Open computer aided innovation to promote innovation in process engineering

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A B S T R A C T

Recent advances in theoretical approaches to innovation and in information and communication technologies provide a more structured knowledge-driven environment for inventors, designers and engineers. Consequently, a new category of tools known as computer aided innovation (CAI) has emerged, with goals of assisting designers in their creative performance and of effectively implementing a complete innovation process throughout the entire product or process life cycle. Based on the concept of Open CAI 2.0 introduced by Hüsig and Kohn (2011), this paper goes further by proposing a prototype software tool for the next evolutionary step of CAI arising from two major recent developments: new advances in technological possibilities in the software field commonly referred to as "Web 2.0" and a strategic paradigm shift from closed to open innovation in many companies. This contribution is one of the first attempts to create a concrete methodological framework based on collective intelligence (through Web 2.0 practices), a collaboration support (with the benefits of on-line social networks) and a problem resolution process. In the proposed Open CAI 2.0, the inventive problem solving method is inspired by the coupling between the innovation theory TRIZ and case based reasoning in order to support the generation of inventive technological solutions because problem solving often requires a reformulation of the initial problem to construct an abstract model of the problem. This paper highlights the importance of knowledge acquisition, capitalization and reuse as well as the problem formulation and resolution in collaboration. A case study on biomass gasification is used to illustrate the method and tool capabilities in the chemical process industry.

1. Introduction

Within the industrial context, innovation is one of the key survival factors for firms. In parallel, the development of new products or processes is faced with major challenges due to the increasing complexity of new technologies, the rapid adaptation to market requirements, the tendency to reduce the life cycle and the need to reduce the time-to-market. To overcome these challenges, firms are in a transition in terms of how they drive the innovation process; they are evolving from a closed model to a more open approach that includes actors and knowledge beyond the enterprise. This evolution requires new methods and tools adapted to this new approach to manage the innovation process and the new knowledge created. The use of computer-aided technologies and, more specifically, computer aided innovation (CAI) is part of the strategy to facilitate this transition (Hüsig and Kohn, 2009).

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.

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Subsequently, the scope was extended such that the goal of CAI systems 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. Recent advances in information and communication technologies and in theoretical approaches to innovation provide a new environment for the next evolutionary step of the CAI to enable users to rapidly reach better solutions to inventive problems and improve cost efficiency. The main contribution of this article is to include both advances in current CAI and to propose the next evolution stage of this type of computer-aided tool, referred as Open CAI 2.0 (concept introduced by Hüsig and Kohn (2011)). However, prior to detailing the proposed method and tool to fill the gap between CAI and Open CAI 2.0, the remainder of this section is primarily focused on the state-of-the-art in CAI in general and in their implementation in process engineering in particular.

1.1. *CAI classification*

CAI systems can range from simple applications for specific activities of the innovation process to systems that support the entire innovation process. Consequently, the CAI field requires a comprehensive classification of the different types of existing systems to clarify the scopes of these tools. To better understand the term CAI, Hüsig and Kohn (2009) have categorized the existing software into the following three categories:

- Strategy management: helps innovation managers to address strategic issues such as portfolio or scenario management.
- Idea management: helps to address the fuzzy front end of innovation process, from idea generation to idea evaluation.
- Patent management: these types of tools are used both to protect inventions and to search and analyse patents as an approach to stimulate creativity.

In some cases, an application might cover the aspects of more than one category. In addition to providing a comprehensive overview of CAI systems, each category of this initial classification can be further divided into subcategories, as shown in Fig. 1. For example, in the idea management category, idea generation refers to tools that implement creative techniques, and idea collection encompasses knowledge-based systems to enhance collection and reuse of knowledge. Because CAI systems are constantly evolving, this framework must be improved to integrate recent developments, for example, all the community aspects linked to open innovation might be considered (Section 2.1).

1.2. *CAI benefits*

In many industries and institutions, the growing trend towards CAI systems would not be possible, unless significant advantages were to be expected from their use. Hüsig and Kohn (2009) have introduced a classification of the potential benefits of innovation software: efficiency, effectiveness, competence and creativity. However, the principal benefits that can arise from CAI systems are linked to expected gains in productivity, speed, reducing costs and stimulating internal innovation. In summary, some of the most significant potential benefits of implementing CAIs are as follows:

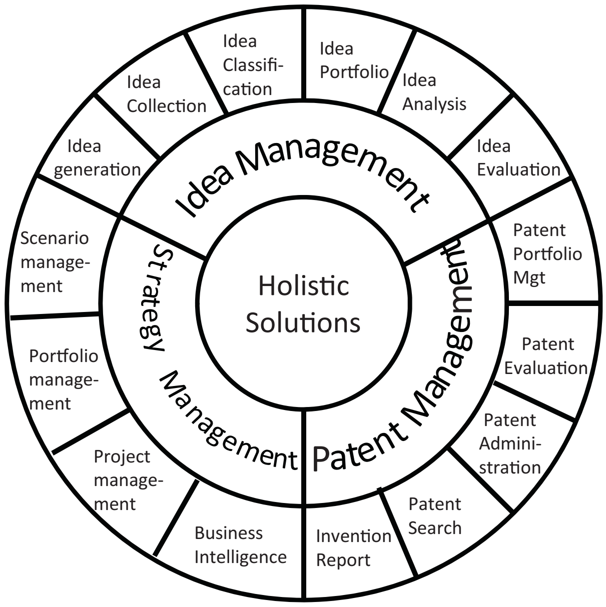


Fig. 1 – Detail CAI software categories (Hüsig and Kohn, 2009).

- More efficient innovation processes thanks to new methods to enhance the storage and reuse of the relevant knowledge; this is improved with advancements in current information and communication technologies (ICT).
- Dedicated tools to support innovation process rather than standard IT-software such as spreadsheet calculation programs.
- Acquisition and knowledge management required for product/process development. This enhances the competence of the system with less effort because knowledge is rapidly updated and its transfer is permanent to provide the new advances.
- Collaborative work within the innovation process, which is a primordial aspect during idea management, from idea generation to idea selection.
- Simplified use of creativity techniques (key innovation success) to generate inventive insights, e.g., TRIZ (Russian acronym for Theory of Inventive Problem Solving). Moreover, software has a positive effect on group productivity and on the novelty of the idea generated because knowledge management helps to stimulate creativity.
- Access to databases and to patent analyses. The goal of patent analyses is to reduce the number of patents to browse to extract the most relevant patents, to identify the knowledge to transfer between technical domains, to aid in idea generation and to translate the description of an invention into a conceptual functional map (Leon, 2009).

1.3. *CAI in chemical process engineering*

In chemical engineering design, computer-aided software tools are used in a wide range of applications for modelling and optimization to design or simulate the performances of processes or products. CAI software tools are more focused on the creative stage to improve the performance of the generated concepts. These tools allow the number of creative solutions to be increased and the different alternatives to be explored more thoroughly. Because the majority of CAI software tools are knowledge-based systems, solutions with important novelty can be suggested based on different ideas.

Historically, the CAI tools developed in process engineering follow the same trends as those developed in the other domains, i.e., they are primarily focused on idea management and document management (more generic than patents). The CAI methods and tools were completely or partially inspired by innovation theories, and more specifically, TRIZ and its evolution or its combination with other methods. TRIZ is well suited for the chemical engineering domain because of its capabilities, such as its structuring, scientific background and technological roots. In their general paper, Poppe and Gras (2002) have detailed the potential benefits of applying TRIZ to specific problems of the process industry.

In process engineering, some of the first CAIs developed were based on an adapted version of the TRIZ tools, to enrich them with specific domain knowledge in the field of expertise. Li et al. (2001) have proposed a CAI system for a complex distillation process; subsequently their approach was improved, but for an application in the synthesis of reactor/separator networks (Li et al., 2002). Li et al. (2003) have detailed another approach with application in waste minimization. Srinivasan and Kraslawski (2006) have also developed a specific CAI tool with application in safer chemical processes. The primary advantage of such CAI tools is that they are very operational due to their specificity to a particular area. However, this integration of more specific knowledge results in less inventive idea generation. To improve knowledge management, Cortes Robles et al. (2009) based reasoning (CBR) and TRIZ to propose a new approach to support knowledge reuse, thereby reducing process or product development time while increasing quality and functionality. Indeed, CBR is a powerful artificial intelligence method for computer reasoning, which is based on analogical reasoning. More precisely, the main axiom in CBR is that the process for solving new problems is based on the solutions of previous similar problems. To propose a CAI tool dedicated to eco-innovation, the previous method was enhanced by including the environmental requirements in the fuzzy front-end phase (Barragan-Ferrer et al., 2012). Samet et al. (2010) have also integrated the environmental issue in their CAI software but it is more specifically oriented towards product eco-innovation rather than process eco-innovation.

Regarding document analysis, in process engineering, the first studies began to appear with the aim of predicting research trends (Jabłońska-Sabuka et al., 2014) or (Sitarz and Kraslawski, 2012) or to studying knowledge flow in research topics (Sitarz et al., 2012). However, documents can be used not only to simulate creativity as previously mentioned but also to create a community for problem resolution and idea generation (Section 3).

The remainder of this manuscript is organized as follows. In Section 2, background for open innovation, ICT benefits, TRIZ and Open CAI 2.0 is presented. Section 3 describes the methodology and the tool architecture and highlights some capabilities of the components. Before drawing conclusions, in Section 4, the approach is illustrated through a case study on heat integration in biomass gasification.

