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“ Tout cela, qui paraît d'abord l'excès de la déraison, est, en effet, l'effort de la finesse et de l'étendue de l'esprit humain, et la méthode de trouver des vérités qui étaient jusqu'alors inconnues.”

Voltaire

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Summary

In economy nowadays, the act of innovation is in general social; it requires the management of knowledge, and the techniques and methodologies to drive it. Innovation is not the product of one isolated intelligence, instead, it is the result of a multi-disciplinary workgroup lead by a process or a methodology. The conceptual design, which is found in the first stages of the innovation process, represents one of the most important challenges in industry nowadays.

One of the main challenges faced by chemical industries related to the conceptual design phase is to provide the means in the form of methods and computational tools, for solving problems systematically, at the same time that benefiting from the collective efforts of individual intelligences involved. Hence, the main objective of this work is to provide a solution to improve the creative capacity of a team involved in the innovation process, in particular the preliminary (critical) phase of conceptual design. Consequently, it is important to understand the techniques, methods and tools that best support the generation of novel ideas and creative solutions. In addition, it is necessary to study the contribution of information and communication technologies as the mean to support collaboration.

Web technologies are considered as complementary tools to implement methods and techniques in collaborative design, and particularly in the conceptual design stage. These technologies allow setting up distributed collaborative environments to bring together the resources and the experts who can relate the existing pieces of knowledge to new contexts. It is the synergy created in this kind of environment, which allow producing valuable concepts and ideas in the form of Collective Intelligence.

Nevertheless in most existing solutions for collective intelligence or crowdsourcing environments, they do not report the use of a particular methodology to improve the participants' creativity. The solution in this work describes a social network service that enables users to cooperatively solve problems oriented (but not limited) to the phase of conceptual design.

In this work we propose that the use of Collective Intelligence in combination with the model TRIZ-CBR could lead the creative efforts in a team to develop innovative solutions. With this work we are looking for connecting experts from one particular field, TRIZ practitioners and stakeholders with the objective to solve problems in collaboration unlashing the collective intelligence to improve creativity. This work uses the basis of the concept named "Open CAI 2.0" to propose a solution in the form of a theoretical framework. The contributions seek to move the development of the field in Computer Aided Innovation a step forward.

Résumé

L'innovation est un processus complexe qui demande des techniques et des outils collaboratifs pour la gestion des connaissances et la communication, afin que les entreprises surmontent les défis d'une économie concurrentielle. Une nouvelle catégorie d'outils connus sous l'acronyme CAI (*Computer Aided Innovation*) émerge parmi l'éventail des technologies assistées par ordinateur afin de répondre aux demandes industrielles pour une plus grande fiabilité des nouveaux produits et procédés. L'objectif de ces outils (en cours de développement) est d'aider les concepteurs durant tout le processus d'innovation. Actuellement la mise en oeuvre d'un tel outil doit prendre en considération deux développements récents majeurs. Le premier est d'ordre technologique avec les possibilités offertes par le Web 2.0 dans le développement de logiciel. Le deuxième est plus stratégique avec un changement de vision de l'innovation passant de l'innovation fermée (interne à l'entreprise) à l'innovation ouverte (Open Innovation). Ces deux aspects conduisent à de nouvelles formes de CAI nommé Open CAI 2.0. Cette recherche propose une des briques d'un tel outil, pour assister les ingénieurs procédés à résoudre des problèmes innovants principalement dans la phase de conception préliminaire. Nous présentons la structure et la fonctionnalité d'un cadre de collaboration qui met en oeuvre une méthode développée basée sur le couplage entre la théorie TRIZ, et une technique de gestion des connaissances: le raisonnement à partir de cas (RàPC). Ce cadre est une extension du modèle TRIZ-RàPC validé dans le domaine du génie de procèdes. L'approche du processus de résolution est illustrée sur une étude de cas traitant de la gazéification de la biomasse.

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Table of contents

List of Figures

List of Tables

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Chapter 1 Introduction

Highlights
• To present the research context and scope. • To introduce the manuscript parts.

1.1 Research proposal

"¿Con qué he de irme?
¿Nada dejaré en pos de mí sobre la tierra?
¿Cómo ha de actuar mi corazón?
¿Acaso en vano venimos a vivir,
a brotar sobre la tierra?
Dejemos al menos flores
Dejemos al menos cantos."
Un Recuerdo que Dejo (Nezahualcóyotl)

One core challenge in the strategic management of technological innovation is the diverse nature and location of sources for innovation. As (Schilling, 2012) argues, innovation can originate from different sources: individuals, universities, firms, non-profit or government-funded entities. However, for the last author the most important source for innovation arises from the linkages between those sources; this dynamic is illustrated in Figure 1.1. Consequently, enterprises require strategies and tools to explore the different sources and their linkages to improve their innovation capacities.

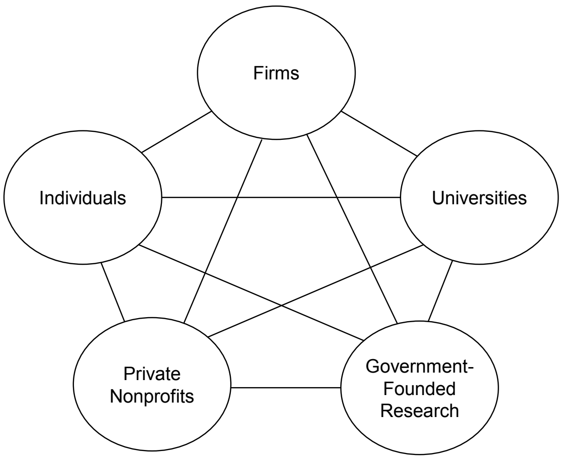

Figure 1.1 Innovation open system (Schilling, 2012)

Currently, advances in theoretical approaches to innovation as well as in information and communication technologies provide a more structured knowledge driven environment for inventors, designers and engineers. As a result a new scientific research field known as Computer Aided Innovation (CAI) is an emerging domain, with the goal to assist designers in their creative performance and to effectively implement a complete innovation process throughout the whole product or process life cycle. Within the front end of innovation process, this work proposes an evolutionary step of CAI towards the concept Open CAI 2.0 defined by (Hüsig and Kohn, 2011). Open CAI 2.0 arises from two major recent developments. One coming from the advances in technological possibilities in the software field commonly referred to "Web 2.0", the other coming from a strategic paradigm shift from closed to open innovation in many companies. This work highlights the importance of knowledge acquisition, capitalization and reused as well as the problem formulation and resolution in collaboration. Therefore, we propose an Open CAI 2.0 tool which is inspired by the coupling between the innovation theory TRIZ and Case Based Reasoning. This Open CAI 2.0 tool looks to support the generation of inventive technological solutions because problem solving often needs a reformulation of the initial problem to build an abstract model of the problem.

1.2 Scientific context

The explored scientific corpus in this work is composed by publications from the following domains: innovation management, knowledge engineering, computer sciences and process system engineering. Figure 1.2 organizes the principal topics studied throughout the development of the research.

Figure 1.2 Scientific corpus (Own construction)

During the last decade, the open innovation paradigm has attracted the attention from researches and business communities because it is a model that promotes the open participation in the way to generate and commercialize ideas and technologies. Specifically, it requires a high degree of interaction between participants - internal and external - who develop strong and weak relationships (Michelfelder and Kratzer, 2013). As a branch of innovation management, open innovation is a paradigm that suggests a change from a closed to an open model (Duval and Speidel, 2014). In a world of widely distributed knowledge, organizations do not have to rely entirely on their own research, not only they should open the innovation to all its employees, but also to external actors (i.e. providers, customers). The adoption of open innovation concerns two complementary modalities: outside-in and inside-out processes (Gassmann and Enkel, 2004).

Outside-in or inbound is the integration of knowledge, ideas, concepts or technologies externally generated. Inside-out or outbound, is the transfer of internal ideas or technology towards the market through external channels. Inbound activities related to conceptual design of new product/process are perhaps one of the most challenging, due to the highly demand of collaboration to develop creative solutions. Consequently, active researches are oriented to provide the means in the form of methods and computational tools for generating innovative ideas (Hüsig and Kohn, 2009), providing structured approaches to problem solving (Ilevbare et al., 2013), and harnessing the benefits of the collective effort of individual intelligences (Garcia-Martinez and Walton, 2014).

The use of purposive inflows of knowledge makes necessary the incorporation of new technologies to collaborate across geographical distances (Huizingh, 2011). Indeed, the introduction of open innovation in organizations entails not just a modification of the corporate process of innovation, but also a cultural change which requires support by an advanced technological infrastructure. Corporate and outside knowledge has to be made explicit, exchanged and shared between participants, and therefore tools for knowledge harvesting and management, analysis support and information structuring are required to make these tools affordable and data available to all involved actors (Carbone et al., 2012). It is acknowledged (Enkel et al., 2009) that developments in Internet and Web technologies enable companies to interact with different sources during innovation activities. Consequently, these technologies allow to set up distributed collaborative environments to bring together the resources and the experts who can relate the existing pieces of knowledge to new contexts (Lee and Lan, 2007). Likewise, collaborative technologies facilitate the aggregation of multiple intelligences for the search of new ideas and innovative solutions within a community. However, the adoption of a collaborative technology does not necessary contribute to the implementation of open innovation itself.

As an application of the collective intelligence, crowdsourcing services are useful in the implementation of Open Innovation (Enkel et al., 2009). An example of the application of crowdsourcing services for open innovation is the InnoCentive platform, which aims to connect people having innovation problems with solution providers to solve business inventive problems (Allio, 2004). However, 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. On the other hand, the TRIZ methodology is presented as a systematic approach to developing creativity for innovation and inventive problem solving. However, software solutions inspired from TRIZ such as Computer Aided Innovation (CAI) tools, are limited to the practice of the closed model of innovation (Hüsig and Kohn, 2009; Leon, 2009). Therefore, the evolution in the development of CAI tools needs to take into account changes in innovation management and recent advances in collaboration technologies.

In Process System Engineering (PSE), computer aided tools are used in numerous activities such as modelling, optimization, simulation of the processes performances. These computer applications play a relevant role for increasing the efficiency of these activities but they are related to the swallow phases of the design process and are clearly oriented towards first and detailed design rather than conceptual design. To accomplish the detailed design task, process designer have at their disposal dedicated Computer Aided Design methods and tools to finalize the best engineering solution taking into account all the constraints. But before this detailed design, there is a phase to define the optimal design of the process. This optimization task is often realized through a mathematical problem. To support designers in both previous design steps, the Process System Engineering has developed mathematical and methodological breakthroughs, but the development of systematic methodologies for the earlier design step is still poorly studied. The goal of CAI can fill this gap in the PSE field.

It is important to highlight that this work is part of a strategy at the Process System Engineering department in the *Laboratoire de Génie Chimique* (LGC) laboratory, to develop methods and tools for design in process engineering. Concerning the topics treated in this manuscript, previous works in the department have been oriented following two axes: knowledge engineering or innovative design.

Knowledge engineering

- Kocsis, Tibor (2011). Study on application possibilities of Case-Based Reasoning (CBR) on the domain of scheduling problems. The work proposes the foundations of a decision-support system (based on Case Base Reasoning) in order to advise efficient modelling options and resolution strategies for scheduling problems in process engineering.
- Roldan Reyes, Eduardo (2012). Extraction and Modeling of Knowledge: Application in Process Design. This work proposes a coupling between CBR and the Constraint programming to provide a methodological framework and a software tool to assist design. The coupling is oriented to the acquisition and adaptation of online new knowledge in the phase of solution adaptation, thanks to a modification of the traditional CBR cycle by including an adaptation loop.

Innovative design

- (Cordova Lopez, 2002). Contribution to a methodological approach to the innovation process (application of the TRIZ theory to product-*procédé*-process systems). This work illustrates the methodological development of TRIZ theory, from problem formulation to solution implementation.
- Cortes Robles, Guillermo (2006). Innovation and Knowledge Management: a synergy between TRIZ theory and Case-Based Reasoning. Application in process and industrial engineering. In this work, the limits and the compatibility observed between TRIZ and CBR are employed to propose a new hybrid. This model presents an approach that combines the

technological vision of TRIZ and the ability developed by CBR to memorize and to reuse knowledge.

- Barragan Ferrer, Jesús Manuel (2013). A method for the formulation and solution of eco-innovation design problems: the application to process engineering. The work develops a methodology for the formulation and solution of eco-innovation problems based on a multi-contradiction resolution.

Particularly, this research work relies on elements from previous works and goes further by introducing the collaborative (social) aspect of the innovation process. The work uses studies from Open Innovation (strategy element), and Web advances (technological element) to propose a methodological process and a software-based framework to advance the field of Computer Aided Innovation to the next evolutionary step known as Open CAI 2.0.

1.3 Industrial context

In the knowledge-based economy, the management of technological innovation is a critical aspect towards the success of modern industry. As (Laperche et al., 2011) argue, the capacity to innovate has evolved to become the engine of competition and industry competitiveness. Therefore, the design and industrialization of new products in a shorter time is a challenge for industrialized countries (Penide et al., 2013). To overcome such scenario, industries are increasingly dependent on knowledge, information and high skill levels. Companies are aware of the importance of links with other organizations as source of specialized knowledge. Such companies see the innovation as an interactive process capable to create, and exchange knowledge within and outside firms and other organizations (OECD, 2005). Within this scenario, methods and computational tools to face industrial challenges in innovation require the ability to mobilize individual tacit knowledge, towards a more interactive strategy. Such strategy should also encourage staff skills to develop innovative products in a shorter time.

1.4 Objectives and intended results

1.4.1 Objectives

Unlike existing implementation of crowdsourcing services for Open Innovation (i.e. InnoCentive, NineSigma or Hypios), the objective of this research is to provide to participants the elements to develop creative solutions under the logical approach of the TRIZ theory. Consequently, the incorporation of the logical approach to crowdsourcing services and vice versa, comes to advance current software solution in the CAI domain. Specifically, this work explores the theoretical elements defined in the Open CAI 2.0 concept, to propose the use of the collective intelligence within the front-end of the innovation process. A general use case to illustrate the approach of this work is presented in Figure 1.3.

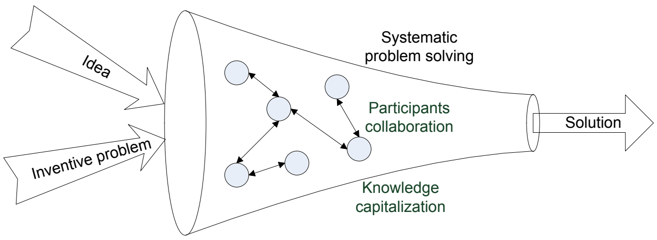

Figure 1.3 Directing inventive problem solving under Open CAI 2.0 (Own construction)

Hence, principal objectives of this work are:

I. To generate a collaborative framework capable to connect scientists, researchers, problem solvers, engineers or any other innovation stakeholders for sharing experiences, ideas and information that could be transformed into knowledge, and then into solutions.
II. To access crucial knowledge available internally and/or externally, and then to exploit it for supporting innovation problem solving.
III. To provide the elements for an information-based framework to improve the capacity for addressing the collective creative effort of participants during the preliminary (critical) phase of conceptual design.
IV. To understand the techniques, methods and tools that best support the generation of novel ideas and creative solutions.
V. To study the contribution of Information and Communication Technologies (ICTs) as tools to effectively support the collective work during the inbound process of Open Innovation.

1.4.2 Intended results

The collaborative open CAI consents several positive benefits: the intrinsic solving process reuses knowledge verified as effective (patents, past solved problems) in several technical domains, reducing time and effort while facing innovation problems. This condition can accelerate the innovation process and also increase the global performance. The solving process can capture, index and reuse knowledge if a similar situation happens. The research also analyzes the main limitations of the TRIZ theory, the case-based reasoning and collective intelligence in order to propose strategies to overcome these limitations and improve their application through a synergy capitalized in a collaborative web. In other terms, this project intents the following results:

- More efficient innovation process thanks to new methods to enhance the storage and reused of the relevant knowledge, this is improved with current information and communication technologies (ICT) evolutions.
- Dedicated tools to support innovation process instead of standard IT-software like spreadsheet calculation programs.

- Acquisition and Knowledge management needed for product/process development. This enhances the competence of the system with less effort as knowledge is rapidly updated and its transfer is permanent to provide the new advances.
- Collaborative work within innovation process, primordial aspect during idea management from the generation to the selection of ideas.
- Simplified the use of creativity techniques (key innovation success) to generate inventive insights, e.g. TRIZ. Moreover software has a positive effect on the group productivity and on the novelty of the idea generated, because knowledge management helps to stimulate creativity.
- Access to databases and to patents analysis. The goal of patents analysis is to reduce the number of patents to browse to extract the most relevant, to identify possible collaborators in the innovation process.

1.4.3 Scientific communication

As part of the scientific communication, the results of this work have been published and presented in the journals and congresses listed in Appendix I. The thematic addressed in the communications are related to the domains of industrial engineering, chemical engineering and computers engineering.

