and especially deliver to the other members the totality of their skills.
- The huge amount of information raises the question of the knowledge maintenance as the knowledge base grows sharply. Another important question to address is how to combine the knowledge stored to generate new knowledge.
- One bias of our framework is that it assumes that all the community members will fully invest in the joint project, but for industrial project the level of investment of each community member remains a problem because some of them might not reveal all their skills for strategic reasons (e.g. capitalization of their knowledge by another firm). In this condition, the architecture of participation will be in default and the positive effect of the collective intelligence will disappear.
- The two primordial related elements concerning the economic model and the intellectual property are still a not covered issue in our approach.

5. Conclusion

A key feature of the FoF is that it bases its competitiveness nor on the optimization of its processes with the aim to reduce costs but rather on the degree of innovation of its products and processes. As a consequence, companies must rethink their approach to the innovation process, indeed they must go beyond the current model of closed innovation towards a more open model. Open innovation appears as a powerful approach to accelerate, reduce risk and costs of innovation. But open innovation advantages are not fully exploited and implemented because the industry has not developed efficient tool to support this approach. By definition this open innovation relies on collaboration. This collaboration dedicated to the inventive design should enable a community, composed of people with a very broad spectrum of skills, to share information, knowledge and ideas around a common design project. Another significant bottleneck is to develop a method supporting systematic engineering creativity in chemical and process engineering. In this context, the process system engineering community has to propose new methods and new computer aided tools that integrate all previous aspects. This is the main contribution of this paper to address these situations and to propose the next evolution stage of the Computer Aided Innovation, i.e. the Open CAI 2.0. Relying on the research leading to the proposed Open CAI 2.0 tool, the following conclusions can be drawn:

- Open innovation provides several advantages, among them: the possibility to deal with complex and broad problem, to enlarge the spectrum of knowledge, to increase the quality of the solution, to accelerate the ideation steps, to find solutions outside the field of expertise of the company.
- Collective intelligence with its capacity to join intelligence and knowledge to achieve a common goal is a powerful enabler for efficient collaboration.
- The raise of the digital company and more particularly the breakthroughs in information and communication technologies help to extend and improve the potential of collective intelligence by facilitating, exploiting and managing more efficiently user's contributions. This is performed by taking advantage of the benefits of on line social networks.
- TRIZ methods and tools are well suited for analyzing and formulating problem in chemical engineering and in remote domains, but also to generate solutions with a high degree of inventiveness. Furthermore, it can be regarded as a universal language to promote collaboration (improve knowledge exchange and transfer) between community members and for the implementation of an ideation stage.
- For improving the problem solving stage and with the purpose for rapidly generating innovative ideas, TRIZ must be combined other problem resolution methods like case based reasoning in our case. The method based on the hybridization of both previous methods exploits a knowledge base of past experiences, offers the possibility to create new knowledge, and it facilitates the transfer of technological solutions while avoiding some pitfalls thanks to information on the implemented solution.

Obviously, the first perspectives for this proposition are to improve methods and tools that compose the three levels of the methodological framework, namely the innovation process, the collaboration support, and the collective intelligence. As an example, we intend to develop missing functionality about collective intelligence. It is possible to incorporate tag clouds, this component would help the user to make a rapid search using the tags concepts generated manually or the process for tags extraction.

The effectiveness of the ideation phase remains perfectible by the improvement of the methods and tools which could ease the collaboration, information and knowledge exchange between people with very different technical and none technical backgrounds, the acceleration of the generation of very inventive ideas in a context increasingly constrained (especially in time). An interesting way to explore could be the coupling between TRIZ and the CK method recently introduced in chemical engineering by (Potier et al., 2015). Likewise, to valorize all the knowledge acquired, it is crucial to consider the peculiarities of these heterogeneous, requiring prompt treatment and big data. The challenge is to transform this raw information into knowledge with high added value for rapidly generating concepts with better quality.

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