2. From CAI to Open CAI 2.0

Because the primary objective of this paper is to propose a theoretical framework for the development of an Open CAI 2.0, it is important to introduce a large number of concepts, as shown in Fig. 2, and then discuss how they are connected and

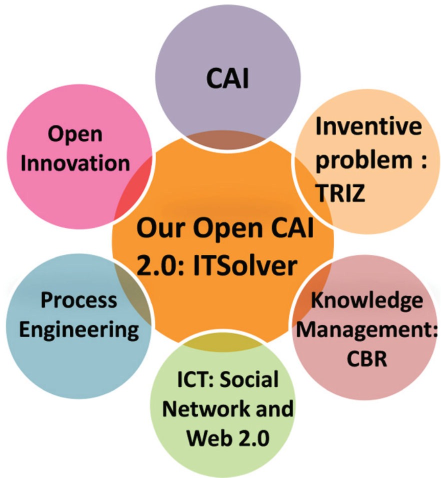


Fig. 2 – Concepts required for reaching contribution objectives.

how they relate to the objective of the paper. First, the concept of CAI is explained in this section because it is the basic concept that we want to extend and ameliorate. One of the two ways for improvement concerns the paradigm of open innovation. To facilitate and support collaborative innovation with people and organizations outside the firm boundaries, the theoretical framework requires some important features, such as high degrees of interactivity, connectivity and information sharing. Consequently, some information and communication technologies (ICT) of Enterprise 2.0 can provide the key features to create such a framework. Furthermore, with the introduction of the open innovation paradigm, the knowledge has to be made explicit, easily formalized, shared and exchanged between all the participants to an inventive solving episode. Moreover, methods for knowledge management and information structuring are required because of the large amount of data involved and created. Consequently, our theoretical framework is based on a previously developed method based on the coupling between TRIZ and case based reasoning (CBR), which allows, on the one hand to formalized, shared and exchanged knowledge thanks to some modified TRIZ tools and, on the other hand, the ability to manage the large amount of knowledge with the CBR.

2.1. *Introduction to TRIZ*

A full understanding of TRIZ requires substantial investment due to its extensive scope. The goal of this part is to provide a mere description of its approach to solve problems and of some of its methods and tools used in the remainder of the paper. TRIZ was developed by Altshuller (1996). TRIZ is a knowledge-based systematic methodology for effective and inventive problem solving dedicated to any types of problems whatever its original domain, as shown in Fig. 3. The main assumption for the establishment of TRIZ is that the technology evolution and the way the inventions are generated are not random processes. To develop his theory, Altshuller (1996) and his colleagues analysed several thousands of patents, the evolution of technical systems and the scientific discoveries.

Rather than finding a concrete solution to a concrete problem, TRIZ is based on reformulating the concrete problem into a conceptual problem (identification of its essential technical barrier), independent of its technical domain of appearance. Then, TRIZ tools help to find conceptual solutions, which must

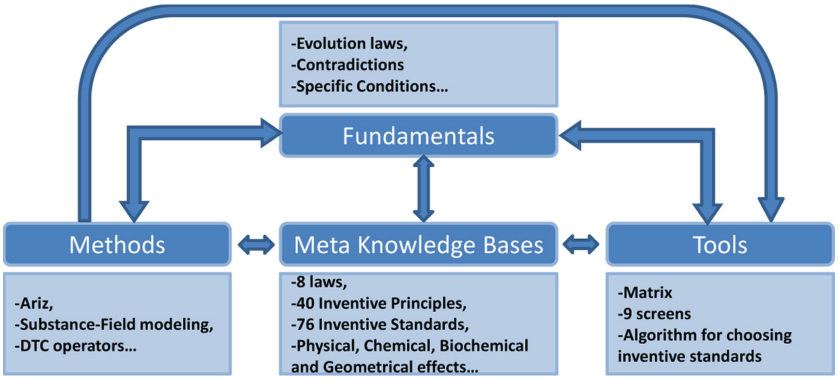


Fig. 3 – Overview of TRIZ (Cavallucci, 2013).

subsequently be adapted to find a concrete solution. The set of conceptual solutions are referred to as meta knowledge bases in Fig. 3. TRIZ supports the resolution process by proposing methods and tools to analyse the problem, to identify the root cause of the problem, to formulate the conceptual problem and finally to give access to knowledge bases leading to conceptual solutions.

Among the TRIZ fundamentals (Fig. 3), the contradiction is the formulation of an inventive problem that expresses the opposition between two desirable but contradictory design parameters. During the analysis of patents, Altshuller identified 39 generic engineering parameters that are used to formulate a contradiction: incompatibility between two of the 39 engineering parameters. The technical contradictions are solved with the contradiction matrix tool (matrix with the 39 engineering parameters that are both on the rows and columns), which is used to extract the most relevant principles (among the 40 inventive principles) that can be applied to solve it. The inventive principles are conceptual solutions (i.e., generic suggestions) that have been identified during the patent analysis.

The eight laws are another fundamental; they indicate that technical systems generally follow regularities in their development (Ilevbare et al., 2013). During development, each system evolves towards ideality: a type 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.

Among the other methods and tools, another prominent method for problem modelling and analysis is the substance-field (Su-Fi) analysis. The general term substance refers to some object regardless of its level of complexity, and field represents the action or the means to accomplish the action. In a system, Su-Fi analysis models the interactions between all the previous components. Su-Fi analysis can also be used to consider different ideas drawn for the knowledge bases (Altshuller, 1996).

2.2. *Open innovation*

As a branch of innovation management, open innovation is a paradigm that suggests a shift from an internal closed model to and open external one (Duval and Speidel, 2014) where companies start to interact with people and organizations outside the company boundaries to improve their innovative capabilities. The benefit of external knowledge to source innovative ideas was implemented very early in the chemical industry (Freeman, 1974). However, the first definition found in the literature for open innovation was proposed later by Chesbrough (2003): "*open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively*". In this definition, "open" refers to the freedom that ideas have to flow into the process or into the market. Then, as explained by West et al. (2014), the scope of open innovation has progressively evolved, first to emphasize the intentionality of the knowledge flows and then to integrate the non-pecuniary knowledge flows, which leads to the extended definition of Chesbrough and Bogers (2014): "*Open innovation is defined as a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with organization's business model*".

Some authors (Hüsig and Kohn, 2011; Chiaroni et al., 2011; Wallin and Von Krogh, 2010; Chesbrough, 2003) agree that open innovation shows its efficiency by changing the way in which enterprises interact with external actors by acquiring exactly the required knowledge, by accelerating internal innovation and by improving cost efficiency thanks to the collaborative creation and development of ideas. This is in contrast with the traditional 'closed' practice of innovation, where firms typically rely entirely on their own research and develop their own ideas and innovation. Chesbrough (2003) makes a comparison between closed and open innovation. The classical funnel representation of the open innovation process is illustrated in Fig. 4; it encompasses the flow of knowledge, technology and ideas within and outside the firm boundaries. However, the useful knowledge is widely distributed, which represents a challenge to identify, interact with and take advantage of these external knowledge sources, to integrate them in the core of the innovation process (Chesbrough et al., 2006).

As illustrated by the arrow in Fig. 4, in open innovation the two sub-processes, the outside-in and inside-out modalities, represent how innovations flow through the companies' boundaries: the integration of externally generated knowledge, ideas, concepts or technology and the transfer of internal ideas or technology to market. A third modality has appeared in companies, which is based on the coupling between both previous sub-processes (Gassmann and Enkel, 2004).

Before Chesbrough coined the term "Open Innovation" in 2003, the concept was inspired by existing industrial practices as demonstrated by the case studies presented and detailed by Steiner (2014): (i) DuPont developed DuPont Technology Bank^{TM} for accessing to its technology and know-how to spread the firm's technologies to become industry standards,

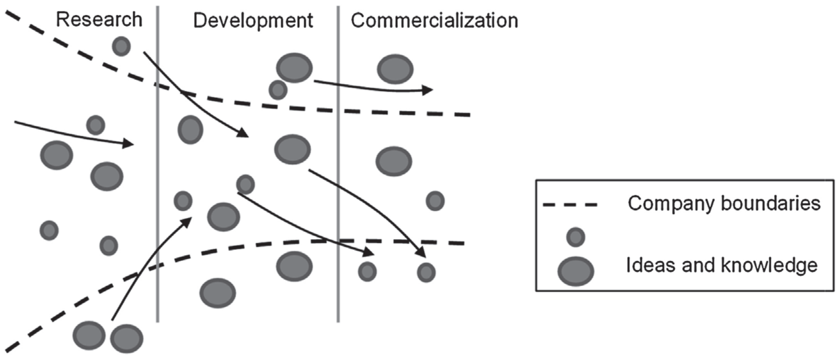


Fig. 4 – Open innovation funnel (Chesbrough, 2003).

(ii) IBM implemented a program named "Ventures in Collaboration" to help entrepreneurs to adopt the technology contained in patents, (iii) Intel's R&D strategy for open innovation relies on the extensive use of external knowledge and (iv) Procter & Gamble developed a Web platform with the following objectives: to increase the value of internal R&D assets, to open internal research to outside participants to improve internal collaboration and to detect and adapt patented technologies from external actors (Duval and Speidel, 2014). Currently, open innovation is being adopted by increasingly more chemical engineering companies, for example Veolia and the oil company Respol. In 2010, the former launched a new program, named the Veolia Open Innovation Accelerator, in which a future entrepreneur proposes ideas and the company provides access to more markets, pilot sites and to its R&D capabilities and expertise. For the latter, Carbone et al. (2012) have explained how open innovation can improve the performance of the company, particularly thanks to a knowledge management system.