1.5 Manuscript organization

As it was exposed in above paragraphs, this project aims to propose the use of the collective intelligence to support individuals for solving innovation problems in collaboration. To achieve this goal, after this introduction the remainder of the manuscript gathers the following aspects: (a) an in-depth understanding of the mechanism for the strategic management of technological innovation in collaboration, (b) an analysis of existing solutions in the domain of Computer Aided Innovation, (c) the theoretical foundations of our Open CAI 2.0 solution, and (d) development and implementation details. We will cover each of these in turn (see Figure 1.4).

The purpose of Chapter 2 and Chapter 3 is to present the literature review about innovation management and Computer Aided Innovation respectively. **Chapter 2** presents the innovation process as a social phenomenon. It starts with elementary definitions, later it addresses the methods and techniques to guide creativity. Then, it introduces the social aspects of the innovation process, before presenting the Open Innovation paradigm. The chapter finalizes with the use of Information-Communication Technologies in innovation activities as a preamble for the following chapters.

Chapter 3 analyses the state-of-the-art in the field of Computer Aided Innovation. It covers trends in the development of this kind of tools. In addition, a section is dedicated to the emergence of new market of ideas through the use of crowdsourcing services; and, their limitations are discussed. Finally, it introduces the Open CAI 2.0 concept.

Chapter 4 introduces our proposal for a conceptual Open CAI 2.0 framework. It describes the theoretical basis to implement solutions following the Open CAI 2.0 approach. The chapter addresses the two main proposed drivers: Open Innovation and the Web 2.0. Building on the Web 2.0, the approach for collective intelligence is presented to improve the collaboration. Furthermore, the chapter provides the details about the integration of a problem resolution driver to assist in innovative design.

Details of the software-based framework development are presented in **Chapter 5.** It includes the architecture of main services, which is based on the operation of a crowdsourcing platform. The chapter also reports the workflow of the problem resolution, and the mechanism to control information integrity. Then the technical aspects include the documentation of functional and logical aspects. A section is dedicated to the human-computer interaction exposing ergonomic and usability parameters for collaborative workspaces. Finally, it is presented the development status of the proposed Open CAI 2.0 tool.

In the **Chapter 6** a case study on biomass gasification is used to illustrate the method and tool capabilities in the process system engineering domain. **Chapter 7** discusses the conclusions and the implications derived from this research, it also outlines perspectives for future works.

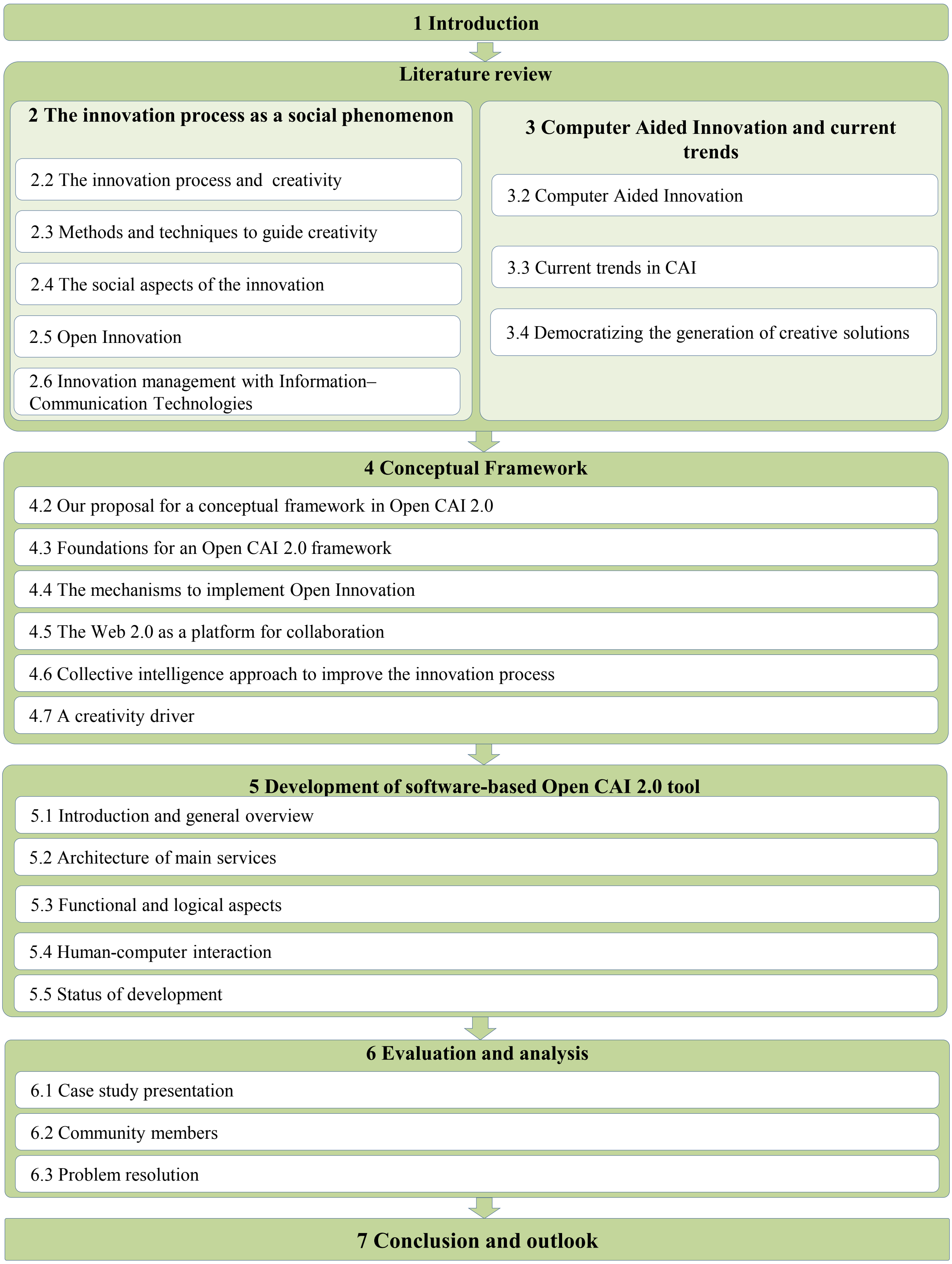

Figure 1.4 Document structure

Chapter 2 The innovation process as a social phenomenon

Highlights
• To define the basic concepts related to innovation management. • To present methods and techniques to assist the creative process. • To reveal the social aspects in collaborative innovation. • To describe the Open Innovation paradigm. • To cover the support of Information-Communication Technologies in innovation activities.

2.1 Introduction

"Disruptive innovation has become the currency of the day. New technology becomes obsolete at a much faster rate. Technology is not static. It is a dynamic fluid process in a constant state of evolutionary change."

(Badawy, 2011)

Why enterprises that were once leading the market in the past with their products (e.g. Kodak, Nokia, Yahoo), now have lost their leading position or even disappeared? Likewise, why companies that only in a short period of time in the market are competing with very well established ones (e.g. Microsoft vs IBM, Google vs Microsoft)? The answer to both questions is linked to their innovation strategies.

More than a subject in managerial, engineering, economic or political domain, innovation is the cornerstone for business survival in the beginnings of the 21st century. Companies that do not include strategies and tools for managing the innovation process are condemned to disappear; as a consequence, innovation strategies should be part of their business core.

Recent advances in Information and Communication Technologies have developed a hyper connected society. More than ever, the creation of new concepts is the result of multiple intelligences; and the companies need to adapt their innovations capacities to this reality, because the "Not Invented Here" syndrome or the "lone genius figure" just became outdated.

The first section of this chapter introduces the concept of innovation and presents aspects related to its classifications. Then, the innovation process is presented covering the managerial and engineering viewpoints. In addition, the importance of innovative design is covered. Finally, to introduce the second part, creativity is presented as a sequence of problem resolution. The second section is devoted to the methods and techniques to guide the creativity; special attention is dedicated to the model TRIZ-CBR developed in our research team.

The third section introduces the social aspects of the innovation process covering the individual and collective dimension. This section prepares the reader to the concept of Open Innovation. The fourth section presents the foundations of a more or less recent paradigm to manage the innovation process, named: Open Innovation.

Finally, the last two sections focus on elements associated with the practice of innovation activities: the concept of collective intelligence and the use of technological components in the form of Information and Communication Technologies.

2.2 The innovation process and the creativity

2.2.1 Definitions

The diverse nature of innovation makes difficult to have a unique definition, in (Walch and Romon, 2013) the authors present the innovation concept as a polysemy, specifically the definition changes according to the viewpoint or the context where it is used. This situation is an opportunity for having an open debate about its meaning. For a further discussion, some definitions are introduced.

From (Merriam-Webster, 2012) dictionary, innovation is: "*the introduction of something new; a new idea, method, or device"*. This definition proposes the action of creation and the introduction of a new concept. However, it is not clear in the aspect of where does take place the introduction (i.e. market, industry, university). This definition refers the innovation as the *subject* which is new for a particular context. The definition addresses two aspects of the concept; on the one hand is the action of creating something new, on the other hand it is the *subject* resulting from such act.

(Schilling, 2012) formulates a more complete definition; the author presents the concept as *"the practical implementation of an idea into a new device or process"*. In addition, he extends the definition to take into account the commercial aspect, presenting technological innovation as*: "the act of introducing a new device, method, or material for application to commercial or practical objectives".* Thus, the technological innovation introduces the idea of commercial exploitation; this idea is also valid in the situation where a technology is introduced in a different market. To clarify the connection with the market, (Trott, 2008) makes a distinction between innovation and invention. He suggests that innovation is concerned with the commercial and practical application of ideas or inventions. Consequently, innovation is the subsequent translation of the invention into the economy, and invention is the conception of the idea. (Trott, 2008) defines innovation as: "*the management of all the activities involved in the process of idea generation, technology development, manufacturing and marketing of a new (or improved) product or manufacturing process or equipment*". As observed, the author describes innovation as the sequence of events to transform an idea into a commercial product.

Finally, a definition based on the industrial context from the Oslo Manual (OECD, 2005) is presented: "*innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations*". This last definition, not only includes the practical implementation of innovation, but it also extends its application to the enterprise operation.

Regardless the definitions previously presented which try to clarify the research field; literature related to innovation is more complex. As (Burgelman et al., 2009) remark, related concepts to the strategic management of technology and innovation are somewhat fuzzy and overlapped. Previous authors, not only define a set of key concepts, but also they outline their interrelations. For them, innovations and discoveries are the origin of technological innovation; a discovery is something which exists but it is unknown. Inventions and discoveries are the result of a creative process, while innovations are the outcome of the innovation process. In the discussion of the key concepts, (Burgelman et al., 2009) suggest that it is useful to distinguish between activities and outcomes; hence they present in Figure 2.1 the interrelation among the key concepts. Inventions, discoveries and technologies are presented as the results of systematic Research & Development[1] activities; whereas, technological innovations are presented as the result of product, process, and market development activities.

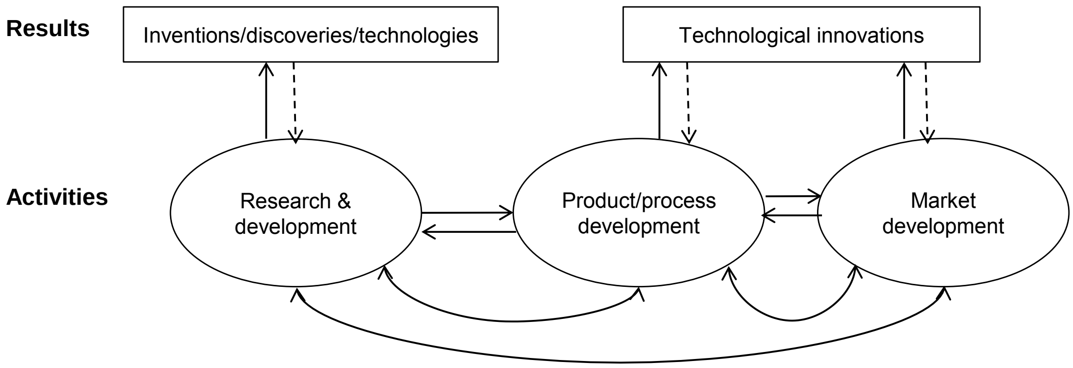

Figure 2.1 Innovation related concepts (Burgelman et al., 2009)

Definitions adapted

The previously presented definitions are adapted in this work; the purpose is to establish a common theoretical framework and to avoid possible confusions; henceforth, the innovation related concepts refer to:

- Invention. The creation of a new idea or concept.
- Innovation. The commercial exploitation of an invention or discovery.
- Discovery. The revelation of existing, but hidden, knowledge.
- Technological innovation. The practical application of an innovation (e.g. product, process or service) in the market, either through creating a new market or adapting its use to a different one.
- Innovation process. Temporary set of activities oriented to transform an invention into an innovation.

[1] (Burgelman et al., 2009) reference to basic and applied R&D. *Basic* scientific research is the activity involved in generating new knowledge about physical, biological, and social phenomena. *Applied* scientific research, on the other hand, is oriented to solving particular technical problems.

2.2.2 Innovation classifications

In order to introduce the classifications about innovation, this work identifies two categories: the target and the degree.

Innovation target

This category deals with the perception that users or organizations have about its implementation. Three possibilities may be distinguished:

- *Innovation on business management:* this kind of innovation implies working on business process to change the configuration of the organization. It covers all areas including strategic, e.g. management, human resources, marketing. The Oslo manual (OECD, 2005) suggests that the organizational innovation could be a necessary precondition for technological innovation; in addition, it can have an important impact on firm performance by improving the quality and efficiency of work or by reducing production costs.
- *Innovation on product/process*: Product and process innovation are closely related to technological innovation. However, they differentiate in the result or perception by final users; while product innovation is more visible in the outputs of an organization; instead process innovation is more internal to the organization. Process innovation is associated with improving the techniques of producing or marketing goods or services. Yet, both are complementary and important to an organization, because new products may enable the development of new processes and vice versa (Schilling, 2012).

  Seeking to understand the transition from product innovation to production process, Figure 2.2 is a model that explains this relationship. The analysis reveals the behavior of innovation through development, first it is required a high level of innovation to conceive new products. Once the product development is advanced, it is time for the manufacturing. At this stage the requirements for process innovation are higher to produce efficiently the new product.

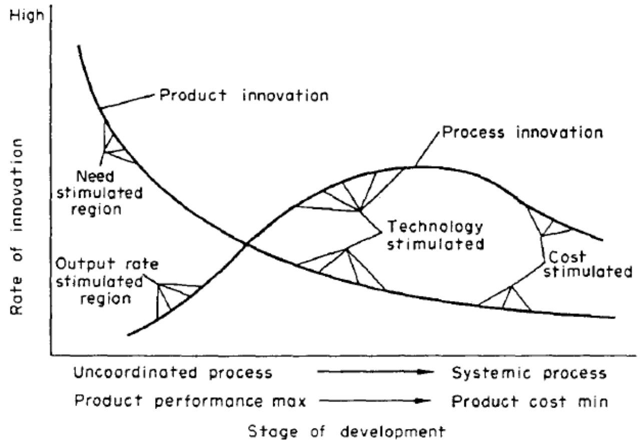

Figure 2.2 Product and process stimulation (Utterback and Abernathy, 1975)

- *Service innovation:* Reference to new ways of providing a service by using a different business model[2]. These kinds of innovations attract less attention to final users because they are often less visible than product innovations.

Innovation degree

This classification measures the degree of novelty of the innovation; it is tied to the impact of the existing technology in the market or industry.

- *Incremental or continuous innovation*: Very close to continuous improvements. It proposes minor changes compared with existing products or processes, and exploits the potential of established technologies. This type of innovation plays with the existing rules for success in industry. The rules for success are the set of conditions that each enterprise must respect to stay in a specific industry (Loarne and Blanco, 2009).
- *Radical or breakthrough innovation***:** The innovation of rupture, as its name suggests, should have a significant impact on the business by conceiving a product or process that breaks the rules of success. Its impact is as important that it creates a new category of products in the market.
- *Component or modular innovation*: An innovation to one or more components that does not significantly affect the overall configuration of a system.
- *Architectural innovation*: An innovation that changes the overall design of a system or the way its components interact with each other.

(Henderson and Clark, 1990) propose a two dimensions matrix to synthetize the typology as shown in Figure 2.3. As observed, the framework not only characterizes innovation in terms of their impact on

[2] Defined as the useful framework to link ideas and technologies to economic outcome (Chesbrough, 2006).

the components, but also in terms of the linkages between components. In addition, it introduces two new classifications, one to describe changes in the core design concepts of a technology (modular innovation), and the other to describe changes in terms of the linkages between subsystems components (architectural innovation).

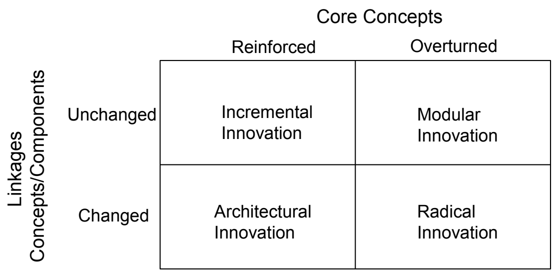

Figure 2.3 (Henderson and Clark, 1990)framework

A summary of the previously presented classification is given in Table 2.1.