The introduction of the open innovation paradigm in an organization modifies the innovation process and it must be coupled with the introduction of new advanced technological tools to foster interaction and collaboration for the creation of new insights. For this reason, we have to introduce the new evolutions of collaborative ICT tools, such as Web 2.0.

2.3. *ICT and Web 2.0*

The previous strategic evolution cannot be efficiently introduced in software applications without new technological drivers in the ICT. By spanning the firms' boundaries, we need to not only enable dynamic and interactive participation of all the members but also to promote collective knowledge exchange. In this context, Web 2.0 is well suited because it offers a more dynamic environment than the previous web version, an important number of social applications and new possibilities with meta-information through the Web of data or Semantic Web. The term Web 2.0 was coined by O'Reilly (2007) to describe the network, mainly the internet, as a platform. This platform provides pathways to deliver software as a continually updated service that becomes better as more people use it; this fact is often referred to as the network effect. The network effect is based on the architecture of participation, whereby users consume and remix data from multiple sources while producing their own data and sharing with others. In addition, Web 2.0 has the potential to deliver full-scale applications with rich user interfaces and more interactivity.

Web 2.0 provides the technological drivers that allow the use of engineering techniques to be integrated in the practice of open innovation, at least for the generation of creative ideas. The Web 2.0 technology supports an emerging form of collaborative innovation based on the many-to-many form of communication. However, prior to discussing collaboration in Web 2.0, it is necessary to formulate a clear definition and to make a semantic distinction with cooperation. As Dillenbourg et al. (2009) argue, these two terms are different, and they define them as follows:

- Cooperation: the division of labour among participants as an activity in which each person is responsible for a portion of the problem solving.
- Collaboration: a mutual engagement of participants in a coordinated effort to solve the problem together.

Although these two terms are similar in some aspect, such as sharing work and creating and sharing knowledge, the principal difference is the degree of organizing the activities between actors. Cooperation requires an orchestration of activities, which justifies the definition and the formalization of a process to synchronize the tasks between participants. However, in collaboration, the participants do not have a formal organization; rather, the work is guided by a common objective that is shared by all the members.

With the evolution of the Internet and Web technologies, it is important to define the concept of "architecture of participation" to better understand the collaborative features associated with Web 2.0. As indicated by O'Reilly (2007), the architecture of participation is a service that acts primarily as a broker, connecting the participants to each other to explicitly and implicitly generate content. This architecture provides the elements required to develop the new generation of collaborative tools, such as blogs, wikis and social network services (Kane, 2009). For O'Reilly (2007), there are two principles that support the architecture of participation:

- Users add value: through active participation and indirectly as a side-effect of their actions.
- Network effects magnify this value: they occur when a product or service become more valuable as the number of people using it increases.

The interest in Web 2.0 technologies is because they provide better communication between people in diverse groups and locations by breaking the time and space restrictions on the one hand, and they provide lower cost, easier-to-adopt and scalable solutions on the other hand. Moreover, Web 2.0 technologies enable forms of collaboration patterns that outline the interactions among participants.

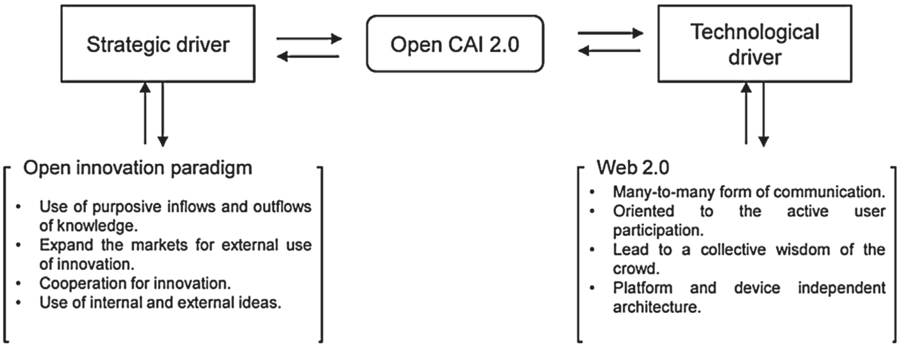


Fig. 5 – Open CAI 2.0 concepts (based on the work of Hüsig and Kohn (2011)).

2.4. *Open CAI 2.0*

Open CAI 2.0 is based on a combination of 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 of the innovation process*", as illustrated in Fig. 5.

It is expected that changes in innovation paradigms will occur through the use of computer-aided innovation methods and tools; consequently, it is necessary to use new information technologies and computational methods for supporting the most recent changes in innovation management strategies. With the introduction of major changes compared to the previous CAI, we can expect new benefits and research challenges. The first major evolution is to help firms expand their boundaries by creating an innovation community which results in a sharp increase in creative potential and thus in an increase in the number of new ideas generated. Here, the challenges are to create the community and to manage and preserve the knowledge created to impel future innovation. The capitalized knowledge consists of that used for the selected idea as well as the knowledge deployed during the idea generation steps but not used in the remainder of the current development. Relying on the community size and skill, the number of ideas would grow tremendously, which leads to the second main challenge: how to assess this increasing quantity of ideas? The methods implemented in traditional CAI, such as expert panels or decision support method requiring score, reach their limits when applied to a potentially large amount of ideas. To potentially have better evaluation results, Hüsig and Kohn (2011) have proposed to manage idea evaluation in a similar way as idea generation, i.e., by the wisdom of the community based on voting methods. However, as the authors have noted giving away the control of idea assessment can lead to a complex situation, particularly when the top-ranked ideas are in contradiction with the strategies of firms.

All the aforementioned theoretical challenges are automatically coupled with technical realization to propose efficient tools. With the Open CAI 2.0 approach, it is possible to develop a platform that facilitates the sharing of problems and solutions among different domains (knowledge transfer), thereby leading to more complex and radical innovations. However, to improve the advantages of adopting new integrated CAI systems, it is not only a matter of integrating information technologies; the in-depth focalization on the outgoing of methodologies and concepts for supporting innovations teams more effectively and efficiently is also indispensable (Leon, 2009). Consequently, the challenge is to develop new theoretical methodology frameworks to integrate the new requirements of open innovation.

3. Theoretical framework

In Fig. 6, the conceptual elements of our proposition for an Open CAI 2.0 solution are illustrated. Each element requires specific theoretical development. In the following sections, we will discuss the functionality of some of the principal elements.

The framework is composed of three dimensions, namely, the project dimension, the creative dimension and the collective intelligence dimension. The goal of the project dimension is to organize and store the information relative to the problem resolution process. In the creative dimension, new methods and tools are proposed to support problem analysis (to propose a share view of the problem and to extract its root cause), problem reformulation with the adapted TRIZ and inventive idea generation (detailed below). The collective intelligence dimension must be explained. Likewise, the link between these key elements must be detailed to define the methodological framework of the tool.

3.1. *Methodological framework*

The core of the components of our framework is organized in three levels, which are introduced in Fig. 7. During operation, the different process stages are executed following an asynchronous pattern, namely, each user works on the sub-activities in the problem formulation activity separately in time within a shared resolution space, and the activities assigned to different members are achieved at distinct times. In the following, we provide a description of the operation of each level.

- Innovation process: it starts when a new problem is faced in a voluntarily sought evolution of a system or when a new idea (not deliberately sought but whose development and deepening are relevant) of evolution emerges but its practical implementation faces a technological problem. Then, the problem is formulated using the TRIZ concepts (Contradiction, Su-Fi Analysis). To propose a solution, it exploits the most utilized TRIZ tools combined with CBR. At the end of this process, the expected results are a new solution, the reuse of existing solutions or an innovative idea. This level encompasses the following elements of Fig. 6 problem

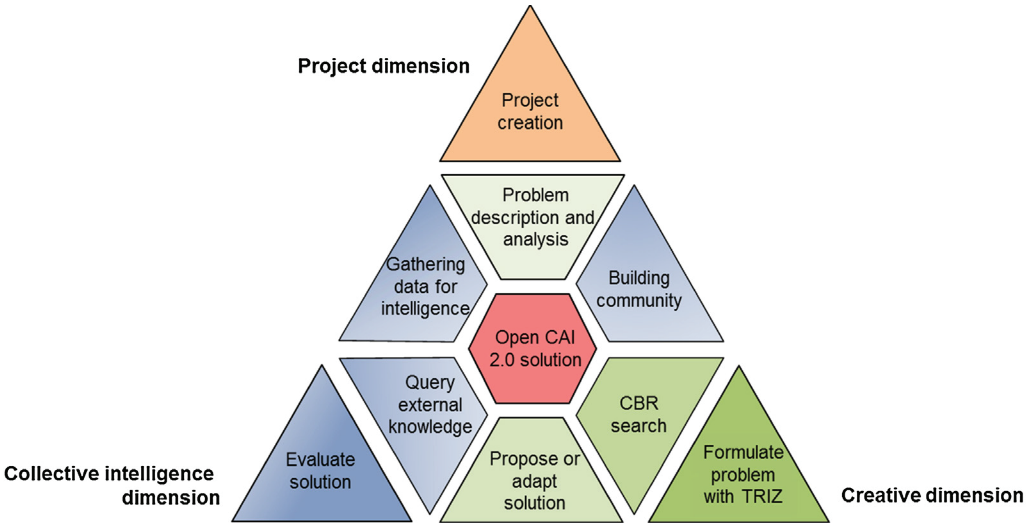


Fig. 6 – Conceptual elements for our Open CAI 2.0 solution.