Table 2.1 Summary of innovation classification

Innovation classification	Target	Business management innovation	Changes on the configuration of the organization. Including strategic management, human resources, marketing, etc.
		Product/process innovation	Characterized by the introduction of a new technology with respect to its characteristics or intended uses.
		Service	Providing a service in new ways by using a different business model.
	Degree	Incremental or continuous innovation	It proposes minor changes compared with existing products or processes, and exploits the potential of established technologies.
		Radical or breakthrough innovation	Should have a significant impact on the business by conceiving a product or process that breaks the rules of success.
		Component or modular innovation	Modification to one or more components that does not significantly affect the overall configuration of a system.
		Architectural innovation	Changes in the overall design of a system or the way its components interact with each other.

As an example comprising the four kinds of innovations, it is presented the evolution of the photography camera technology. The example starts from the photographic film camera which appeared in the late 19th and early 20th centuries, because it is the time when the technology was available to amateur photographers. The first camera available in the market was the No 1 Kodak (Lahue and Bailey, 2001). Minimal changes are observed in the film camera technology after the introduction of the No 1 Kodak, such as reducing the size or improving the precision; in addition, the market segment starts to expand. Continuing the evolution, the appearance of the 35mm camera can be considered as an architectural innovation. The 35mm keeps the photographic film technology but it introduces changes in the configuration to conceive a smaller and cheaper camera. On the other hand, digital camera technology is considered as a significant innovation in the capturing and storing photo system (Nakamura, 2005). Finally, the different components which are part of the camera system have experienced improvements without affecting the camera technology itself. The Figure 2.4 provides a graphical representation about the evolution in the camera technology to illustrate the innovation types.

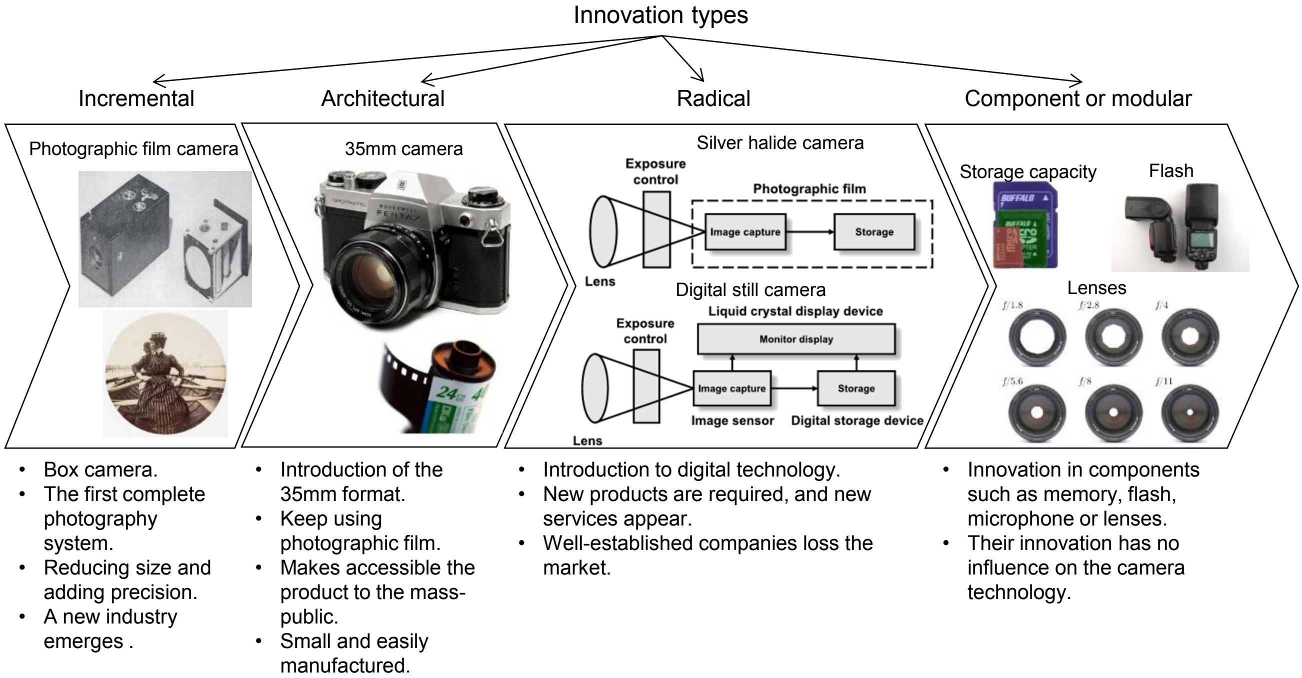

Figure 2.4 Camera technology evolution. Based on (Lahue and Bailey, 2001; Nakamura, 2005)

Once the definitions and classifications about innovation are covered, to gaining an in-depth understanding about the dynamic of innovation is necessary to study the mechanism to manage it.

2.2.3 Innovation management

The ability to develop new products quickly, and efficiently is treated as the single most important factor driving success in many industries (Schilling, 2012). Moreover, according to last author many firms receive more than one-third of their profits from products developed within the past five years. Therefore, it becomes necessary to have a managed organizational process to drive innovation and new product development. For (Penide et al., 2013), the alignment of the enterprise strategy with the innovation activity involves to identify a strategy, an infrastructure and a process.

Regarding the models for managing innovation activities, the following terms are often used interchangeably (Herzog and Leker, 2011): 'research & development', 'innovation process' and 'new product/process development'. Although the three models are closely related, this work tries to identify minimal differences which are listed in Table 2.2. As observed, the differences between the models include the involved participants and the outcomes. Research & development has an orientation to the generation of scientific knowledge. Innovation process deals with management aspects, and it is the most common term found in literature. New product/process development has as a result a technological innovation, and it offers an engineering perspective. Henceforth, the discussion takes into account only the innovation process and new product/process development models because both of them are easily addressed in a wide range of companies; whereas, research & development is limited to companies having an important number of resources (i.e. human, economic, material).

Table 2.2 Innovation management models (Own compilation)

Model	Activities	Main Actors	Outcomes
Research & development	• Basic and applied research to acquire new knowledge. • Direct research towards specified inventions or discoveries	Scientists and researches	Inventions Discoveries New technologies
Innovation process	• Front end of innovation • Development • Commercialization	Managers, economist and marketing	Innovations
New product/process development	• Opportunity identification • Concept development • Product design • Process design	Engineers	Technological innovations

The process of innovation

In order to improve the innovation capacity companies are looking for much efficient and creative innovation process. As a result, innovation process requires an organizational structure and control system to encourage the generation of inventive ideas, while also ensuring efficient selection and implementation (Schilling, 2012). The typical innovation process shown in Figure 2.5 is presented as a sequence of phases which start with idea generation (front end or fuzzy frond end), and finish with a product launch (commercialization). According to (Herzog and Leker, 2011), the first phase includes the efforts to generate and select new ideas. In the second phase, selected ideas are realized and developed. Finally, the third phase includes planning, execution and diffusion. Despite the distinction between each phase is clear, the sequential implementation of this model may entail disadvantages, such as missing feedback.

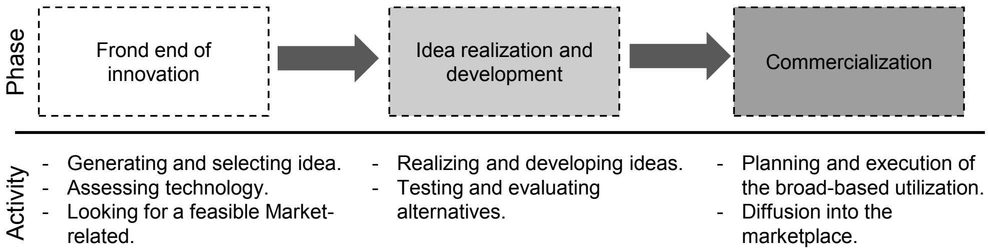

Figure 2.5 Typical innovation process and activities related (Herzog and Leker, 2011)

In an attempt to include the evaluation of ideas, (Prax, 2012) considers that the innovation process is defined by the interaction of two cycles. The first cycle goes from the idea generation to the establishment of a project. The second cycle includes the implementation of a prototype, the introduction to market and the evaluation. To clarify this idea the Figure 2.6 illustrates the macro-process in a double loop. The double loop attempts to include two of the principal elements from the innovation definition: the creative aspect and the commercial exploitation of an idea. It reflects the idea of a flexible process, in which the interaction between creativity and implementation of an idea are connected through the phases of decision taken and evaluation.

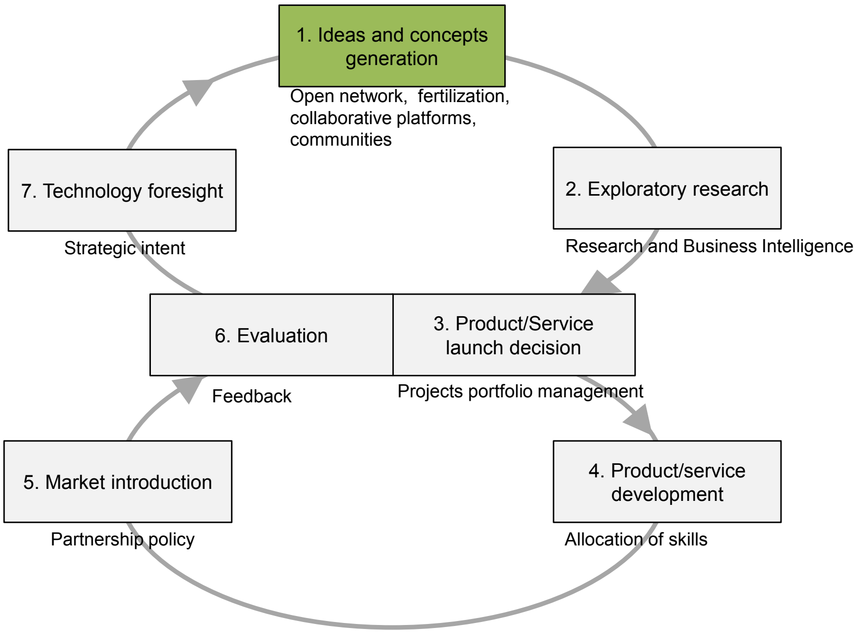

Figure 2.6 Prax's double cycle for the macro-process of innovation

A more detailed process punctuated by milestone activities is introduced in Figure 2.7. This model proposed by (Penide et al., 2013) attempts to align operational, supporting, and management activities. It allows assessing each step and setting up evaluation activities at the management level, in addition it helps to describe which best practice applies to which business process. As observed in the Figure 2.7, three complementary parts compose the process: (a) management activities at the upper level, (b) operational at the middle level, and (c) supporting at the bottom level. The input and output streams of the operational activities are drawn in white rectangles. The activities, on the other hand, are represented in gray rectangles. For (Penide et al., 2013), innovation is a process of problem resolution and knowledge transformation, e.g., the first activity aims to define or redefine a problem.

However, the opinions from practitioners and research community about the conception of the innovation process are diverse. As (Fernez-Walch and Romon, 2013) suggest, the innovation process has different representations. For instance, it is abstracted as a decision-making process, valorization process of technological change, process of adopting a novelty, marketing process, political process, the transformation of a technical system, project management process or a learning process.

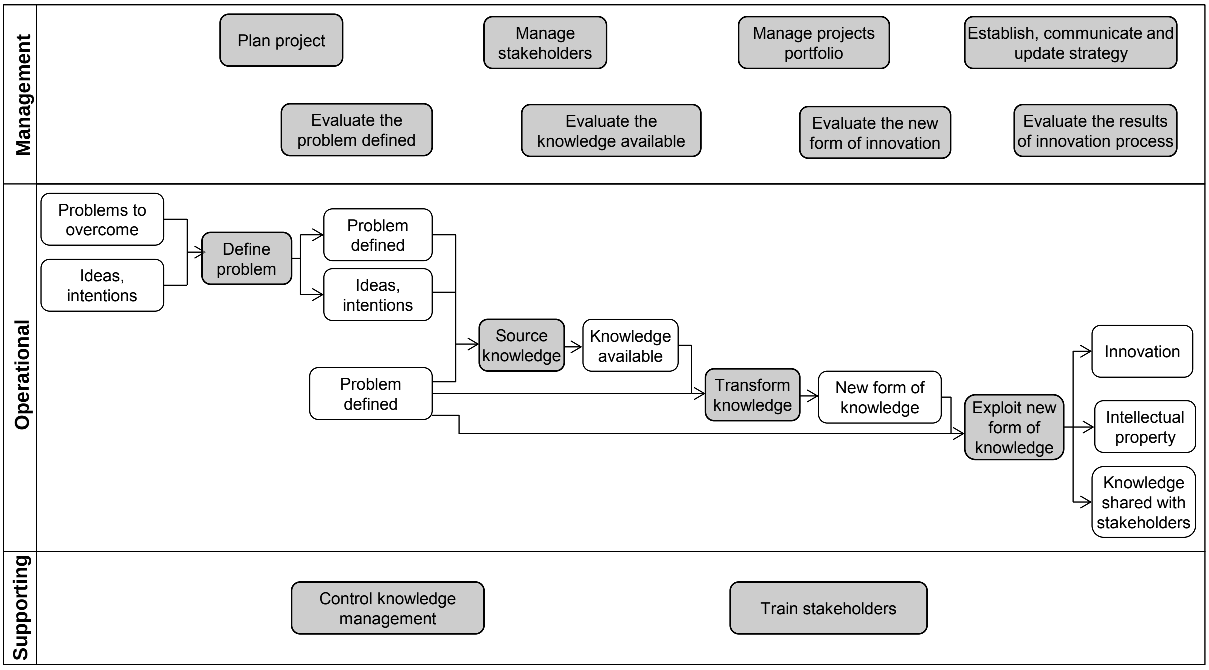

Figure 2.7 Detailed innovation process (Penide et al., 2013)

Since product/process design is closely related to the design of a technical systems, in our approach the innovation process is the transformation of a technical system; Figure 2.8 presents the sequences involved. This conceptualization not only agrees with (Penide et al., 2013) in the perception about innovation as a problem resolution process, but also suggests an engineering logic[3].

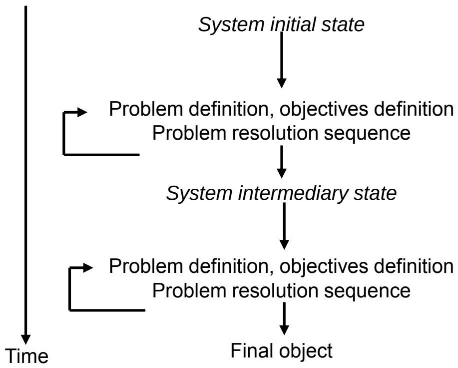

Figure 2.8 Transformation of a technological system (Fernez-Walch and Romon, 2013)

Under the logic of technological system transformation, the innovation process in different industries is represented using the activities of new product development (Fernez-Walch and Romon, 2013). In new product development, product design encompasses the transformation of an idea into the detailed definition of a system.

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[3] Marketing and manufacturing have a different approach about the innovation process.

2.2.4 New product development

According to (Sorli and Stokic, 2009; Trott, 2008) the success in market for industrial companies is based on their capabilities to create new business opportunities. The pipeline to create those opportunities starts with the development of new products. New product development comprises the activities to transform business opportunities into tangible products. Numerous representation of the phases are found in literature, but the simplest one is a linear model created by (Pahl and Beitz, 1996), which is described in Figure 2.9. The figure makes the relationship between the classical representation of the Pahl and Beitz model with the basic view of the innovation process.

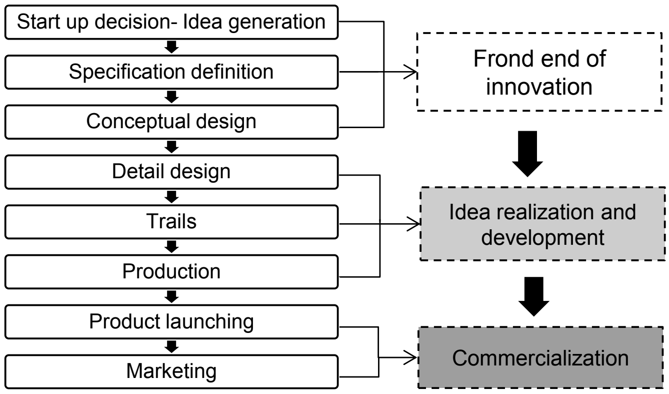

Figure 2.9 Relationship between Pahl and Beitz model and the innovation process

For (Avramenko and Kraslawski, 2008; Trott, 2008), idea generation and design represent the development of an idea to get a detailed design of a system providing a set of specifications. The decisions taken in preliminary stages have an important impact in the total cost of the final product. For example for the chemical industry, (Douglas, 1988) estimates that 80% of the total project cost is estimated in product design; the main reason is because it is easier to change a concept than a physical product. For (True and Izzi, 2002) the influence of decisions taken in the design phase represents a 70% of total cost (see Figure 2.10).

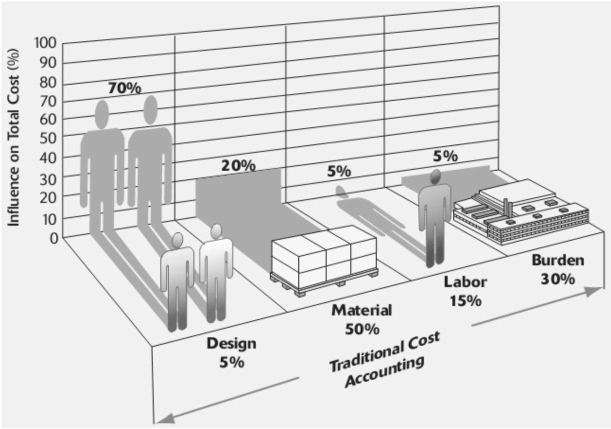

Figure 2.10 True and Izzi estimation of product design impact in total cost

Although, Pahl and Beitz attempt to propose a model to capture the key activities involved in the process; it has some drawbacks (Sorli and Stokic, 2009): it is a sequential process, it is practice in isolation, and a very low communication among departments exists. The combination of these factors makes the new product development process uncertain and complex. Consequently, it is necessary to integrate methodologies and tools to avoid failures. Particularly, the front-end should ensure the developments of new products with innovative designs, in order to enhance opportunities for success. Tools such as Total Quality Management, TRIZ methodology or Functional Analysis are part of the assisting methods to drive the complexity in product design.

2.2.5 Inventive design

According to (Wang et al., 2002), conceptual design is perhaps the most important task in product design. (Dieter, 2000) identifies this phase as the one that involves the most uncertainty, requires the most creativity and the coordination of different actors. To deal with these creative efforts, engineers use different methods, either by manual or computational means. In (Shai et al., 2009), the authors notice the importance of using strategies for improving creativity in conceptual design. According to (Belleval et al., 2010), creative conceptual design has the following characteristics: (a) the statement of an unresolved and poorly defined problem, (b) the problem has a number of contradictions, (c) the achievement of a new solution, (d) and finally the construction of new knowledge.

For (Savransky, 2000), inventive problems are a subclass of creative problems and have the potential to become a new product, process or service. Usually to solve inventive problems or to generate ideas in conceptual design, engineers use empirical methods such as: concept-knowledge theory, brainstorming, and trial-error. Nevertheless, these methods have some drawbacks (Cortes, 2006): randomness, the lack of systematization, the psychological inertia and relying on participants' talent. From a systematic perspective, innovative design can be addressed through a controllable creative thinking. Creativity thinking contributes to take new perspectives on problems and to explore unknown cognitive pathways (Kerdini and Hooge, 2013). Not surprisingly, creativity is involved in the generation of innovative ideas.

(Mumford, 2011) defines creativity as "*the production of high quality, original, and elegant solutions to problems*". For (Boden, 1998), creativity is the product of the human intelligence and it plays an important role in the design of innovative products. Regarding creativity as a powerful tool of the radical thinking, it supports the innovative design either by creating new ideas or by exploring the conceptual space of exiting ideas to combine them in novel ways. In our approach, the innovative design is conceived using the problem-resolution approach. In addition, other considerations are taken into account: knowledge management and the benefits derived from the effort of a collective intelligence community of problem solvers.

2.3 Methods and techniques to guide creativity

2.3.1 Methods classification

(Srinivasan and Kraslawski, 2006) classify these methods into two main categories: analytical and intuitive methods. The latter searches solutions using randomized process because they do not have a formalized logical structure; they lead to many iterations to generate a solution, thus a waste of time, money and human resources. In these methods the creativity process is composed of two successive logics of actions: first divergence which is followed by convergence. During the divergent part, engineers generate randomly as many ideas as possible along many directions. Because it is not conceivable to consider all these ideas for further design, the convergent part tries to manage them by merging some of them or by eliminating the less promising solutions using a multi-criteria decision but with a high risk to loose very promising concepts.

In contrast, the analytical methods partially withdraw the previous issue by proposing well-structured methods. For (Sheu and Lee, 2011), analytical methods provide more comprehensive coverage of the solution space. According to last authors, having a structured process enables systematically identifying business opportunities, stimulating the creation of innovative ideas, developing ways to transform ideas into products, and storing innovative information into a structured knowledge repository. In addition, analytical methods follow a knowledge-based approach (Savransky, 2000). For instance, they extract knowledge related to heuristics from different engineering fields, they use knowledge of effects in the natural and engineering sciences, and they include knowledge about the domain where the problem occurs. Figure 2.11 illustrates the difference between both approaches; it is observed how the empirical represents a random search for a solution. While in the analytical methods, the search for the solution is aided and delimited.

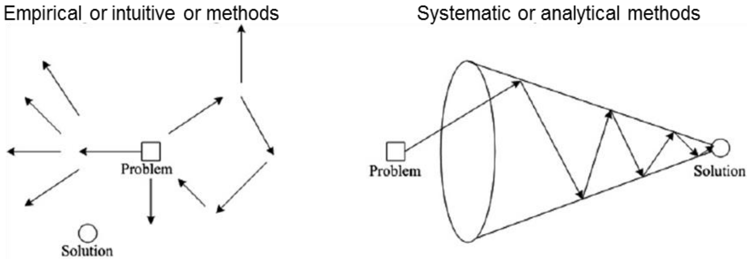

Figure 2.11 Empirical approach vs systematic innovation (Sheu and Lee, 2011)

For a better understanding about the creative methods, Table 2.3 presents an analysis about the advantages and disadvantages. It is worth to mention, that the analysis presented in the table is far from being exhaustive. However, the analysis is useful to have an overview of other methods to introduce the TRIZ method. Afterward, in this section is revealed the reason to focus on TRIZ as method to enhance creativity. An in-depth analysis about the methods is reported in (Horowitz, 1999).

Table 2.3 Creativity methods comparison (Zouaoua et al., 2010)

Method name	**Principle**	**Advantages**	**Disadvantages**
Value analysis	Satisfy user's needs and minimize company spending.	Identifies functions meeting user expectations.	Cannot be used for complex systems.
PAPSA Method	Rely on the experience of a team and their knowledge on research tools.	Removing barriers of psychological inertia through working groups and the diversity of principles proposed by tools.	Approach that lacks rigor. It needs also specific tools.
The method of brainstorming	A group of people meet to propose new ideas around a specific area of interest.	Simplicity of its implementation, brainstorming requires minimal financial investment.	The loss of time where don't find any new idea.
Quality function deployment (QFD)	Transform user demands into design quality.	Useful and efficient in the management of total quality.	If the study is of poor quality, then the entire analysis can have unfortunate consequences.
TRIZ	TRIZ is based on a very large knowledge base which leads to generate new ideas.	Can actually unlock the psychological inertia and led to real discovery.	Complicated to use, it does not provide the necessary tools to model the specific problem (pre-processing), and post-processing to find a specific solution.

Going further, (Zouaoua et al., 2010) complement the analysis with a graphical illustration comparing the level of inventiveness and the kind of innovation each method proposes. The comparison in Figure 2.12 shows the weakness of traditional methods to develop new concepts and discoveries; they are useful for minimal and major improvements. In contrast, TRIZ theory was developed to propose a systematic method, based on universal principles, generic concepts and resolution rules for inventive problems no matter the domain. Therefore, TRIZ represents a very strong method for creativity (Zouaoua, 2012).

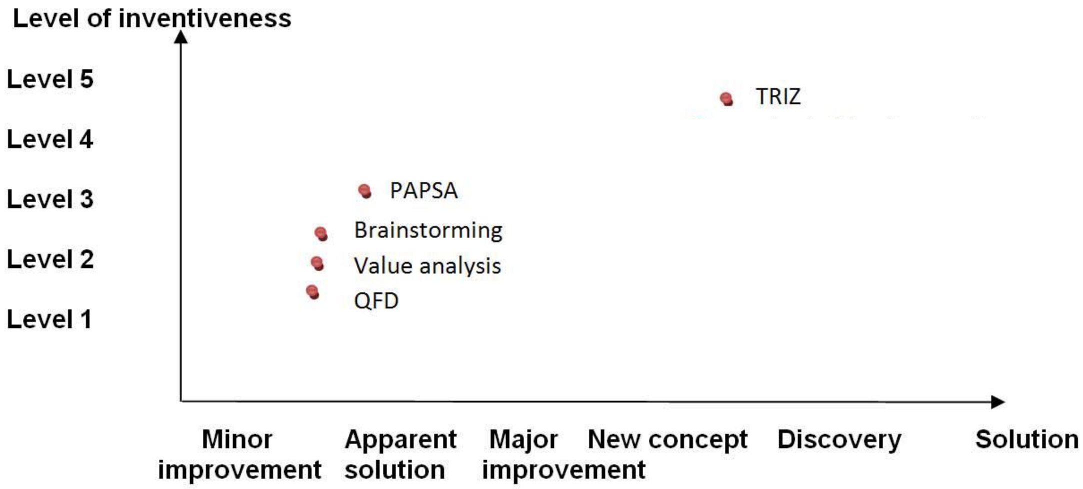

Figure 2.12 Creativity methods comparison (Zouaoua et al., 2010)

In TRIZ the creativity process is converging only because it postulates that no matter the number of concepts generated, quality prevails, i.e. viability of the concepts. TRIZ is different from other inventive methods because it operates through generic models and not through the spontaneous creativity of individuals that is why it is widely used by industries and research community. It encompasses methods and tools to propose inventive solutions for not typical problems, and helps corporations and individuals to reach their peak potential. TRIZ has been successfully applied to the extremely challenging technical barriers in design and new product development (Silverstein et al., 2007). For the aforementioned reasons, this work focuses on TRIZ to approach creativity in innovative design.

2.3.2 Elements of the TRIZ theory

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 this work. TRIZ was developed by Altshuller (Altshuller, 1996). TRIZ is a knowledge-based systematic methodology for effective and inventive problem solving dedicated to technical problems, as shown in Figure 2.13. 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 analyzed 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 subsequently be adapted to find a concrete solution. The set of conceptual solutions are referred to as meta-knowledge bases in Figure 2.13. TRIZ supports the resolution process by proposing methods and tools to analyze 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 illustrated in Figure 2.13, 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-Field) 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.

In the path to a solution, resources and ideality are two analytical tools which are also part of the TRIZ core (Rantanen and Domb, 2002). Resources are substance, information, energy, or properties of the materials. In a word, anything in the context of the problematic situation that can be used for solving the problem. Sometimes it is possible to reach a solution by solving the contradiction with a resource analysis. Ideality is a concept to describe the ultimate goal to reach in a technical system. It has its root in philosophy, where it refers to the status of ideas and pattern "per se" in metaphysics. In TRIZ, ideality applications include the ideal system, ideal process, ideal resource, ideal final result, ideal method, ideal machine and ideal substance.

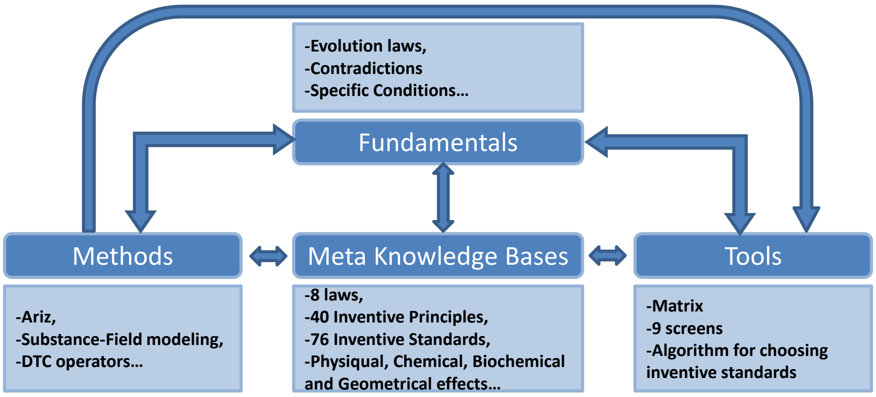

Figure 2.13 Overview of TRIZ (Cavallucci, 2013)

For (Cortes, 2006), the resolution process with TRIZ involves transforming the initial problem situation into a standard model. The next step is to propose a standard solution using TRIZ tools. Finally, there is an implementation phase; a generic solution is adapted to the specific problematic. This process is represented in Figure 2.14

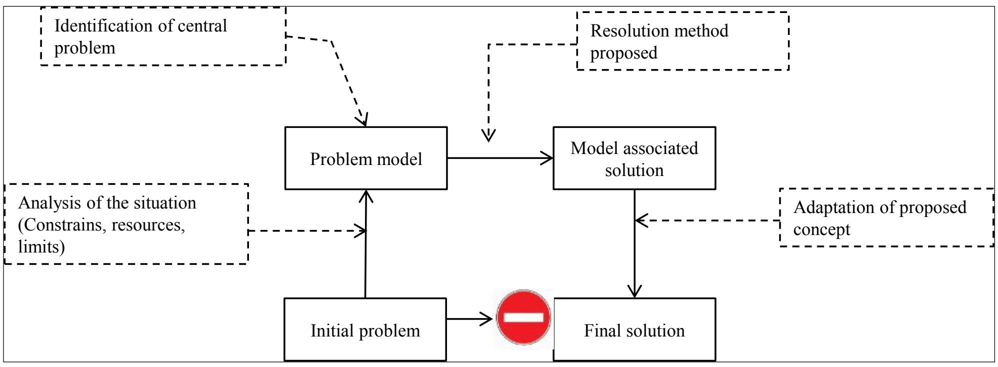

Figure 2.14 TRIZ process

Although, it might seem a simple operation, this process takes the initial problem to a higher level of abstraction. This process is mainly supported by the TRIZ main concepts and tools previously introduced in Figure 2.13. However, due to the high abstract level of TRIZ, practitioners have experienced some difficulties in implementing it because TRIZ relies on meta knowledge (high abstract level). 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, when the innovation process is deployed in collaboration, 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. Concerned by creativity enhancement and knowledge management issues, the Process System Engineering (PSI) research department has previously explored improvements to the TRIZ methodology. In (Cortes Robles et al., 2009b), is proposed a method based on the hybridization between TRIZ and a knowledge management approach, namely Case Based Reasoning (CBR). 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.
- 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).

2.3.3 The TRIZ-CBR model

As defined previously, creative design is composed with activities of a problem resolution process. Thus, this work uses the model TRIZ-CBR (Cortes Robles et al., 2009b) as the approach to systematically guide the creative design. This model proposes the integration of the Theory of Inventive Problem Solving (TRIZ), and the Case-Based Reasoning (CBR) process in order to conceive a solving process, capable to guide creativity while generating innovative solutions and also to store, index and reuse knowledge with the aim to accelerate the innovation process (Figure 2.15).

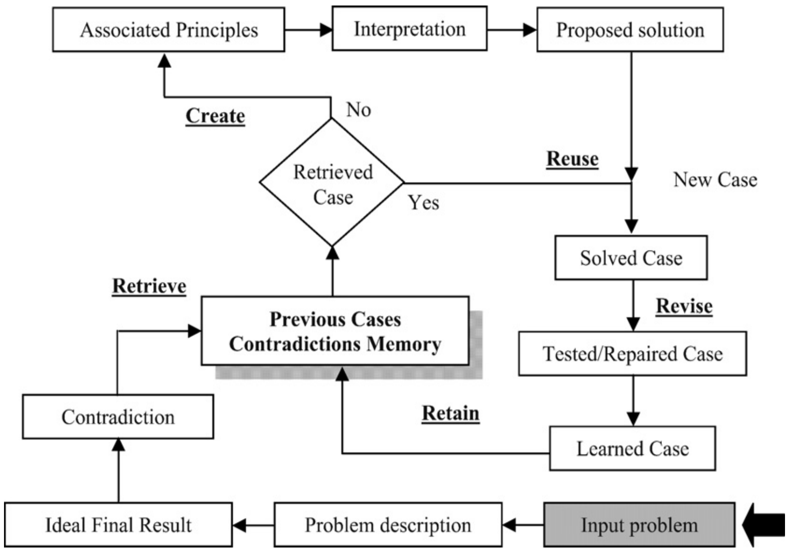

Figure 2.15 Model TRIZ-CBR (Cortes, 2006)

The solving process in the Figure 2.15 is composed as follows: The preliminary step is to collect data on the handling problem and to describe it. Before filling the five features concerning the problem description, the ideal solution is as well stated in order to propose a guide for the search direction of the future solution. Then, the problem, which is stated as a contradiction is coupled with the whole problem description (contradiction and the other features), and used to explore the memory content for a similar problem. At this point of the synergy process, two different sub processes can take place:

1) The retrieval offers a sufficiently similar problem or set of problems. Such a situation leads to the evaluation of the associated solutions to decide which solution or solving strategy has to be used as initial solution. Here the similarity between two problems is calculated with a similarity global function like Euclidean distance and then classified using the nearest neighbor algorithm.
2) The memory does not have any similar solved case or sufficiently similar case (the similarity global function has a too small value). Under this condition, the system offers inventive principles associated to the contradiction, by which a satisfactory solution could be derived. The contradiction matrix or a separation principle finds its initial use.

Whatever the chosen sub-process, both converge to a proposed initial solution. Then the solution obtained is revised, tested and repaired if necessary with the aim to produce a satisfactory solution. Finally, the new solution is incorporated in the memory in order to be reutilized in the future.

Despite the resolution process proposed in model TRIZ-CBR has demonstrated its efficiency, the reports in literature (Cortes Robles et al., 2009a, 2008; Negny et al., 2012) illustrate an individual operation. Indeed, the model needs to evolve and adapt to new innovation practices (i.e. the open innovation paradigm). Other major element to create the conditions for collaboration is the technological component, and companies are including the Web 2.0 as a platform for collaborative work.