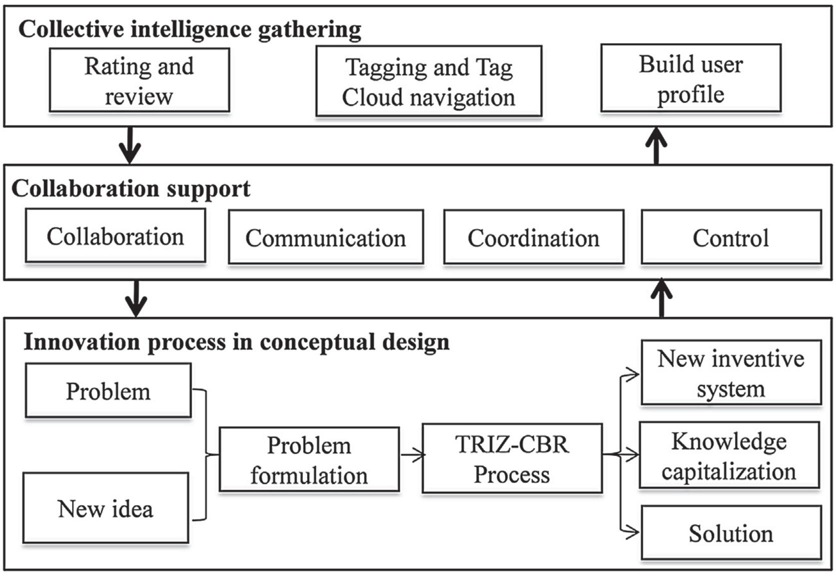


Fig. 7 – Framework core components.

description and analysis, Formulate problem with TRIZ, CBR search, Propose solution.

- Collaboration support: this module supports the four basic operations in a collaborative environment (Spector and Edmonds, 2002): (i) communication among various users with a section to share information; (ii) coordination of users' activities with the implementation of a dashboard component to keep track of the changes; (iii) collaboration among user groups on the creation, modification and dissemination of artefacts and products, in this case, the project that contains the information related to the problem resolution process; and (iv) control processes to ensure integrity and to track the progress of projects. The control is performed through the mutual exclusion pattern. Project creation, Building community and Query external knowledge are the blocks of Fig. 6 addressed in this part.
- Collective intelligence: the capacity to gather the resulting intelligence from the collective effort implicates the use of practices related to Web 2.0 application. 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, as detailed in Section 3.2. This level addresses with the Gathering data intelligence and Evaluate solutions blocks of Fig. 6.

3.2. *Collective intelligence*

In a distributed architecture for collaboration, participants can express their creativity in a more open way. Nevertheless, if not handled correctly, there is a risk of losing the produced information and knowledge. The human creative effort in a community in combination with the power of computer algorithms can lead to what is known as collective intelligence. Figs. 8 describe the relationship between the problem formulation and the community. Therefore, this section introduces 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. Table 1 summarizes the requirements to take into account 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 (e.g., text content). In the architecture of participation, it is possible to combine

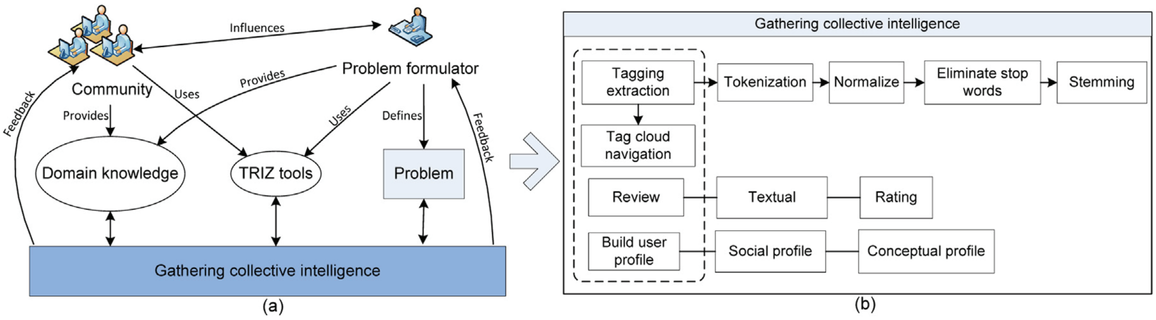


Fig. 8 – Interaction between problem formulation and community.

Table 1 – Collective intelligence requirements in the collaborative innovation process.

Innovation process	Type of activity	Collective intelligence techniques
Identification of collaboration situation	Individual	
Form team	Individual	• Recommender
Describe problem situation	Collective	• Tag integration • Analyse content to build user profile
Deploy resolution process • Use of analytical tools • Problem definition	Collective	• Reputation tracking • Analyse content to build user profile • Review • Harness external content
Evaluate solution	Collective	• Review

this user-generated content with sophisticated algorithms to exploit explicit and implicit information. They are classified, but not limited to, as techniques to gather data for intelligence in web applications according to Alag (2008).

Tagging: Tagging facilitates the addition of keywords to classify items (e.g., pictures, videos, articles and profiles). Tag and tag cloud navigation is part of the dynamic classification of content through terms generated using one or more of the following techniques: machine-generated, professionally generated, or user-generated. According to Esteban-Gil et al. (2012), in collaborative environments, tagging is useful for indexing purposes, facilitating searches and navigating resources.

Building user profiles: The profile represents the users' membership in the collaboration; it serves as an online identity within the environment. The content to construct the user profile originates from different sources: personal information (e.g., skills), tracking user activities and reputation (ranking and review are two of the most common mediums for obtaining the feedback to implement a reputation system).

Harness external content: It is a mechanism to provide relevant information from external sources (e.g., open linked data). Harnessing information sensitive to the context of the problematic situation improves the process of problem resolution, even if the information comes from a different domain.

Review: Review is an opinion that the users express about an item (idea, concept. . .). Opinions are often formulated either in a numerical way (e.g., rating) or in a textual way, and they could influence or support decisions. According to O'Reilly (2007) tags, comments and reviews are mechanisms that allow users to enrich the information.

3.3. Collaboration support

Situations of collaboration in industry seek to facilitate the participation of different actors in activities related to reaching a common objective (e.g., problem solving and design). Fig. 9 shows a generic model for the activities common to all collaboration processes (Sorli and Stokic, 2009).

These activities encompass the following:

I. Identification of a situation. A stakeholder (individual or a group of individuals) identifies the situation that requires collaboration to meet a specific goal.
II. Form team. The starting actor has to identify members of a community to form the collaboration team. For a better result, a recommendation service can support this optimal team composition based on member skills.
III. Collect relevant information. The participants provide the necessary information for the situation by gathering knowledge from different sources and then processing and analyzing this information.
IV. Collaboration process. According to the nature of the situation, different tools and collaboration patterns will be possible.

Regarding this last point, with ICT evolution, new forms of collaboration have emerged over the last years through the concept of architecture of participation as previously discussed. Moreover, these technologies enable new collaboration patterns to outline the interactions among participants to share information and objectives and to divide the work. For further details, Campos et al. (2006) have classified these patterns. The two main challenges in this part are how to organize the collaboration between members of a community and how to create this community.

In our CAI, the organization relies on on-line social network because they support new relevant forms of communication, interaction, information sharing and collaboration (Wilson et al., 2009), leading to what is known as Enterprise 2.0. Organizing collaboration between members becomes the core of the open innovation process because the creative actors transform information into knowledge and then knowledge into solutions. Social networks allow interactions among different users causing the network effect (as previously explained).

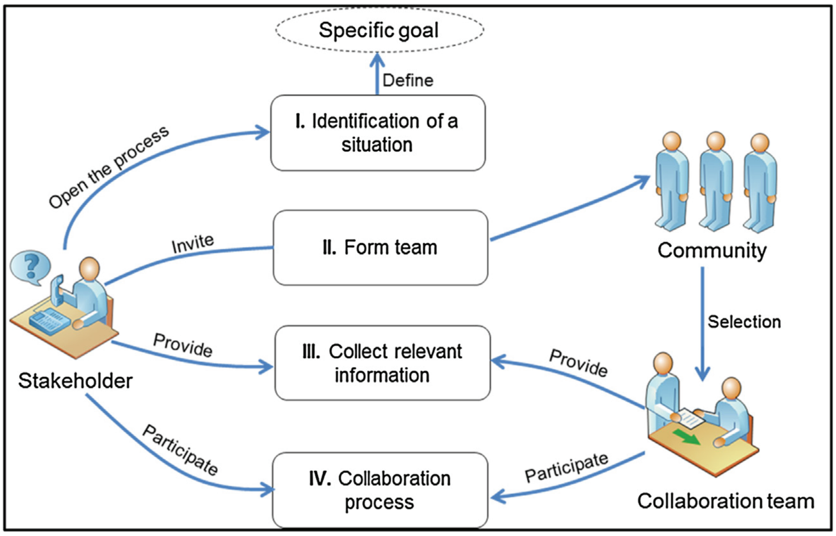


Fig. 9 – Generic collaboration model.

According to Abrams (2006), the main advantages of interacting through on-line social network are as follows:

- It is more comfortable for interaction.
- It reduces the risks of rejection and deception.
- It enhances the efficiency of the process.
- It allows a high level of quality in established relationships.

We have also identified some disadvantages to overcome:

- The larger the group, the more ties that are needed for members to join (Forsyth, 2010).
- Not all members participate in the generation of content.
- Social links do not implicate a real interaction among participants (Wilson et al., 2009).