2.4 The social aspects of the innovation process

2.4.1 Two dimensions of the innovation: individual and collective

Concerning the type of participation, the companies have two strategies for searching innovative solutions: individual or collective. “The lone genius figure” (Montuori and Purser, 1995) is a common reference for evoking the individual strategy. It represents the search for a solution when it happens in isolation, either at department or organization level. For example, in the Pahl and Beitz model one of its drawbacks is the “design over the wall” problem. Design over the wall means that each department work in isolation and they do not cooperate or share information with other departments (Sorli and Stokic, 2009). At the organization level, one of the isolation symptoms is the “Not Invented Here” syndrome (Katz and Allen, 2007), in this situation organizations reject collaboration or the incorporation of external generated knowledge.

Thus, the individual dimension of innovation is characterized by:

- Difficulties in knowledge flow.
- No cooperation.
- Rejection of external knowledge.
- Rejection of external ideas.
- Practiced in isolation either at department or organization level.

On the other hand, (Montuori and Purser, 1995) reference the collective strategy of the innovation process when the creative thinking requires a social context to develop itself. For (Forsyth, 2010), a social context is defined by a complex sets of relationships between a group of individuals, and its reason to exist is when one of the participants generates valuable information that influences the other members and vice versa. In this case, creativity is the result of the collective resolution of problems to generate high quality novel ideas. Moreover, (Mumford, 2011) argues that within an organization the innovative effort involves multiple parties which contribute to transform a creative solution into a product, service, or process marketable; placing the innovation as an organizational social phenomenon. When the collective effort goes beyond the organization’s boundaries a new form of collaborative innovation named “Open Innovation” (concept is discussed deeper in section 2.5).

Then, the collective dimension of the innovation process is characterized by:

- A collective problem resolution.
- A social phenomenon.

- A high communication between participants is required.
- Involving different organizational parties.
- The organization boundaries are expanded.
- Requiring an openness to work in collaboration.

As (Christofol et al., 2004) underline the quality of the interactions between actors within an enterprise is a key performance factor. In this scenario, the hierarchy schemes are changing. However, the transition from the individual dimension of creativity, to a social context is not evident. For (Lazer and Bernstein, 2012), the key question is how individuals aggregate their contributions to the collectivity. Thus, in order to coordinate the efforts of involved actors, it is required to have effective environments for collaboration.

2.4.2 Collaborative innovation

The concept of collaborative innovation is an expression of the social aspect in innovation management; it implicates that innovations are less and less the outcome of an individual company's isolated efforts (Nieto and Santamaria 2007). According to previous authors, collaboration with suppliers, clients or research organizations has a positive impact on the novelty of innovations. In addition to collaboration, the integration and management of internal and external knowledge, is important to improve the levels of innovativeness and competitiveness. Collaborative innovation means to gain access to external sources of knowledge and skills. The collaborative social aspect of innovation, not only represents a change in the conceptualization of innovation process, but also it requires the support of collaborative technologies (Standing and Kiniti 2011; Hüsig and Kohn 2011). Regarding knowledge management, diversification in knowledge sources in combination with complexity in organizations requires the means to interpret in the same way the different knowledge structures (AFIS and Meinadier, 2012). Therefore, high degree of interactivity, intensive knowledge management, connectivity and sharing are the key feature to consider when designing and implementing a technological framework for supporting collaborative innovations. These problems are studied by a relative new paradigm in innovation management named Open Innovation.

Collaboration within the enterprise starts when the creative efforts are developed beyond the boundaries of the Research & Development (R&D) department (Duval and Speidel, 2014). They argued that the lack of internal collaboration is because of an inappropriate organization or departmental silos, consequently the enterprise does not benefit from talented internal workers.

Collaboration outside the enterprise boundaries does not replace the internal capabilities to develop innovative solutions; instead it is a complementary way to foster the creation of ideas and the development of new solutions. Collaborative innovation involves a deep understanding and the combination of knowledge from different domains; for this reason the collaboration has to be very closed and must involve different experts (Christofol et al., 2004). In addition, heterogeneity in knowledge resulting from collaboration encourages the development of radical innovations (Enkel and Heil, 2014). Besides the emergence of an unexpected idea, collaboration has the advantages of accelerating the innovation process and reducing the risks (Bruce et al., 1995; de Man and Duysters, 2005).

A classification of different forms of collaboration is presented in (Christofol et al., 2004). The classification illustrated in Figure 2.16 uses an approach associated with information technologies and collaborative networking, it identifies the following organizations:

- Employees. It is the simplest working form. It is individual work that does not require any specific collaboration activity.
- Teams. Each employee belongs to a second organization level, specifically one or more teams in which the employees are grouped for making collective work. Teams are located within the enterprise boundaries, and they could be composed with members from different domains or departments, resulting in multidisciplinary groups.
- Communities of economic interests. A third level that is out of the enterprise limits, because it concerns the companies that share resources or certain operations and the risk associated; it is the case of centrals purchasing, cooperatives or eco-industrial parks. Different organizations share resources to get the maximum benefit, however they are not call for sharing knowledge.
- A community of practice. In this organization level, the objective is to develop common practices for specific interests. The participation in these groups is voluntary, the employees communicate with their partners, for instance, to elaborate standards or norms in specific domains. It is a kind of formal organization.
- Virtual communities. Individuals that share the same interest group using the platforms proposed in the Web, like forums, to share information and opinions. These communities do not need a physical existence.
- Concurrent business. In this upper level, it exists a really collaborative work. In fact, the necessity to collaborate is originated when companies join efforts to participate in a common objective. Employees and teams from participating companies have to share their knowledge and experience in order to innovate in the market; specifically this approach requires having a common product vision or innovative services to be done. Furthermore, the contractual aspects are primordial in this form of collaboration.

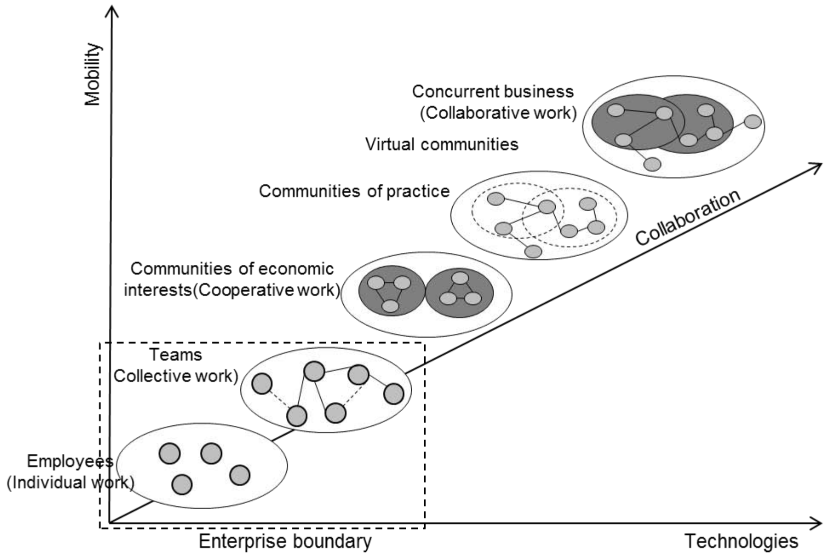

Figure 2.16 Different collaboration levels (Christofol et al., 2004)

2.5 Open Innovation

As a branch of innovation management, open innovation is a paradigm suggesting a change from a closed to and open model (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). (Trott and Hartmann, 2009) have also listed various "old" industrial success stories in open innovation. But the first definition found in literature was proposed latter by (Chesbrough, 2003), it says: "*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"*. According to Chesbrough (2003), firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as firms look to advance their technology. It is important to point the definition of "open" in the concept, is related to the liberty that ideas have in order to flow into the process, and the liberty to flow 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, then to integrate the non-pecuniary knowledge flows. To integrate these evolutions, (Chesbrough and Bogers, 2014) have extended the definition as follows: "*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 (Chesbrough, 2003; Chiaroni et al., 2011; Hüsig and Kohn, 2011; Wallin and Von Krogh, 2010) agree that open innovation shows its efficiency by changing the way in which the enterprises interact with customers and other external actors (suppliers, or universities). The interaction is practiced in a more open way to improve their innovative capabilities and to accelerate internal innovation. This is contrasted with the 'closed' model of innovation, where firms typically generate and develop their own ideas and innovation in isolation. To detail the open innovation concept, Table 2.4 makes a comparison between close innovation and open innovation. But (Trott and Hartmann, 2009) showed that the dichotomy between closed and open innovation may be true in theory, but does not really exist in industry. They have examined the six principles of close innovation (and by consequence those of open innovation), and they have contributed to the debate on open innovation. Indeed, they have explained that the open innovation paradigm has created a partial perception by describing something which is true (limitations of close innovation), but false in converging the impression that firms follows these principles. Furthermore, the relationship between concepts and practices associated is uncertain, as some practices were broadly defined (van de Vrande et al., 2009). Another major limitation is to undervalue the practice of open innovation inside the organizations, and to think that it should be exclusively based on interacting outside the company boundaries (Duval and Speidel, 2014).

Table 2.4 Close Innovation vs. Open Innovation (Chesbrough, 2003)

Closed innovation	**Open Innovation**
• The smart people in the field work for us	• Not all the smart people work for us
• To profit from R&D we must discover, develop and ship it ourselves	• External R&D can create value; internal R&D is needed to claim a portion of that value
• If we discover it ourselves, we go to market first	• We don't have to originate the research in order to profit from it
• If we are the first to commercialize an innovation, we will win	• Building a better business model is better than getting to market first
• If we create the most and best ideas in the industry, we will win	• If we make the best use of both internal and external ideas, we will win
• We should control our IP so that our competitors don't profit from our ideas	• We should profit from others' use of our IP and vice versa

For the industry, open innovation represents the antithesis of traditional vertical model in new product development process, and it is a solution to problems and drawbacks for the design process in traditional hierarchical organizations (Sorli and Stokic, 2009). The open innovation paradigm is mainly centered in the use of explicit internal as well as external knowledge, in order to accelerate internal innovation; in opposition to the "Not Invented Here" syndrome (Katz and Allen, 2007).

As a process, open innovation has a heavy management of knowledge. It is based on the principle that valuable ideas can come from inside or outside the company, and can go to market inside or outside the company as well; often this knowledge flow is represented by the classical funnel, Figure 2.17. However, the useful knowledge is widely distributed, this represents a challenge to identify, interact and take advantage of external knowledge sources, in order to integrate it in the core of the innovation process (Chesbrough et al., 2006).

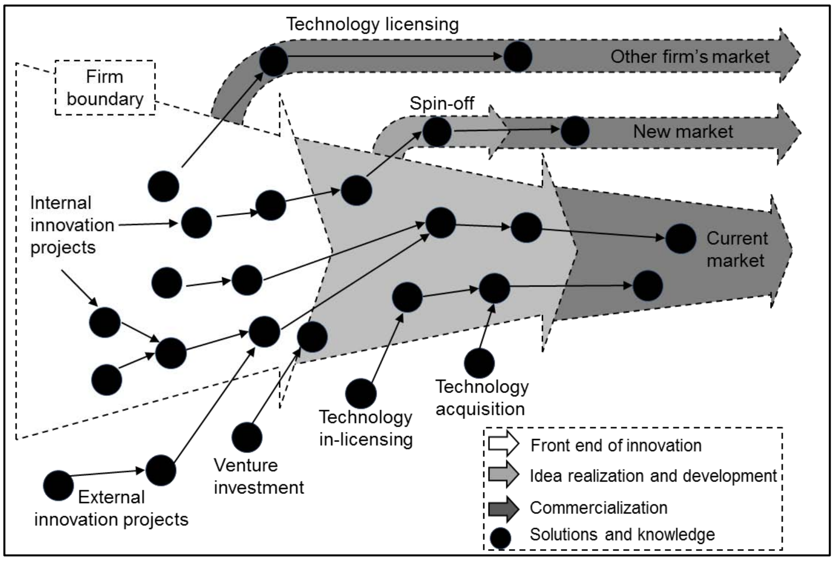

Figure 2.17 Open innovation model (Herzog and Leker, 2011)

2.5.1 Two modalities: outside-in and inside-out

Outside-in and inside-out modalities represent knowledge flow through the companies' boundaries. Outside-in or inbound is the integration of knowledge, ideas, concepts or technology externally generated, namely it denotes the integration of outside sources of innovation within one or more phases of the internal innovation process (Herzog and Leker, 2011). For (Gassmann and Enkel, 2004) the practices associated to outside-in are:

- Earlier supplier integration.
- Customer co-development.
- External knowledge sourcing and integration.
- In-licensing and buying patents.

Inside-out or outbound is the transfer of internal ideas or technology to market through external channels, in order to generate additional value. The concerned technologies are those not exploited commercially because they do not correspond to the business model (Chesbrough et al., 2006). For (Gassmann and Enkel, 2004) the practices associated to this process are:

- Bringing ideas to market.
- Out-licensing and/or selling Intellectual Property (IP).
- Multiplying technology through different applications.

A third modality is observed in companies that coupled both previous modalities, illustrated in Figure 2.18. In (Gassmann and Enkel, 2004), the authors describe the coupled modality as the combination of outside-in and inside-out modalities by co-operating with other companies in strategic networks. This approach characterizes that in practice is required integrating both processes, however it is a generic model without implementation details.

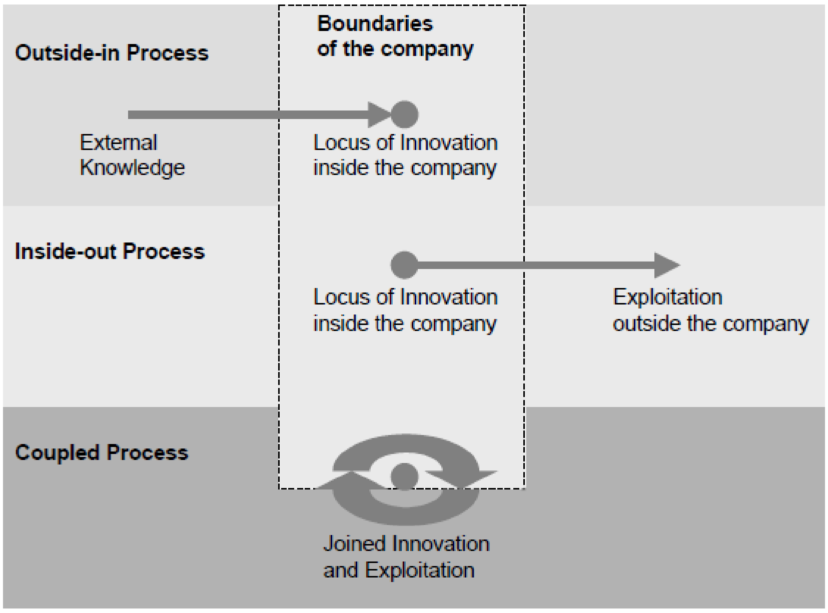

Figure 2.18 Coupling outside-in and inside-out (Gassmann and Enkel, 2004)

Although Open Innovation is composed of activities related to both modalities, (Huizingh, 2011) reports that empirical studies have found that companies perform more inbound than outbound activities. (Huizingh, 2011) argues that historical reasons and the fear of diffusing relevant knowledge are the major justifications.

2.5.2 Open Innovation by examples

After Chesbrough coined the term Open Innovation in 2003, the concept has attracted the interest in the area of innovation management; even to become one of the hottest topics in the field (Huizingh, 2011). However, managerial practices such as licensing (in and out), joint R&D agreements, or spin-offs were known before the apparition of the term (Herzog and Leker, 2011). In fact, Open Innovation is inspired by existing industrial practices to formulate its concepts and processes (Steiner, 2014). Steiner presents case studies to document the existing industrial practices.

- Dupont

After 1970, Dupont has an important politic for licensing patents related to production process. This strategy has allowed the company to improve the incomes with technology that is out of its business plan. Moreover, some technologies are only developed to be commercialized, and the principal customers come from emerging economies.

Built upon the service of Yet.com, Dupont has developed DuPont TechnologyBank™ for accessing to its technology and know-how, in order to spread technologies for becoming industry standards. Finally after the mid-1990s, Dupont has made available at no cost some of its patents in universities, hospitals and non-profit organizations. The benefits are twofold: the company improves its public image, and at the same time it reduces the payment of taxes.

- IBM

To value more than 40,000 patents, IBM has implemented the program named "Ventures in Collaboration". IBM helps entrepreneurs to adopt the technology contained in the patent. Other open strategy implemented in IBM is to supply its software in Open Source license with the interests of linking the enterprises to IBM technologies. In 2005, it leaved 500 patents to the Open Source community.

- Intel

Intel approach for Open Innovation relies on the extensive use of external knowledge. In fact, its R&D strategy is based on four pillars:

(i) contract research with universities,
(ii) partnership with laboratories which are related to universities,
(iii) venture capital,
and (iv) internal research programs.

The collaboration is done in the basis of equality; as a result, they create a strong mutual confidence that makes easy information exchange. About the strategy of venture capital, Intel plays the role of business angel for funding start-up projects. Besides the role of business angel, Intel participates in the Open Source movement by releasing the licenses of some of its drivers for network and graphic cards.