According to Nguyen et al. (2012), three main architectures exist for organizing the collaboration, as illustrated in Fig. 10:

- Centralized: there is a central unit that controls participations and information flow.
- Decentralized: this organization divides the tasks and assigns them to smaller groups.
- Distributed: all the participants are linked in the bases of equality, independence and cooperation without a centre. This model makes the composition of self-organized communities easy.

In the fuzzy front end of the design process and in open innovation, we must select an architecture that facilitates exchanges between members and knowledge flow in the organization; consequently the distributed scheme was implemented in our CAI.

According to Prax (2012), a professional community is the ideal space for promoting collective intelligence, innovation and value creation. However, one issue is 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 scientific knowledge. In this work, we propose identifying appropriated partners by looking in these documents (more focused on patents in our explanation). For patent analysis, the network analysis, a branch of graph theory, provides intuitive methods for representing patent networks and analysing them. For example, a graph structure can be created in which the nodes represent the patents on a specific domain and the edges represent the citation or co-citation relationships. In a previous work, Choe et al. (2013) have shown the feasibility of this approach, as illustrated in Fig. 11, although some limitations remain in phases 2 and 3.

At first glance, the patent citation network appear to be a good representation for determining the importance of a patent, because highly cited patents would contain important technological advances (Chang et al., 2009; Leu et al., 2012). This network also has a crucial role in representing the knowledge flow through the network. The identification of the inventors in highly cited patents suggests that they can have a valuable role as complementary expertise for future collaborations.

In the network analysis, the number of citation, or co-citation, for each patent can be assessed through mathematical measures, i.e., centrality measures. In graph theory, the degree centrality allows estimation of this indicator. However, the importance of a patent is not limited to its number of links with other patents. Indeed, a new patent with a real technological breakthrough will not appear in the list of

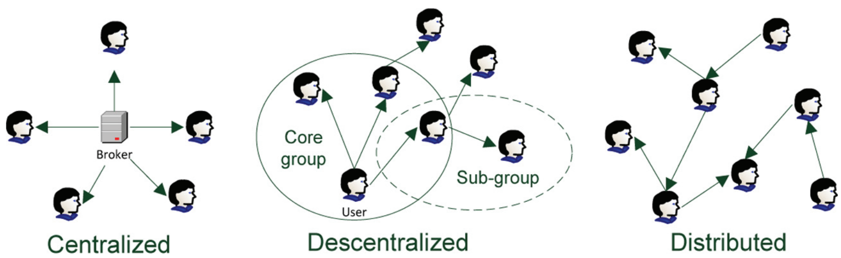


Fig. 10 – Collaboration organization (Nguyen et al., 2012).

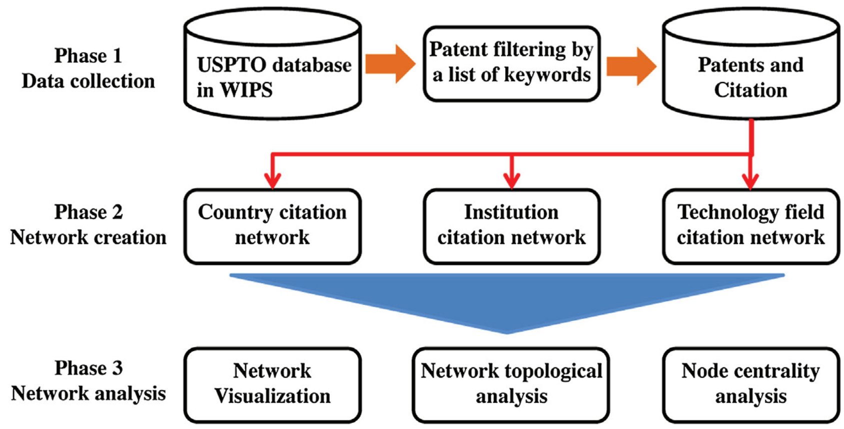


Fig. 11 – Phases in network analysis of patents citation (Choe et al., 2013).

important patents because it has not had sufficient time to be highly cited. Another example of an important patent arises when it is the entry point that provides access to a sub-part of the graph, i.e., this patent has led to many new inventions. Consequently, other mathematical indicators for assessing the importance of a patent in a graph must be introduced (both previous one and others) with additional centrality measures, such as closeness centrality, betweenness centrality and eigenvector centrality among others. All of these new metrics can be estimated during our analysis step. Furthermore, the patent citation network is not the only significant network to analyse. For instance, the inventor network is also relevant for community creation in terms of identifying whether some inventors used to work together or whether they had previously exchanged some knowledge in the past.

As an example, Fig. 12 presents the proposed workflow for discovering potential collaborators based on the patent citation network. The workflow begins with indexing of the patent database, which is followed by retrieving the documents using specific keywords or a patent category; the keywords are free text introduced by the users to describe and categorize the problematic situation. A pre-treatment consisting of the elimination of duplicated patents is required, because in the patent databases, there are repeated patents with different numbers. Step 4 consists of identifying the "referenced by" patents to create the adjacent list that collects the source patent and the patents that reference the source patent. To construct, visualize and analyse the network, the NodeXL tool was used (Hansen et al., 2010). Finally, the last step is to recover the collaborators list by applying the filter indicators, which in our case are the different measures of centrality.

3.4. Creative method

Because of the high abstract level of TRIZ, chemical engineers have experienced some difficulties in implementing it because TRIZ relies on meta knowledge (high abstract level), as illustrated in Fig. 3. Consequently, to improve the efficiency and quality of the ideas generated, domain knowledge must be well organized to assist in formulating and solving of problems. Furthermore, due to open innovation foundations and goals, the amount of knowledge to manage is sharply increasing. The proposition for a framework for the problem definition and for knowledge acquisition and reuse is the key cornerstone for this issue. Cortes Robles et al. (2009) have proposed a method based on the hybridization between TRIZ and a knowledge management approach, namely case based reasoning. The potential of an effective integration of both methodologies has not been fully exploited; thus, the method has been improved with two major evolutions:

- Always with the purpose of reducing the level of abstraction, Negny et al. (2012) have proposed applying the physical, chemical, biological, geometrical effects or phenomenon as solutions because they are more concrete. This is performed thanks to a resources-oriented search to better exploit the resources encompassed in a system.

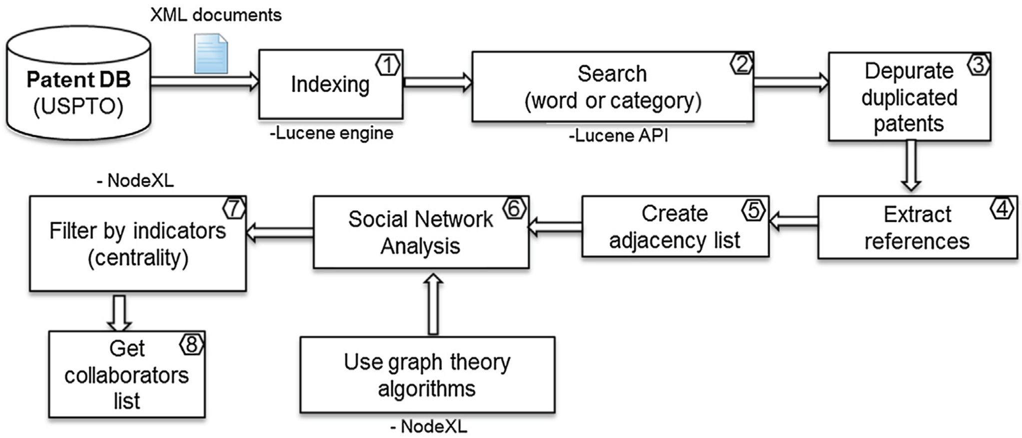


Fig. 12 – Collaborator discovering workflow.