- Procter & Gamble

In early 2000s, Procter & Gamble started the program named "Connect & Develop" with the 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. Procter & Gamble started developing a Web platform for inter-department communication, asking for all possible expertise in the development of projects. With this strategy, they tried to avoid duplicate efforts or to buy existing solutions within other departments (Duval and Speidel, 2014).

Ten years after the lunching of Connect and Development program, the participation of external elements in the development of a product is more than 50%, in contrast with only 15% in the beginning. Moreover, the rate of innovation success has double while the cost has decreased, and there are more than 1,000 active collaborations have taken place.

Nowadays, Open innovation is adopted by more and more chemical engineering companies for instance Veolia and the oil company Repsol. In 2010 the former launches a new program, namely Veolia Open Innovation Accelerator, future entrepreneur proposes ideas and the company gives access to more markets, pilot sites and to its R&D capability and expertise. For the latter, (Carbone et al., 2012) have explained how open innovation can improve the performance of the company, more specifically thanks to a knowledge management systems in large corporations.

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. Thus, specific computer aided tools are required to support each phase of the opening of innovation process to foster interaction and collaboration for the creation of new insights. The technologies are needed to collaborate in achieving a common goal by sharing ideas, information and work. They facilitate exchanges, and are the necessary connectivity and interactivity required in open innovation. For this reason, we have to introduce the new evolutions of collaborative tools like Information and Communication Technologies (ICT).

2.6 Innovation management with Information–Communication Technologies

ICT provide the mechanisms for communicating and exchanging information and knowledge in organizations (see Figure 2.19). ICT is a term that gathers different technologies, applications and services that enable access to knowledge, information and communications, often working over telecommunication networks. As a consequence, ICT not only improve social interaction, but also they transform the operation of organizations (Hoogeweegen et al., 1999).

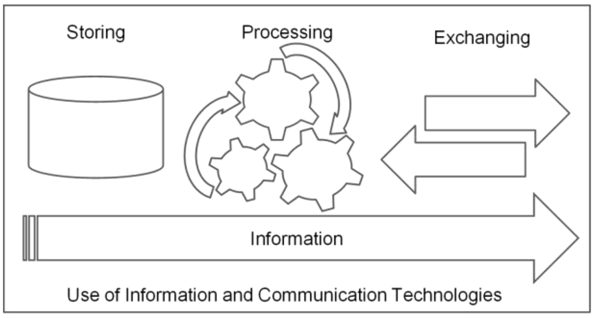

Figure 2.19 The use of ICT in organizations (Own construction)

Nowadays, the role that Information–Communication Technologies (ICT) plays in business is changing (Awazu et al., 2009). In the era of open and distributed innovation, businesses and organizations use ICT in order to manage ideas from internal and external actors. The result of those changes is that ICT act as a driver for the entire innovation process, from idea generation and development to experiment and test, and, finally, to commercialization. Another contribution of ICT is that they facilitate collaborative efforts.

For example, Whirlpool (Melymuka, 2004) created an electronic workspace on its intranet where employees can share their insights with other employees. It was named "Innovation E-Space" and it allows individuals to access both electronic and human resources. Also the websites links to a variety source of information like electronic libraries, and helps to connect employees with in-house innovation consultants, that they call "I-Mentors". In this application individuals can access human innovation experts via networks that are not restricted by formal hierarchical structures. The approach of I-Mentors demonstrates that knowledge-capturing systems can be most effective when they take human-centered view of knowledge. Social enabling tools allow people to form mentoring relationships and create special interest groups. A conclusion from this example is that ICT not only facilitate communication between individuals, but also strength organizational structure.

The market of Information and Communication Technologies for supporting innovation process is evolving, as are evolving the methods for managing innovation. There is a real interest, and new ones are continually emerging (Sorli and Stokic 2009). Specifically the Web technologies are transforming all human activities dependent on information, including social interactions.

2.6.1 Web Technologies

According to the World Wide Web Consortium (W3C) the World Wide Web (known as "WWW", "Web" or "W3") is the universe of network-accessible information, the embodiment of human knowledge. It is a system of interlinked hypertext documents accessed via the Internet (W3C, 2012a).

The Web has evolved by stages: in the first generation there were web sites with static information, the second generation or Web 2.0 is a more dynamic environment, where have emerged an important number of social applications. And now, it is the transition through the Web of data or Semantic Web.

The Web 2.0

The Web 2.0 term was coined by (O'Reilly, 2007) to describe the network, mainly internet, as a platform. This platform gives pathways to deliver software as a continually-updated service that gets better the more people use it, this fact is often reference as the network effect. The network effect in the Web 2.0 has given as consequence a rise of social applications. The Web 2.0 is based on architecture of participation, where users consume and remix data from multiple sources, while producing their own data and sharing with others. In addition, the Web 2.0 has the potential to deliver full scale applications with rich user interfaces and high interactivity.

Frequently, the Web 2.0 is associated with well-known application (e.g. Facebook, Youtube, Wikipedia). Table 2.5 introduces a comparison using some examples from Web 1.0 and Web 2.0.

Table 2.5 Web 1.0 and Web 2.0 samples (O'Reilly 2007)

Web 1.0	Web 2.0
DoubleClick	Google AdSense
Ofoto	Flickr
Akamai	BitTorrent
mp3.com	Napster
Britannica Online	Wikipedia
personal websites	blogging
screen scraping	web services

For (Tacke, 2010), the Web 2.0 and open innovation are concepts related in order to support the collaboration of different people and the emergence of new ideas. For the last author, the Web 2.0 community constitutes an ideal environment for implementing open innovation, because both are based on openness and participation of a wide range of people. (Lindermann et al., 2009) argue that the Web 2.0 has a positive impact on innovation activities because:

- Employees are motivated to transfer their experience using Web 2.0-applications on private life to a cross-organizational environment.
- Heterogeneous groups offer a high potential for creativity and innovation.

Even though, the applications from the Web 2.0 give an important place to data and have progressed in the automatization to treat information to harness collective intelligence, those applications face limitations because current Web 2.0 technologies were not conceived to give meaning to the information. In the approach of semantic Web, there are newer possibilities to represent and exchange big amount of information not only by humans, but also by machines within the Web context.

The Semantic Web

The W3C (W3C, 2012b) defines the semantic Web as: "*a technology stack to support a Web of data. The ultimate goal of the Web of data is to enable computers to do more useful work and to develop systems that can support trusted interactions over the network. The term Semantic refers the vision of the Web of linked data. Semantic Web technologies enable people to create data stores on the Web, build vocabularies, and write rules for handling data*". The principal technologies that empower Linked data are: RDF, SPARQL, OWL, and SKOS.

A shorter definition by (Hebeler et al., 2009) about semantic Web stands: "*Semantic Web is simply a web of data described and linked in ways to establish context or semantics that adhere to defined grammar and language constructs*".

Both definitions make an emphasis in giving a meaning to the information. A way to archive it is by adding meta-data to the information. The W3C propose the use of semantic technologies represented in Figure 2.20. This architecture was first proposed by Tim Berners-Lee (2000), as observed the layers are organized in hierarchy, where the lower layers provide support to upper layers. All the components are important, but it can be said that RDF and Ontology layers are the core technologies building the semantic web. Technologies such as XML or URI have a wider use in other kinds of applications.

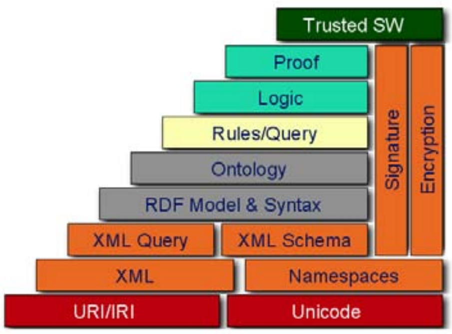

Figure 2.20 Semantic Web Stack (W3C, 2012c)

For (Bojārs et al., 2008), the semantic Web can help to cross some of the boundaries that Web 2.0 is facing by offering a generic infrastructure for interchange, integration and creative reuse of structured data. To approach the goal of automated information sharing, the Sematic Web differentiates from its previous versions (Web 1.0 and Web 2.0) according to the Table 2.6.

Table 2.6 Comparison between Web and Semantic Web (Hebeler et al., 2009)

Feature	Web (1.0 and 2.0)	Semantic Web
Fundamental component	Unstructured content	Formal statements
Primary audience	Humans	Applications
Links	Indicate location	Indicate location and meaning
Primary vocabulary	Formatting instructions	Semantics and logic
Logic	Informal/nonstandard	Description logic

2.7 Lessons and conclusions

This chapter has introduced the different concepts, activities and strategies related to innovation and the strategic management of innovation. From this study we have retained the following lessons and conclusions.

Innovation is a complex word, with different definitions, classifications and perspectives. Within the context of this work, innovation is approached from and engineering viewpoint and a management viewpoint. Consequently, vocabulary associated comprises activities (e.g. innovation management, product/process development), and the results of these activities (e.g. inventions and technological innovations). From the engineering viewpoint, creativity is outlined as a problem resolution process.

From a management viewpoint, the innovation activities are too important to depend on the skills of only one staff or department. Open innovation is an opportunity to develop a strategy to be in synergy with the marketplace, either to acquire solutions or to commercialize ideas out of the business model. However, as a more or less recent paradigm the open innovation adoption is under development.

We highlight the importance of the fuzzy front end of the innovation process (i.e. product design), because it is the phase that requires the most of creativity. In addition, the decisions taken in this phase will impact even 80% of the total cost of the product. Formal techniques to guide creativity such as TRIZ help to overcome the difficulties in idea generation and problem resolution. However, TRIZ theory is still evolving and new models are proposed in literature. The model TRIZ-CBR as an extension of TRIZ comprises the tasks to benefit from past experiences with a knowledge capitalization approach. Although, TRIZ in general, and the model TRIZ-CBR in particular have demonstrated their efficiency, the reports in literature illustrate examples of individual operation. To tackle a collaborative approach, as proposed by the open innovation paradigm, we include the use of Information and Communication Technologies (ICT).

ICT provide the technological elements that could reduce the gap between the individual operation of TRIZ, and the lack for systematization of creativity in open innovation. The benefits are twofold: integrating the use of engineering techniques in the practice of Open Innovation, at least for the generation of creative ideas. On the other hand, TRIZ practitioners have the possibility to open up the problem resolution process to the inclusion of multiple sources of knowledge and intelligences.

Further research in the development of integrating solutions should take into consideration:

- The state of the art in Computer Aided Innovation
- Engineering practices in Open Innovation
- Advances in ICT field
- Collaboration patterns
- The management of Intellectual Property

Computer Aided Innovation is a research field that studies the theoretical basis and the implementation of Information-based systems regarding the phases of the innovation process. The Chapter 3 describes in detail this research field. It addresses also trends in evolution; special attention is given to the use of the "wisdom of the crowds" in innovation activities.

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Chapter 3 Computer Aided Innovation and current trends

Highlights
• To define the theoretical basis of the research field Computer Aided Innovation. • To describe the existing developments, commercial as well as academic. • To present the new trends in the development of Computer Aided Innovation. • To introduce the Open CAI 2.0 proposition as the next evolutionary step in Computer Aided Innovation. • To present the emerging market of ideas influenced by the power of the "wisdom of the crowds". • To detail the mechanism of collective intelligence.

3.1 Introduction

"…ignorance more frequently begets confidence than does knowledge: it is those who know little, and not those who know much, who so positively assert that this or that problem will never be solved."

The Descent of Man (Darwin, 1871)

The use of Computer Aided technologies is part of the strategic to facilitate the transition from a close model to drive the innovation process, to a more open approach which includes actors and knowledge beyond the enterprise boundaries. In this scenario Computer Aided Innovation(CAI) tools are useful to facilitate collaborative work, to implement knowledge management systems, to perform routine and time consuming activities (e.g. patents search), and to access external sources of information (Michael, 2006).

Computer Aided Innovation is a software-based solution assisting the participants involved through the innovation process. In the beginnings, CAI software was mainly inspired by TRIZ methods and tools. However, CAI solutions are progressively evolving and adapting to enterprises' needs.

This chapter focuses on describing the CAI solutions. Aspects such as classification, development, benefits and challenges are outlined for academic and commercial solutions. Then, new trends in CAI are presented. From the trends, the emerging market of ideas is documented to highlight the advantages of the "wisdom of the crowds" in the innovation processes, particularly for the conceptual design phase. Finally the Open CAI 2.0 proposition is introduced as the next evolutionary step in the development of CAI solution.

3.2 Computer Aided Innovation

According to (Schilling, 2012) the innovation process is often conceived as a funnel, with many potential new ideas, but very few are successfully implemented as products. The innovation funnel is useful to study the relationship between the success and failure of innovation projects (see Figure 3.1). (Schilling, 2012) concludes that most innovative ideas do not become successful new products, thus to improve the potential of innovation success well-crafted strategies and suitable tools are indispensable. CAI tools extend new product development systems for assisting in the conception of innovative products.

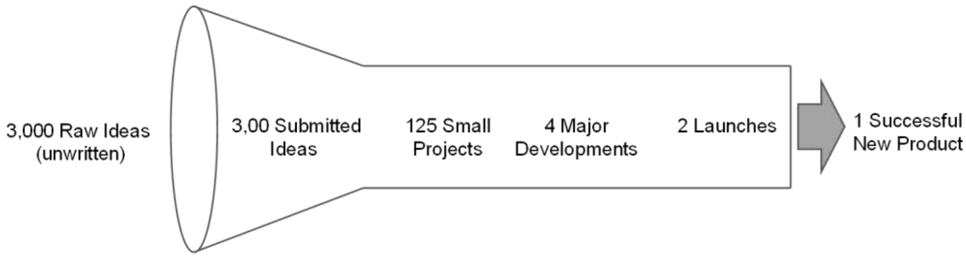


Figure 3.1 The innovation funnel (Schilling, 2012)

In agreement with (Hüsig and Kohn, 2009), different management and engineering approaches influence the building of such Computer Aided technologies (CAx). This section proposes to position Computer Aided Innovation (CAI) as one kind of solution oriented to assist the participants of the first stage of the innovation process. For (Leon, 2009) CAI is the research field that leads the efforts to develop a new category of computers solutions in order to support the different activities of the innovation process. Although, the research is still under development, academia and industry show a growing interest for software systems that can assist in new product development (Cascini et al., 2009).

The difficulty to define CAI is derived from the difficulties found to define innovation and the innovation process. Although in the state-of-art there is not a widely accepted definition, but based on the work of (Leon, 2009), it is possible to describe CAI as follow: a discipline in Computer Aided technologies influenced by innovation theories to develop information-based systems for assisting enterprises throughout any stage or the entire innovation process.

Historically, CAI tools were created based on TRIZ methods and tools (Hüsig and Kohn, 2009), nevertheless innovation management is not exclusive to TRIZ. Therefore, CAI definition should not be anchored to the problem-solving approach. As (Dereli and Altun, 2013) demonstrate, the perception of CAI in literature is associated with three pillars: *design* (e.g. computer aided design), *problem solving techniques* (e.g. TRIZ), and *optimization* (e.g. evolutionary algorithms, genetic algorithm).

Besides CAI tools, the development of other computational tools have progressively extended to enhance product development cycles. Computer Aided Design and Engineering (CAD/E), and Computer Aided Manufacturing (CAM)[4] are the leading solutions for an efficient design process and high quality representation of products (Zeng and Horváth, 2012). However, as (Cascini, 2004) remarks, previous tools are involved just in detailed design phases and their performance is still poor for preliminary design phase. In order to fill the gap of specific tools, Computer-Aided Innovation (CAI) systems emerge for suitably assisting the conceptual design phase (Becattini et al., 2011).

[4] Computer-Aided Design is the use of computers to build and test product design. Computer-Aided Manufacturing is the implementation of machine-controlled processes in manufacturing (Schilling, 2012).

Figure 3.2 illustrates the difference between CAI applications and other computational tools used within new product development. The figure identifies the abstraction level corresponding to CAI tools for supporting the development of new products; in addition it shows how CAI tools are positioned in preliminary design phase. Hereafter, this work considers Computer Aided Innovation as a dedicated effort for covering the front end of the innovation process, particularly the conceptual design phase.

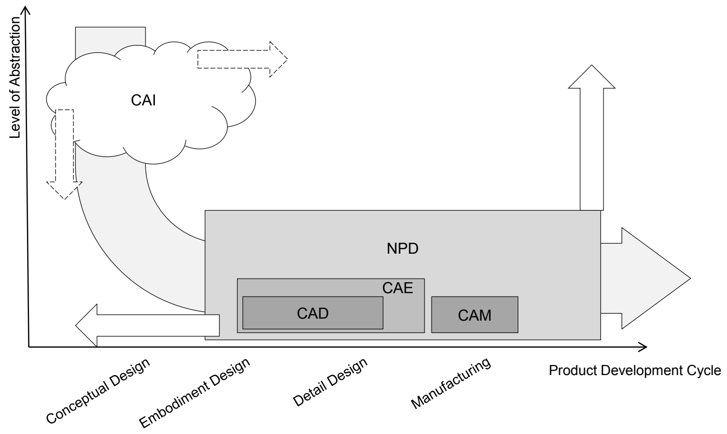


Figure 3.2 Application of CAI in NPD according to (Becattini et al., 2011)

From new product development (NPD) perspective, CAI represents an alternative to standard and generic tools that are used for different activities in the innovation process. In NPD the software support is still mainly based on technologies like workflow, document and data management software, e-mail as communication media, standard office tools and workgroup, instead of more sophisticated and completed frameworks (Hüsig and Kohn, 2009). A different comparison of methods and tools to support the tasks of product development is illustrated in Figure 3.3. This illustration makes the relationship between the specific approaches for product design with the tasks and tools associated. The authors (Cascini et al., 2009), present this effort as an attempt to set up a framework for integrating the NPD, optimization and CAI tools to increase the effectiveness in design activities.

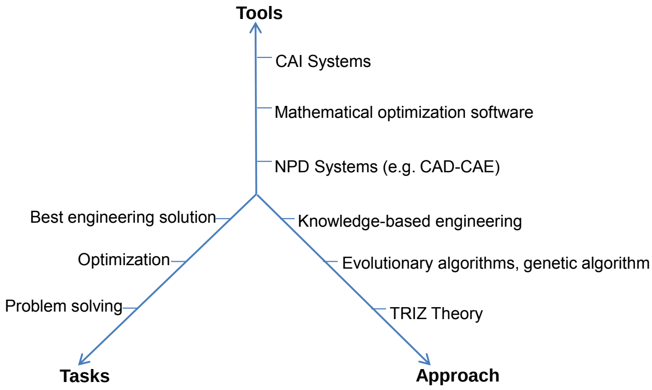


Figure 3.3 Product development tools and methods. Adapted from (Cascini et al., 2009)

3.2.1 CAI classification

The development of the CAI field requires a comprehensive classification. Specially, the classification should comprise the different type of tools to assist during the front end of the innovation process. In (Hüsig and Kohn, 2009), the authors categorized the tools based on the involved innovation activities. The tools are classified in the following three categories:

- Strategy Management: help innovation managers to deal with strategic issues like portfolio or scenario management.
- Idea Management: help to deal with the front end of innovation process from idea generation to idea evaluation.
- Patent Management: these kinds of tools are used to search and analyze patents as a way to stimulate inventions.

In some cases, an application might cover the aspects of more than one category. Besides this initial classification, each category can be divided in subcategories as Figure 3.4 shows.

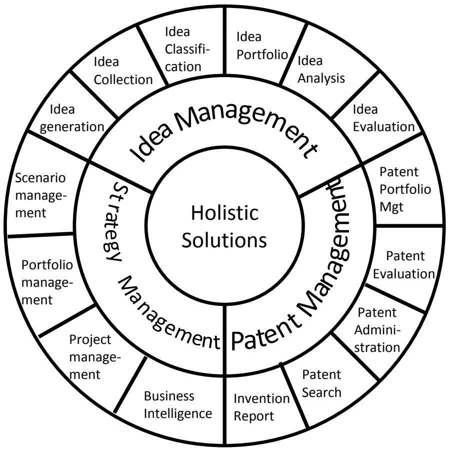


Figure 3.4 CAI tools classification (Hüsig and Kohn, 2009)

3.2.2 Benefits and drawbacks

In (Kohn and Hüsig, 2006), the authors introduce a classification of the potential benefits of innovation software. The benefits are classified by: efficiency, effectiveness, competence and creativity.

- Efficiency. Concerns the fast gathering and diffusion of relevant information and knowledge in NPD projects.
- Effectiveness. It is about identifying and selecting the most promising ideas as early as possible in the innovation process.
- Competence. The transparency foster through innovation software makes the innovation process more understandable and accepted within the firm.
- Creativity. It is about stimulating creativity by providing assistance in the recording, recalling and reconstruction of knowledge in creative processes.

CAI tools, either commercial or academic, have been adopted all around the world by different leading companies across many industries and institutions. This growing trend towards CAI systems would not be possible, unless significant advantages were to be expected from its use. The principal benefits that can arise from CAI systems are linked to expected gains in productivity, speed, reducing cost and stimulating internal innovation. CAI offers integration in the different stages of the innovation process and can reduce the effort in data collection.

In summary the major benefits of implementing CAI solutions are:

- Assisting the conceptual design phase by supporting the solution of inventive problems (Becattini et al., 2011).
- A framework for a more efficient innovation process.

- Dedicated tools to support innovation process instead of standard IT-software like spreadsheet calculation programs or word processors.
- Collaboration in the creative activities of the innovation process.
- Simplified use of techniques for systematic innovation (e.g. TRIZ, QFD).
- Access to databases of patents.

Despite the contributions in new product development, CAI applications have some drawbacks. The CAI limitations are mainly because it is a research field under development; however these limitations represent opportunities to expand the fundamentals of the youth research field. Among the limitations it is possible to identify:

- The lack of Integration between CAI and other existing tools for new product development.
- The need of an adequate theoretical background to get the expected benefits (Becattini et al., 2011).
- Automate the generation of new solutions (Cugini et al., 2009).

3.2.3 Development of CAI tools

3.2.3.1 Benchmark of commercial CAI tools

In last years the development of CAI tools has gave birth to different commercial software applications. Some of them are focused on special tasks of the innovation process, while others try to cover the whole innovation process. An area of opportunity is exposed because most of the CAI products are focused on task like idea management or patent search, and only a few of them include the whole innovation process. Concerning CAI tools, this work covers only developments oriented to New Product Development. Specifically, it covers the tools implementing TRIZ for improving creativity in the resolutions of inventive problems. As previously revealed in the Chapter 2, the context of this work is focalized on preliminary phases of design (e.g. conceptual design), due to the need for adapted solutions.

(Zouaoua, 2012) presents a report about the state of art in commercial CAI applications based on TRIZ. The author made a review of their main characteristics; some of the most relevant results of the comparative analysis are presented in this section. The results are divided into two parts: description of the commercial software applications and comparison analysis.

Description of the commercial software

CREAX: it is a CAI application composed by different TRIZ-based tools to make easy the deployment of innovation process within enterprises. CREAX integrates many methods and tools, to support the different stages of problem resolution like: problem description, problem reformulation, resources, constraints, system model, ideality, laws of evolution, principles, contradictions, and Substance-Field (Su-field) Analysis.

Goldfire Innovator: it is a software that incorporates many characteristics from TechOptimizer. With Goldfire Innovator, problem solvers not only have access to TRIZ tools, but also to a resolution process based on the following stages:

a) A search through a semantic analysis engine within the company internal database and external (internet, patents).
b) Analysis of cause- effect to help problem modeling.
c) Automation to transfer the problem analyzed to the problem resolution module, for generation of the innovative solution using TRIZ theory tools.

Guided Innovation Toolkit: it is a software product based on TRIZ theory concepts. It provides a tool for problem modeling and functional analysis, and it uses principles of separation to solve problems. Some of its functionalities are:

a) Options to describe the problem, the objectives, the constraints, and the idea concepts.
b) Graphical modeling functions
c) The solutions evaluation.

Ideal Matrix: it is a tool based on contradiction matrix. Ideal Matrix proposes a new visually structured way to use inventive principles and the contradiction matrix for solving problems. The software is dedicated to student, engineer or small business innovator. With this positioning, it includes exercises to master the use of the contradiction matrix and the innovative principles.

Innokraft Software: uses the main TRIZ tools for solving inventive problems. It proposes an approach to solve problems related to the organization and the optimization of the innovation process, enabling companies developing innovative product concepts. An interesting characteristic from Innokraft, is that enables the collaborative work via a Web application.

Innovation WorkBench or I-TRIZ Software: implementation of classic TRIZ tools.

The commercial tools presented have as common denominator the implementation of TRIZ theory concepts, in order to simplify the generation of creative solutions in the innovation process. While some of them (i.e. Ideal Matrix) implement a specific TRIZ tool, others (CREAX, Goldfire Innovator) propose complete process to support the different stages of problem resolution. A comparison analysis brings more elements about the characteristics and differences between these commercial tools.

Analysis of commercial CAI

(Zouaoua, 2012) finds that most of the CAIs have problem resolution in three consecutive stages. The first is related with the description of the problem, in order to clarify its identification; although it can be done in several ways, the result in Table 3.1 shows that 50% of applications favor the use of a questionnaire. The second step concerns the problem modeling, and to do it, 50% of the applications include a graphical model to representing the functional interactions between the elements of a system; others use the Su-field model for a graphic model to formulate the problems. The last step concerns the problem resolution, which it is represented with TRIZ generic solution. In the results of Table 3.1, the author reports that 80% of the CAIs rely on TRIZ resolution tools.

Table 3.1 Results from the benchmark of CAI applications (Zouaoua, 2012)

Criteria	Result
Implementation of TRIZ tools	• 80% implement the problem resolution tools from TRIZ. • 20 % have implemented functionality study of the products evolution using the evolution laws of TRIZ.
Characterization of the problem situation	• 60% use the characterization of the problem. • 50% use the questionnaire method for the characterization of the problem.
Modeling of the problem situation	50% use a graphical model to model the problem.
Problem resolution	80% use TRIZ tools for problem solving in the process of problem resolution, and 20% complete this process using the techniques of semantic search.
Providing databases	50% use the database as an additional means to overcome the psychological inertia.
Use of the theory on other non-technological areas	10% try to expand the use of the TRIZ theory to non-technological domains.
Possibility of collaborative work	20% offers the possibility of collaborative work via internet.
Evolution of the system or the solution	20% allow tracing the evolution of the products or the solution.

In the work of (Zouaoua, 2012) reports different CAI applications based on TRIZ tools, which are available as commercial software products. Most of them (80%), implement the contradiction matrix for the resolution of inventive problems. The rest of CAI applications (20%), integrate new features that allow searching patents on databases, or the possibility for collaborative work (e.g. Goldfire Innovator and Innokraft Software). This analysis reveals that commercial CAI based on TRIZ aim to facilitate the implementation of the methodology. However, these commercial solutions miss to include recent advances in the evolution of the methodology. Moreover, most of them do not use state of the art in ICT developments. For instance, the use of the collective intelligence as mechanism to enhance collaboration, the use of Web Semantic technologies to represent knowledge, or the integration of wide sources of information (e.g. Open Linked Data). Therefore, these challenges are opportunities for new researches in academia.

3.2.3.2 Academia developments

TRIZ methodology provides the concepts and tools to enhance creativity while providing a logical framework for problem resolution. However, commercial tools implementing TRIZ are limited to the classic methodology. Therefore, the development of integrated CAI products based on TRIZ tools, and modifications to TRIZ is still an area of opportunities, and the academia proposes new developments.

Although the list of academic works analyzed is far from being complete, it gives a perspective about CAI looking to propose more global and inclusive solutions. From this list it is possible to identify new characteristics looking to advance the methodology, as well as to advance the theoretical foundations of the CAI field. Table 3.2 presents an analysis about advantages and disadvantages. Analyzed works incorporate relevant elements of this kind of tools. Appendix II provides a detailed description for each work presented in the table.

Table 3.2 Academia development analysis (Own compilation)

Work	Objective	Advantages	Disadvantages
(TREFLE-ENSAM, 2003)	To adapt TRIZ tools with Functional analysis. And, to introduce ecological concerns in the earlier steps of the design.	- Adapted to preliminary design. - To develop innovative concepts from existing products.	- Brainstorming organization for interpretation, and the choice of concept.
(Cavallucci and Leon, 2004)	To establish the theoretical basis to build a CAI tool by	- Formulating theoretical bases to build CAI systems.	- The proposition to design up a

Work	Objective	Advantages	Disadvantages
	interacting with a Computer-Aided Design (CAD) architecture.	- Defining generic model adopting a guided design approach.	contradiction network is complicated.
(Cugini et al., 2009)	To improve product development cycle integrating CAIs tools with optimization and Product Lifecycle Management.	- Design tool integrating optimization techniques. - Interoperability with CAD environments.	- Oriented to incremental innovation. - Limited to the use of contradictions.
(Chen et al., 2009)	To involve non-technical staff in the innovation process.	- Highlighting the importance to involve non-technical department staff. - Well-structured process divided into: analysis problem, solve problem and action plan.	- The interaction between non-technical and TRIZ practitioners is not defined.
(Li et al., 2009)	To set up a process of technology innovation based on TRIZ and CAIs according to the characteristics and existing problem of the manufacturing enterprises.	- Combination of a classical innovation process with TRIZ tools and CAI technology.	- Interested only in product innovation. - Problem-solving strategy needs to be detailed.
(Zhang, 2011)	To simulate the thinking process of human in the innovation to shorten the innovating time.	- Incorporation of a knowledge discovery system. - Proposition of an expert system to accelerate the process of invention.	- The process workflow is not clear.
(Tan, 2011)	To apply computer-aided innovation (CAI) systems based on TRIZ to solve some ill-structured problems that appear in an innovation pipeline.	- Application to solve ill-structured problems in an innovation pipeline. - Applying TRIZ in two sub-processes, the input design and conceptual design separately.	- Limited to a two stages analogy process model.
(Li et al., 2012)	To classify patents according to level of inventiveness as	- Detailed workflow for conceptual design activity.	- Drawbacks for scaling up the work or

Work	Objective	Advantages	Disadvantages
	defined in the theory of inventive problem solving (TRIZ).	- Incorporating data mining of patents, natural language processing, and machine learning.	applying the proposed method into practice. - Increasing the computational burden for processing newly published patents.
(Hu et al., 2013)	To combine the approach Case-Based Decision Theory (to store and reuse knowledge) with TRIZ.	- Support decision-making during the design process. - Incorporating knowledge management.	- Limited to formulate the problem as a contradiction. - The process is not organized in phases.

The works included in Table 3.2 document the interest in the academia community for complementing TRIZ with other approaches. The first case (TREFLE-ENSAM, 2003) proposes a tool to integrate TRIZ creativity tools with other approaches such as Functional Analysis. In other proposals (Cavallucci and Leon, 2004; Cugini et al., 2009), authors try to have a more inclusive process and interoperable tools covering all the phases of Product Lifecycle Management. Regarding knowledge capitalization, (Hu et al., 2013) propose to combine TRIZ with Case-Based Decision Theory, and (Li et al., 2012) incorporate data mining of patents. Finally, as an effort to simplify the use of TRIZ, (Chen et al., 2009) propose the involvement of non-technical employees, and (Zhang, 2011) tries to simulate the thinking process of humans. As observed, the interest to advance TRIZ and the CAI tools associated is different: from covering the whole Product Life Cycle and the incorporation of knowledge capitalization approaches, until trying to make easy the practice of TRIZ for non-technical employees. However, few of them report to address the collaborative dimension.

3.2.4 CAI in chemical process engineering

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

In process engineering, some of the first developed CAIs were based on an adapted version of the TRIZ tools, in order to enrich them with specific domain knowledge in the field of expertise. (Li et al.,

2001) have proposed a CAI system for complex distillation process, then their approach was improved but for an application in 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 process. The main advantage of such CAI tools is that they are very operational due to their specificity to a particular area. On the other hand, this integration of more specific knowledge results in less inventive idea generation. To improve knowledge management, (Cortes Robles et al., 2009b) have hybridized Case Based Reasoning and TRIZ to propose a new approach to support knowledge reuse, thus reducing process or product development time while increasing quality and functionality. 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 but not process.

Concerning documents analysis, in process engineering the first studies start to appear with the aim to predict research trends (Jabłońska-Sabuka et al., 2014) or (Sitarz and Kraslawski, 2012), or to study knowledge flow in research topics (Sitarz et al., 2012). But documents can also be used to simulate creativity, as well as to create a community for problem resolution and idea generation.

3.2.5 Challenges developing CAI tools

Different challenges have been identified in the development of CAI tools (Cascini et al., 2009; Leon, 2009). The main issues reported are:

- Poor interoperability between computer tools adopted in innovation activities.
- Lack of formalized procedures and means to accomplish conceptual design tasks.
- The limited usability of CAD systems for conceptual design.
- Clarification of the role of CAI tools.
- Support for innovation efforts with computer tools and methods.
- Focus on all stages of new product development process.
- Organizational, technological and cognitive aspects of the application of CAI methods and tools.
- Evaluation of the effectiveness and efficiency of CAI methods and tools.
- CAI theoretical foundations.

The integration of multi-disciplinary knowledge sources for creative conceptual design is necessary. As well as Computer Aided Design (CAD) tools, CAI tools often fail in knowledge management through various disciplines (Chen et al., 2012). Because of the latter reason, one of the observed trends in the development of CAI tools is the design of ontologies as a means to model and communicate knowledge. A different trend suggests the use of virtual worlds in creative tasks.

3.3 Current trends in CAI

Although, there are different opinions about the diversification and the future of CAI tools, they all converge in the idea that this kind of tools are evolving through the adoption of newer technologies and techniques in the Information Technology field like: Web technologies, Virtualization, knowledge representation, among others. These new tendencies are explored in this section.

3.3.1 Ontology-based CAI

(Cavallucci et al., 2011) discuss the usefulness of an ontology for TRIZ. The ontology presented by previous authors aims to be a domain ontology of TRIZ, in specifying its basic notions for operating inventive design. Their ontology aims also to ensure that experts have a common understanding of those notions. Despite the authors try to formalize theory's main concepts, and compile partially the vocabulary that is used by TRIZ experts, the ontology is anchored to a specific resolution methodology OTSM-TRIZ (Khomenko et al., 2007). This is an inconvenient because the ontology should remain as abstract as possible to be used in different contexts.