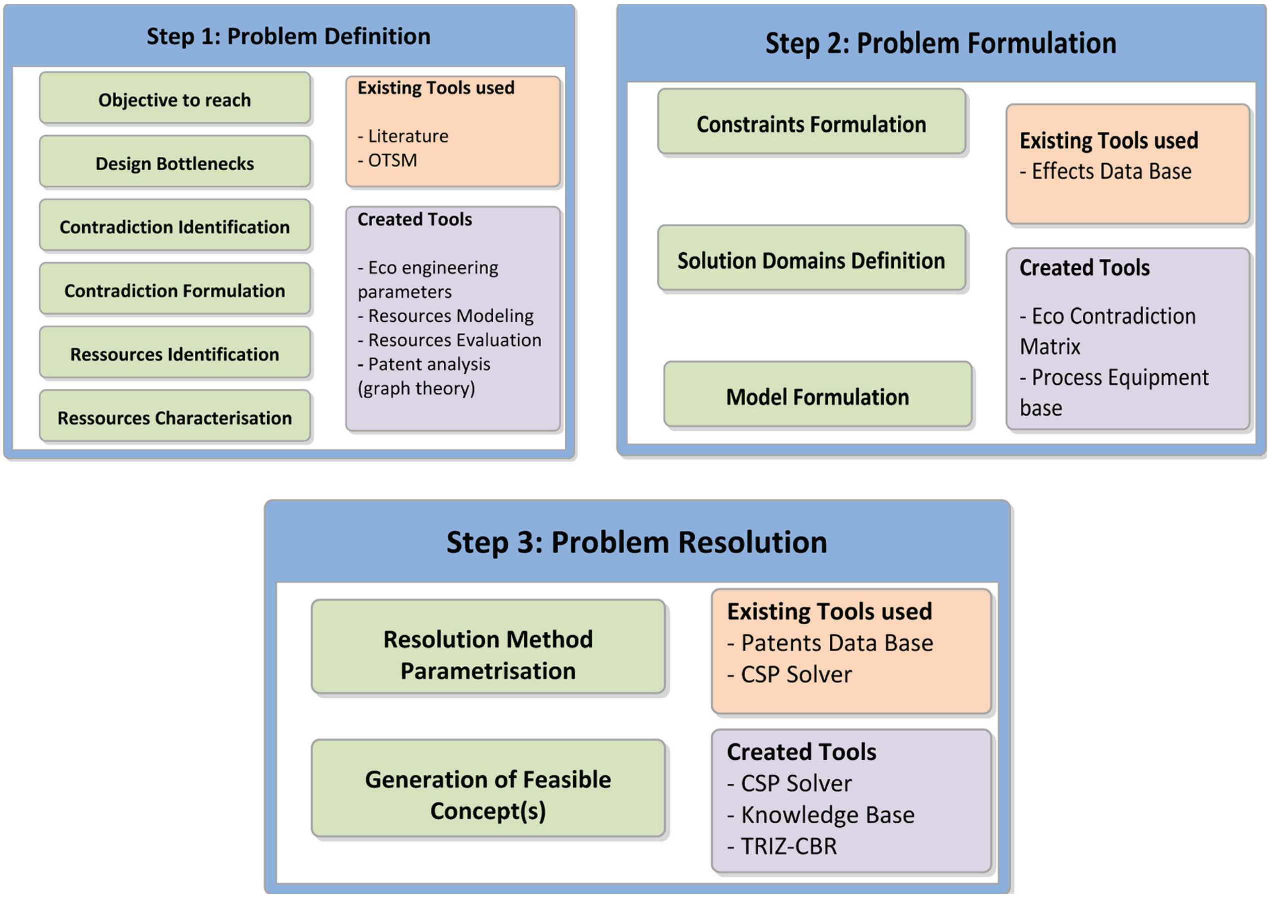


Fig. 13 – General workflow of the creative methodology. Modified version of Barragan-Ferrer et al. (2012).

- The second development is more focused on technological eco-innovation for chemical engineering. The general systematic framework integrates an environment-oriented design approach by simultaneously considering the technological and environmental factors in the fuzzy front-end design phase (Barragan-Ferrer et al., 2012).

As the foundation of our creative method, we have to propose the following: (i) an environment in which users can reach the boundaries of their creativity by avoiding their natural tendency to think that the solution resides within their field of expertise or experience and (ii) a more structured knowledge-driven environment with the community. The workflow of the implemented methodology is composed of three main steps, which are decomposed into sub-steps as detailed in Fig. 13 (improved version of the workflow presented in Barragan-Ferrer et al. (2012)). For each step, some existing methods and tools were adapted to chemical engineering, and some tools of the structured TRIZ theory are modified and improved to construct a specific methodology oriented towards the increasing technological complexity and environmental issues of current designs. The goal of the first step is to share a common vision of the design issue by establishing the objectives, requirements, constraints and bottlenecks. In the second step, the community members search to have a formulation of the encountered problem. Finally, the objective of the last step is to identify the best ideas by solving the problem using the TRIZ case based reasoning method, which once developed, will be translated into a promising process option that encompasses a category of process equipment that can be modified to establish the desired effect or phenomenon. Further details of each sub-step and tool are given in Barragan-Ferrer et al. (2012).

4. Case example

In the current context, there is a trend to use renewable resources for energy and to substitute or complement chemicals. New viable energy alternatives are in the context of a growing worldwide demand, leading to an urgent need for anticipating the future energy requirements. Among the various possibilities, biomass will definitely be in deciding countries energy mix. Biomass not only has the potential to contribute to fulfilling the energy needs for many countries and to ensure their energy independence, but also to combat global warming and climate changes. The primary advantage of biomass is its worldwide availability due to its diverse sources. This paper is primarily focused on the conversion of biomass into energy through thermos-chemical processes, particularly on the gasification process.

Regarding gasifier technologies, two main technologies are feasible: (i) fixed beds with different options according to the manner in which the gases are introduced in the device and (ii) fluidized beds that are dependent on the gas superficial velocity. The choice of technology not only depends on the inlet biomass features but also on the outlet requirements, e.g., syngas valorization and the power required. In the case study, we decided to improve the fluidized bed reactors, and among the reactor configurations, the circulating fluidized bed because it is more industrially established due to its biomass conversion rate and efficiency.

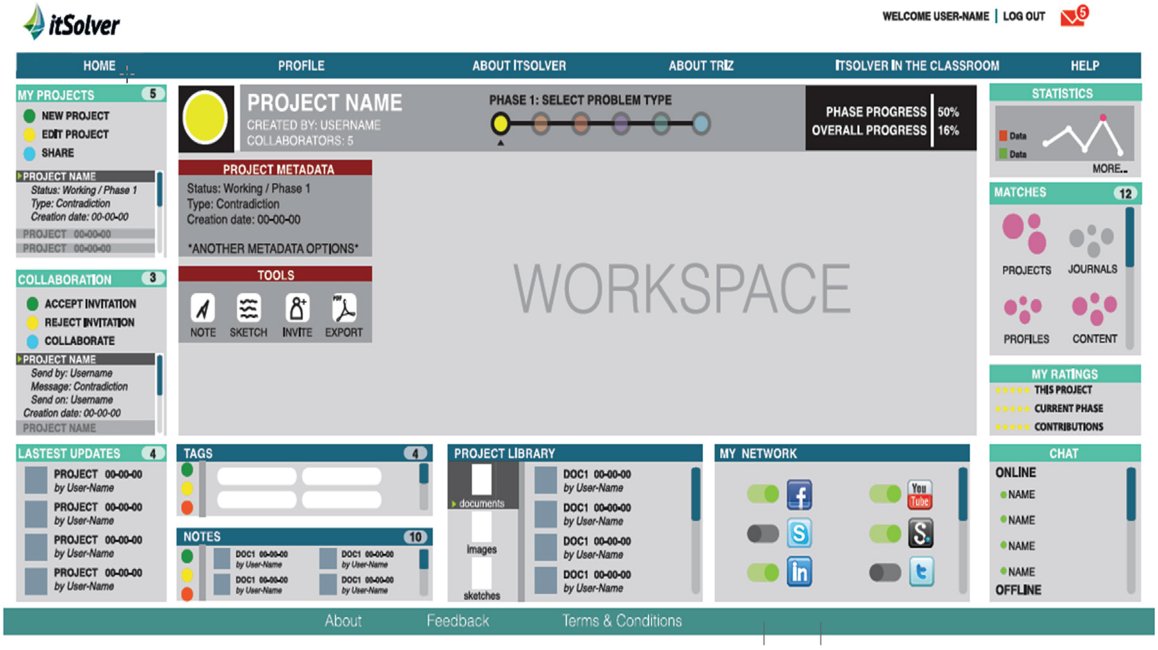


Fig. 14 – Home page of the Open CAI 2.0, ItSolver prototype.

4.1. *Prototype presentation*

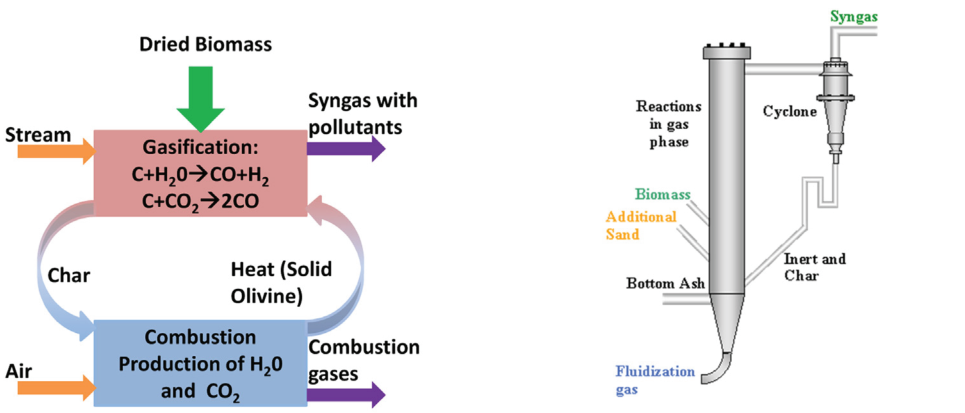
Fig. 14 presents an overview of the home page of the prototype, namely, ItSolver of Open CAI 2.0 developed on the aforementioned theoretical framework. In the upper part, information on the project management, such as the project phase and indicators on the progress, are reported. The left part encompasses all the elements concerning collaboration and community creation. The central part is dedicated to the method and tools for problem formulation, resolution and visualization of the output data for each tool. The lower part of this home page is related to the exchange of information to ensure good communication between members.

The case study does not present all the components of Figs. 6 and 7 in detail. The blocks regarding the problem description analysis are not presented because they have been detailed in previous studies (Negny et al., 2012) and (Barragan-Ferrer et al., 2012). The project management creation is not processed because it is mostly dedicated to the parameterization of the tool. Consequently, the case study is mostly focused on the other parts of the framework.

4.2. *Problem statement*

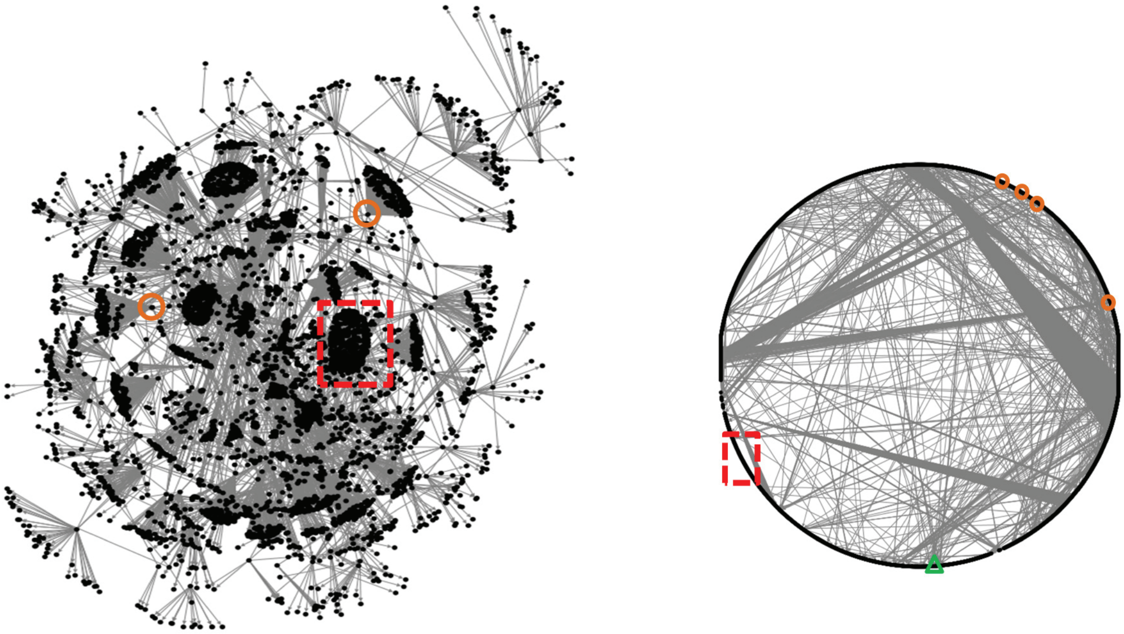
The circulating fluidized bed process consists of a gasification chamber, a combustion chamber, upper and lower streams between both chambers, an outlet stream in the combustion chamber to withdraw the combustion gases, and an outlet stream in the gasification chamber for the produced syngas, shown in Fig. 15. The dried biomass is fed into 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 through an exothermic reaction. This energy is transferred (through the upper stream) to the gasification chamber, where the biomass is converted into solid residues (char) and the previous compounds react to produce syngas and tars via an endothermic reaction.

The three major drawbacks of circulating fluidized bed reactors for biomass gasification are as follows: (i) the production of ashes and tars in the outflow syngas, (ii) low heat recovery and (iii) difficulty in operating with a biomass moisture content greater than 20%. The first drawback was



a) Schematic representation of Gasification b) Visual description of the device

Fig. 15 – (a) Schematic representation of gasification. (b) Visual description of the device.



a) Citation network for patent dealing with biomass. b) Collaboration between inventors.

Fig. 16 – (a) Citation network for patent dealing with biomass. (b) Collaboration between inventors.

addressed in the work of Barragan-Ferrer et al. (2012). The two other drawbacks are the subject of this part.

In a traditional gasifier, the heat recovery between the combustion chamber (exothermic) and the gasification chamber (endothermic) is ensured by solid grain media (due to the high temperature reached in both chambers), i.e., solid olivine (consequently 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 the first configuration, the combustion chamber can be directly in contact (common wall) with the gasification chamber to improve the heat exchanges through thermal conduction. Regarding the biomass moisture content, depending on the biomass source, a drying pre-treatment can be added to the process to reach the operating threshold for moisture.

Furthermore, this process is subjected to constraints on the level of temperature. First, for security purposes, the temperature in the drying operation does not exceed 150 °C to avoid the risk of ignition of the biomass. There are also operational limits on 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 heat loses. In addition, the temperature of the combustion chamber cannot be greater than 1000 °C to avoid reaching the melting point of the ashes and for economic reasons. Indeed, increasing the temperature means a greater consumption of biomass in this operation, thereby resulting in a lower production of syngas and consequently a decrease of the cash return of the process.

4.3. *Community members*

This part highlights the software tool for examining patents as a mean to reduce the number of patent to browse for identifying the knowledge flow, the important skills and the potential members of a community. This section is particularly focused on the building community block but it partially covers some parts of the query external knowledge block.

A first set of 8400 patents were extracted based on the word biomass, and then this first list was reduced by filtering patents with respect to the centrality measures. As a result, it remains only the most important patents remain. Fig. 16a presents the citation network for the remaining patents; this graph is helpful for detecting the different clusters of knowledge and how they interact. In this figure, we can identify groups of patents, such as in the dashed rectangle, which collects studies based on very close subjects of interest. The links between different groups highlight the knowledge flow in the network. The patents in the boundary of this network are predominantly patents with a solution with a low level of inventiveness or very recent patents, which is why there are few patents that have been cited. For the latter, the results of the centrality analysis do not allow recent patents to provide a breakthrough technology for the subject being studied to be retrieved. Nevertheless, with this centrality analysis expanded to the entire network, we can extract patents with important breakthroughs because they provide access to sub-parts of the graph (circles in Fig. 16a). These patents are at the origin of numerous other discoveries. The inventors of these patents have relevant skills and are potentially interesting people to include in the community provided to complement this information with the network of inventors.

Fig. 16b highlights the collaboration between inventors. Each point on the outside circle represents an inventorb and each edge is a link between two co-authors on a patent. Thanks to this representation, we can identify different categories of inventors: (i) inventors that do not collaborate with other people (rectangle). More precisely, after the filtering techniques, inventors remaining on the circle participate in at least more than 3 patents. As a result, inventors with no incident edge are those who collaborate with co-authors of less than 3 patents. (ii) The second category concerns inventors who have an important number of collaborations but always with the same group of co-inventors (circle in Fig. 15b). While they can be considered experts because of their involvement in numerous patents, by analysing this category more deeply, we can see that these people mostly interact with members of their firms. Consequently, they have a collaboration mode oriented towards closed innovation probably because of the strategy of their firm. (iii) The final category gathers people who are involved in numerous patents but with co-authors belonging to different firms (triangle in Fig. 16b). Compared to the previous category, they are more in the logic of open innovation. The people belonging to the two last categories are relevant to the creation of a community with a preference for those in the third category because they are already sensitized to external collaboration.

Unfortunately, to test our prototype, we cannot afford to have a wide and diversified community with industrial, academics, etc. Consequently, we create a small community composed of researchers in universities with the different profiles, as described in Table 2 (people belonging to the same country are not with the same university).

This community raises the question of how a small community of researchers biases the openness and randomness of the results. Indeed, one popular claim to explain the success of community work, is that the bigger the community, the more reliable the result. For instance, this is particularly true for the open source community and the development of software because all the requirements of the community members can be taken into account. It is more difficult in the engineering domain because a too wide community may lead to a large number of design constraints (to express each specific need), and thus to an infeasible solution. As a result, the size of the community cannot provide a sufficient answer to the previous question. Three additional arguments can provide some answers to the question:

- The implication of future users: the reliability and implication of the community members depend on the measure in which they will be impacted by the consequences of potential failures. Furthermore, people become involved to ensure that the final product will work according to their requirements.
- Openness of the community: openness allows members to locate the root problem or a flaw, to propose a model and eventually to propose a way to solve the problem.
- Flow of information: here, the focus is on the type of information that is delivered to the community. The more the flow is controlled, the lower the success. All types of information must flow between members. This implies that the members who are involved in the inventive process must have the ability to be receptive to criticism and to learn from mistakes (on the problem faced or on previous problems encountered).

The previous arguments are propositions to try to understand the relationship between openness, randomness, reliability and the size of the community. The goal of this paper is not to provide an answer to this research question but our community and case study help to highlight the importance of the last two points.

4.4. *Problem resolution*

4.4.1. *Formulate problem with TRIZ*

In this part, the entire resolution process (Fig. 13) is not detailed because the crucial phases and sub-phases were previously reported and detailed in Barragan-Ferrer et al. (2012). Here, the attention is primarily focused on the input data required for the resolution and the description of the retained idea. The methods and tools developed in the first step of the resolution process enable a deep and detailed analysis of the problematic situation to reach the following problem features necessary as input information for the resolution:

- Objectives of the design: to increase energy efficiency, to use the same device for a wide range of biomass without increasing the energy consumption (in the pre-treatment stage).
- Contradictions (according to TRIZ): Energy intensity vs Productivity, Recyclability vs Ease of operation.
- Resources: the previous inlet and produced gases (all the chemical compounds are listed), solid char, olivine, biomass composition and characteristics, mechanical and heat fields, pressure field, characteristics of the reaction, void space and temporal information.
- Constraints: the aforementioned temperature levels intensify the device. The number of constraints must be restrained to not limit the creativity.

4.4.2. *Evaluate solution*

The evaluation is based on cross-evaluation, in which the key is allowing the members of the community to be the judges, i.e., the method uses precisely the same group of people who work on the system as judges. The evaluation process consists of two stages: (i) creation of a questionnaire by the members and (ii) assessment of the ideas by the members. The specific questionnaire is based on the design goal but with a limited number of topics and with a weight assigned to each topic. In the second stage, each member provides their opinion on the set of ideas that they produced as well as on those of the other members. Then, a collective restitution of the assessment with a ranking is made by the community members. Obviously, the potential flaw is the self-judgment bias, i.e., an individual can be inclined to give a higher score to their idea during the evaluation stage. To neutralize this potential flaw, two filters were first used to identify erroneous values: the

Table 2 – Participant features.

Country	Field of expertise	TRIZ practitioner	Participation to external collaboration
Mexico	Mechanical	Yes	Never
Mexico	Industrial engineering	No	Regularly
France	Chemical engineering	Yes	Regularly
France	Computer science	No	Occasionally
Lithuania	Electronic	Yes	Occasionally
Russia	Chemical engineering	Yes	Never
Spain	Mechanical	No	Occasionally

double confidence interval (by ideas and by topics) and Student's *t*-test (method of mean test). After several tests, the two previous filters were not sufficient; consequently, the analytical model based on analysis of variance proposed by Sun and Kantor (2006) was implemented.

Regarding the case study, several ideas were generated, and a two-round process was used to extract the most promising one, with a cross-evaluation for each round. After the first round, the first three ideas were retained and were studied in more detail by the community members to ensure their pertinence and feasibility. With this additional information for each idea, the second cross-evaluation provides a second ranking, and this is the first idea that was chosen and is detailed below.

4.4.3. *Proposed solution*

When the resolution process is deployed, the TRIZ principle number 7, "Nested Doll", which is based on the geometrical effect "Put a system inside another", is one of the preferential solutions to explore for transforming it into a concrete concept. The first direction explored was to increase heat exchange by increasing the gas residence time in the combustion chamber. However, this leads to an increase in the size of the apparatus, which is not with 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 chamber is reduced.

To proceed further with the research of the solution, the TRIZ-CBR tool is used. After the retrieve step and relying on the previous problem description (Objectives, Contradictions, and Resources), the cases based reasoning system extracts several devices from the knowledge base with the recommended order of use: heat exchanger coil, dividing wall column (classic, extractive or reactive column), heat exchanger. The common denominator between all these devices is that they are feasible technological way for saving energy with a reduced capital investment. The exchanger coil is not a relevant solution as a similar system is already implemented with the solid grain media for heat recovery. Concerning the dividing wall column, it is a concrete application of process intensification for a better heat integration. It is a special column obtained by including a vertical wall inside the column shell.

Based on the combination of the TRIZ principle 7 and the concept of the dividing wall column, the following solution can be proposed: the combustion chamber could be inside the gasification chamber to reach a high exchange surface and thus increase the thermal transfer. Always with the idea of energy integration, the gasification chamber could be situated within the storage enclosure to value the external thermal loses and to dry the biomass prior to gasification to reach the 20% moisture content. 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 applied between them. As a result, the proposed device is similar to nested dolls, with successive overlapping of the different chambers.

Nevertheless, in a traditional gasifier, the hydrodynamic and thermal behaviours and the produced gas are closely related to the first reaction that occurs when the biomass is fed into the fluidized bed: devolatilization. Consequently, for the proposed device, 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 because the devolatilization phenomenon has a strong influence on the local hydrodynamics of the fluidized bed.

4.5. *Discussion*

The first returns on the method and tool have allowed us to identify the following positive aspects:

- When dedicated to engineering design, the idea generation method must rely on technological bases for problem formulation and resolution.
- This method must include some TRIZ methods and tools because on 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. Furthermore, it can be easily handled by new practitioners.
- Collaboration not only provides access to an undefined number of numerous sources of knowledge but also produces new knowledge. Consequently, our method based on the coupling between TRIZ and case based reasoning enables us to store and easily reuse this knowledge for future problem resolution episodes. This knowledge management was one of the major aspects that motivated the coupling of TRIZ and CBR. Indeed, collecting and aggregating huge amount of knowledge (and data) comfortably is the basis for improving decisions, leading to improved effectiveness of the innovation system. This method based on the coupling stimulates creativity by assisting in the recording, reusing and reconstructing of knowledge in creative process. The others are presented in Cortes Robles et al. (2009).
- An Open CAI must include a document analysis method both for creating a community of experts and to extract relevant information for formulating the problem, while avoiding browsing the substantial amount of available documents.
- The expected benefits of open innovation were achieved: more constructive exchanges, prevent psychological inertia, accelerate idea generation, improve the level of inventiveness of the generated ideas, and improve of the network effects during collaboration.
- The collaborative technology Web 2.0 provides the elements required to implement a generic collaboration model. Moreover, the social web services help to unlock the potential of the collective intelligence, and the creative capabilities of each individual.

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

- Existing crowdsourcing solutions to foster open innovation practices are limited to taking a problem and broadcasting it to a community.
- The success of collaborative innovation is primarily determined by the selection of appropriated participants. Even if the document analysis part of the tool enables the identification of community members, the analysis is not thorough enough to exactly identify the skills of each member to form the most efficient community. Moreover, to anticipate a priori whether the collaboration between members will work is not an easy task.

- The substantial amount of information generated by users makes the identification of applicable ideas difficult. It also raises the question of knowledge maintenance as the knowledge base sharply grows. Another important question to address is how to create new knowledge through combination of the stored knowledge.
- The considered example is limited because it is academic. In a real industrial environment, the level of investment of each community member remains a problem because some of them might not reveal all of their skills for strategic reasons (e.g., capitalization of their knowledge by another firm).
- Difficulties in attracting skilled people (correlated with the previous point).
- The intellectual property of the generated ideas is still not an addressed issue in our approach.

More generally, the last points raise questions regarding the incentives and disincentives of people involved in the network and indirectly of the business model. Indeed, a relevant business model is one way to overcome the previous drawbacks provided that, at the end of the innovation process, the participants would aim a better technology rather than a better business model. As external ideas and participants are included in the innovation process, the issues concerning the rewards of the innovators is crucial. The key factor is to select the relevant model that corresponds to the strategic purpose of the innovation process. Currently, four principal models have emerged in industrial practices: (i) incubation or acceleration program (such as Veolia innovation accelerator presented above) where start-ups are selected by large industrial organization to support creative entrepreneurship, (ii) crowdsourcing or ideas contests (unfold in various forms), e.g., companies propose its challenge problems to anyone and give cash awards to solvers who provide the best solutions, (iii) co-creation platforms between firms and some of its customers to enhance the product portfolio in accordance with user wishes (in some case external participants can receive royalties) and (iv) co-developments where participants engage material collaboration to develop new products. In each of the previous categories of model, it exists various alternatives, for example for the first one, depending on the degree of maturity of the project and of the starts-ups strategy, the range of possibilities is wide from simple tests to the purchase and deployment of technologies, through a specific adaptation of technology to the needs of the large industrial organization. The definition of a relevant business model adapted to the objectives of the collaboration and ensuring the success of the collaboration based on the type of participants remain a topic for further research.

5. Conclusion

In processing engineering, computer aided innovation becomes an important research domain with the purpose of supporting the entire innovation process. CAI systems provide methods and tools for each step of the innovation process, i.e., from the creative stage to the transformation of an invention into a successful innovation. After a literature review on CAI, it can be concluded that various directions for development in this research field remain. However, the more challenging direction is the shift from CAI to Open CAI 2.0, proposed by Hüsig and Kohn (2011), by including major current developments both on innovation studies with the new paradigm of open innovation and on advances in information and communications technologies. With open innovation, the knowledge is exploited in a more collaborative way as knowledge can be exchanged and shared between internal and external sources. This new way to collaborate is made possible thanks to ICT evolution and particularly with Web 2.0, which offers the technological framework to facilitate relationships between people and the exchange of knowledge and interests. With these two key evolutions, new alternatives arise regarding the development of CAI. This proposition of a concrete software prototype is also motivated by the fact that organizations need to introduce new advanced applications to impulse and drive innovation, and to efficiently acquire and manage knowledge. Indeed, in innovation, knowledge management is one of the central issues not only to impel innovation but also to rapidly adapt to changing environments.

To our knowledge, this is the first Open CAI 2.0 software developed in the chemical process domain and one of the first in the engineering domain. The proposed theoretical framework is organized in three levels. The lower level concerns the innovation process, and it is mainly focused on the generation and selection of ideas. To manage the large amount of knowledge deployed in open innovation while continuing to rapidly generate innovative ideas, we have developed a dedicated methodology based on the most utilized TRIZ tools combined with case based reasoning. This synergy is motivated by the complementarities between both approaches, i.e., the analogical reasoning, but it also exploits a knowledge base of past experiences but at a different level of abstraction. The proposed approach allows the exchange of knowledge between disciplines while remaining within process engineering. It 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. The intermediary level is focused on the collaboration and on the way to create a collaborative environment to facilitate knowledge exchange. This is performed by taking advantage of the benefits of on line social networks. In this level, we also address the creation of the community with relevant skills for the problem being treated. To discover potential community members, we propose to use patents and/or research articles and to analyse them through the network analysis of graph theory. Different types of networks and different types of measures to extract relevant information in these networks are implemented. Finally, the last level is dedicated to the collective intelligence, i.e., human creative effort in a community in combination with the power of computer algorithms. The knowledge created during collective efforts is encompassed through Web 2.0 practices, such as rating and tagging. The goal is to extract the tacit knowledge that arises from the user's interactions. All the elements of this theoretical framework are implemented into a software prototype: ITSolver.

In addition to the advances described above, further developments are required to improve our Open CAI 2.0 prototype. First, the methodology must be enlarged by integrating the strategy management dimension and, more specifically by proposing methods and tools to help managers address strategic issues such as portfolio management, and the identification of market opportunities. Regarding open innovation the presented approach is based on the outside-in subprocess; however, the other sub-process, i.e., the inside-out, could be included to improve invention valorization and to generate additional value. The development of inventive ideas through the open innovation process, and more specifically by using skills outside the firms' boundaries, automatically raises questions of intellectual property. The issues of protection of inventions and inventor rewards must be addressed.

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