(Li et al., 2015) argue that the indexation of different knowledge sources to solve inventive problems is promoting the development of CAI systems including ontology-based models; these types of systems combine TRIZ with various computer technologies such as: Text Mining or Natural Language Processing. For example, (Prickett and Aparicio, 2012) propose the design and development of a TRIZ Technical System ontology for indexing knowledge contained within available resources (e.g. patent database). The objective of the proposed ontology is to incorporate a web based information retrieval system in the problem solving process. For these authors, the development of ontologies integrated with Natural Language Processing and Artificial Intelligence, reduces the gap to have web agents with an analysis capacity close to humans.

On the other hand, the use of semantic technologies is explored in (Yan et al., 2014) to formalize the main concepts in the TRIZ knowledge sources through an ontology. Previous authors intend to build an "intelligent manager" system based on short-text semantic similarity and ontologies. Short-text semantics similarity defines missing links among TRIZ knowledge sources, and the solutions are obtained through ontology reasoning. The objective of the proposed systems is to reach more accurate defined solution models.

3.3.2 Avatar-based innovation

Traditionally in the market-pull strategy for innovation[5], manufacturers start exploring user needs and then develop products to fulfill the requirements; nevertheless this activity is complicated, time-consuming and expensive. Moreover, the approach shows its limitations when user needs change rapidly. (Von Hippel and Katz, 2002) propose the use of Toolkits as an emerging alternative to understand user needs in details. As a design tool, toolkits transfer *need-related* aspects of new products or services to users. On the other hand, a more interactive approach to address this problem is found in the emerging technology of virtual worlds.

Virtual worlds offer new possibilities for enhancing innovation activities through virtual customer integration. The use of virtual worlds for real-world innovation is explored in (Kohler et al., 2011, 2009) with the concept of avatar-based innovation. Avatar-based innovation provides a digital environment conductive to develop open innovation and creative tasks. The authors demonstrated how virtual worlds deploy an Open Innovation platform, that allow producers and customers to swarm together with like-minded individuals not only to create new products but also to find audience to test, use, and provide feedback about those creations.

The previous authors formulated two questions in order to understand the potential of virtual worlds for real-life innovation:

- How are virtual worlds different from two-dimensional web and from the real world?
- What opportunities arise from this difference?

Avatar-based innovation offers a new medium to understand the user needs, through virtual customer integration in an open innovation processes. Using this approach, companies can enhance their innovation efforts, by learning how to engage and co-create with avatars (the latest visual representation of their potential customers).

3.3.3 The concept Open CAI 2.0

In today knowledge-driven economy, there is a great potential for the use and development of CAI tools, unfortunately they are reduced due to the lack of integration between different systems; as these applications are developed following a stand-alone (desktop applications) approach. Consequently, the evolution of Computer Aided Innovation requires the integration of the Web 2.0 and the Semantic Web technologies, in order to encourage the creation of collaborative environments which contribute to the emergence of innovations. As (Stankovic, 2012) highlights, current innovation

[5] *Market-pull* identifies the innovations' source as an inadequate satisfaction of customer needs (Brem and Voigt, 2009).

challenges require a certain openness to allow users to access to relevant information and to learn and translate ideas from one domain to another. But it is not only a problem of Information Technologies integration, for improving the advantages of adopting new integrated CAI systems, it is indispensable the in-depth focalization on the outgoing of methodologies and concepts for supporting innovations teams more effectively and efficiently (Leon, 2009). Given this context, the possibilities explored in this work are supported by the concept of Open CAI 2.0.

Open CAI 2.0 is a concept proposed (Hüsig and Kohn, 2011) as the next evolutionary step in the CAI development. Previous authors define Open CAI 2.0 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*".

Although, tools using collective intelligence have performed better than expected for innovation activities (Bonabeau, 2009), they do not report the incorporation of methodologies for product design and problem resolution. On the other hand, CAI tools are strongly influenced by innovation methodologies, but their operation does not involve large crowd of participants. In this paradox, the Open CAI 2.0 proposition tries to make the convergence through the generation of creative solution by a crowd that follows a formal methodology. Open CAI 2.0 examines current technical possibilities of the Web 2.0. One of those possibilities requires that companies outsource idea generation as well as idea evaluation

It is expected that changes in innovation paradigms will occur through the use of computer aided innovation methods and tools (Leon, 2009), consequently it is necessary to use new information technologies and computational methods for supporting most recent changes in innovation management strategies. In the approach of Open CAI 2.0 there is a convergence of technological and management strategic elements. The technological point of view is based on the use of the Web 2.0 paradigm, the management strategic is driven by a recent change where companies are shifting from the predominantly closed innovation to the popularized open innovation paradigm (Hüsig and Kohn, 2011). Among the characteristics for Open CAI 2.0 solutions, it is possible to mention:

- They expand the innovation beyond the enterprise boundaries.
- They propose an innovation process no longer focused on the internal employees and proprietary software (e.g. GoldFire Innovator, CREAX).
- They include participation of external actors like customers, researchers and people interested via a simple Web application.

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 its solutions among different domains (knowledge transfer) giving as a result more complex and radical innovations. Therefore, we think that these kinds of developments are necessary for the industry because of the following reasons:

- Firms need to accelerate the development of new innovations because they receive more than one-third of their profits from products developed within the past five years.
- Around 3,000 raw ideas (unwritten) give as a result only 1 successful innovation.
- The sources for innovations are located inside, as well as outside of the enterprise.
- Networking from different sources of innovation is one of the most powerful mechanisms to accelerate the creation new technological innovations.
- Existing crowdsourcing services for Open Innovation do not include tools to assist the development of innovative solutions.

Finally, we introduce Figure 3.5 to evaluate the success opportunities for Open CAI 2.0 solutions with an adapted SWOT[6] analysis. The analysis aims to identify strengths and weakness that have influenced the Open CAI 2.0 field. But mostly, it tries to outline what can be the future of the field. In the near future, Open CAI 2.0 has an opportunity for the development of dedicated solutions for new product design (in particular conceptual design). One step for spreading its incorporation in industrial contexts is the introduction in universities courses. However, changes in management paradigm or the emergence of a new collaboration technology remain the main treats.

[6] Abbreviation for Strengths, Weaknesses, Opportunities and Threats

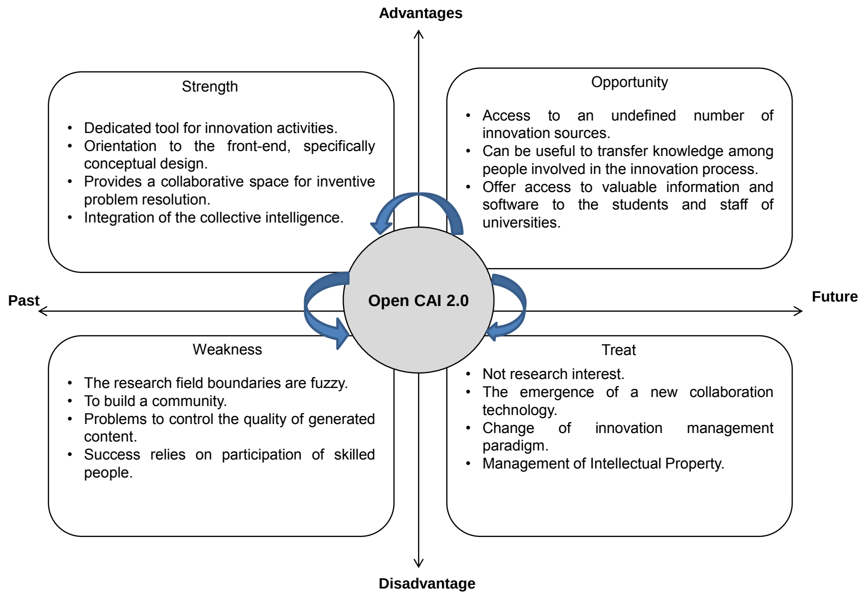


Figure 3.5 Adapted SWOT analysis for Open CAI 2.0 (Own construction)

As revealed in section 2.4.2, the innovation process is not an activity done by a solitary person, instead it is developed by a group of people working together joining efforts. For that reason, CAI tools should drive the aspect of collaborative work. In the development of modern CAI tools, the support of collaborative activities should be a basic requirement. Making a brief analysis, we introduce the Figure 3.6 to illustrate the evolution of Computer Aided software for innovative activities. This analysis shows the transformation in the practice of innovation activities, from the use of standard software (e.g. word, excel), the development of specific support software (e.g. CAD, CAI), until the use of collective approaches nowadays (e.g. groupware). It is peculiar to observe that the evolution continues, and the integration of social software tools in corporate intranets offers new possibilities to develop innovation activities. In addition, social software allows the emergence of a new form of collective intelligence, which can accelerate the development of creative solutions. The next section 3.4 highlights, as a trend with an active research, the incorporation of collective intelligence in the execution of the innovation process.

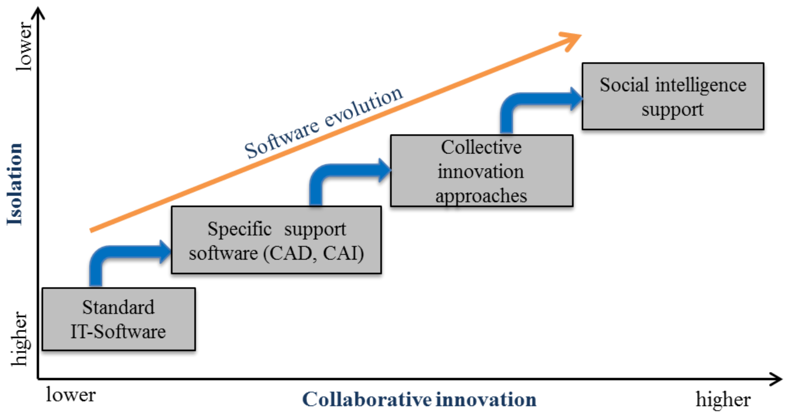


Figure 3.6 Evolution of software to support innovation activities (Own construction)

3.4 Democratizing the generation of creative solutions

3.4.1 Elements of collective intelligence

The evolution of an innovation, from an idea to production and marketing requires the participation of different intelligences. Around an idea that seems innovative, it is required an organization to aggregate the collective intelligence to complete, improve and implement such idea (Christofol et al., 2004). Collective intelligence (CI) has existed since humans started to bring together intellectual efforts to develop specific tasks. Nowadays, industries start to focus on immaterial elements to define the firm value (i.e. brand portfolio, collective intelligence). Collective intelligence is a kind of intelligence that emerges from the synergy of individual creative efforts when a cognitive task (e.g. collaborative innovation) takes place (Yannou et al., 2008). This synergy is important in new product development in order to reduce time-to-market and to improve the possibilities of a product success.

Collective intelligence is a multidisciplinary research field, and according to (Greselle, 2007) definitions of collective intelligence are reported in literature of different domains (e.g. management sciences, communication and computer sciences, organizational psychology). For instance, (Zara, 2008) argues that the challenge of collective intelligence and knowledge management is how to improve the collective efforts in order to be better than individual efforts. Zara defines collective intelligence as "*the capacity to join intelligence and knowledge to achieve a common objective*". Collective intelligence takes a new dimension with the incorporation of computers. In fact, the nature of the participants is not clear. For example, the definition given by (Malone et al., 2009) is about "*groups of individuals doing things collectively that seem intelligent*". For this reason, the Center for Collective Intelligence at the MIT, works on developing systems to connect people and computers so that collectively they act more intelligent (Leimeister, 2010). For instance, Innocentive is presented as an information-based platform that connects people with innovation problems to solution providers around the world, with the aim to unleash human creativity to solve problems that matter to business and society (Allio, 2004). Within the context of this work, the orientation of collective intelligence is through its implementation with ICTs.

The emergence of Web 2.0 platform allows to study the intelligence derived from groups of individuals doing things together through web applications (Leimeister, 2010). It is documented (Alag, 2008; Malone et al., 2009; O'Reilly, 2006) that relying on the sharing and cooperation architecture provided by Web 2.0 technologies, it is feasible to deploy applications using collective intelligence capabilities.

The use of collective intelligence to outsource open innovation activities is creating what can be called a market of ideas. In literature, the concepts collective intelligence, crowdsourcing, and broker are used indistinctly to describe such market. However, some differences between them are highlighted. Consequently, we propose the Figure 3.7 to organize the concepts in the following interrelated three levels: in the top the theoretical basis, in the middle the operation mechanism, and in the bottom the technological elements of implementation. Collective intelligence as a research field, provides the foundations to understand the behavior of a group of agents (humans and computers) doing cognitive tasks. Besides, it provides the elements to enhance the collaborative effort to solve problems together. One mechanism derived from the implementation of the collective intelligence is the crowdsourcing services. For the practice of open innovation, crowdsourcing services aim to outsource creative activities of an organization through an open call to a community. The strength of this type of services lies in the diversity of profiles found in the community members, as well as their disposal to participate. Finally, the technological implementation of crowdsourcing services is through the use of a broker. The broker coordinates the interaction between the Stakeholder (e.g. innovation seeker) and the community of solution providers. It is a well-documented pattern to design distributed collaborative systems.

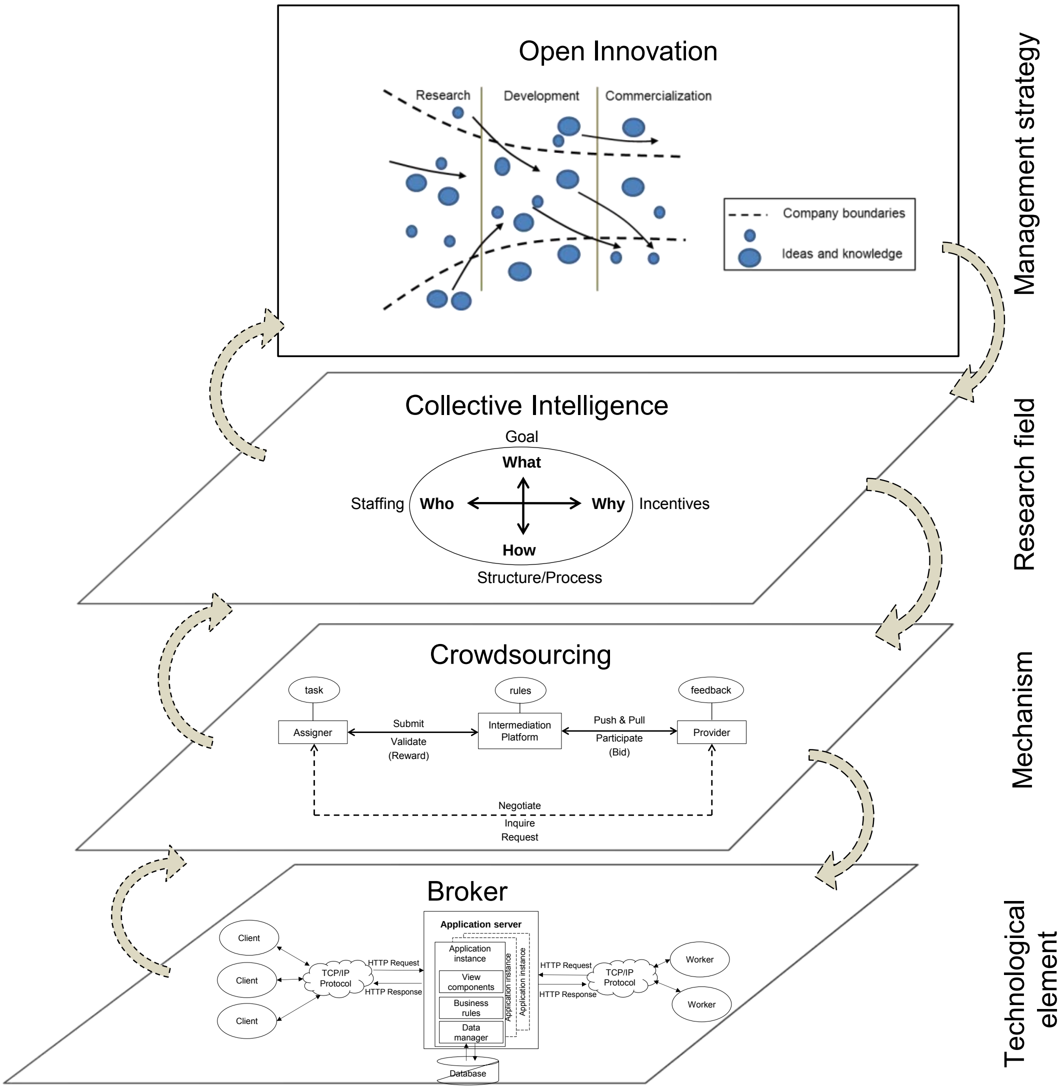


Figure 3.7 Elements of a market of ideas (Own construction)

3.4.2 The collective intelligence architecture

In (Malone et al., 2009), authors identify the elements found in web application which implement collective intelligence. They define a building block or "gene"[7] as a particular answer to the questions represented in Figure 3.8. The first intersection (who and why) identifies the actor (e.g. the crowd) and the motivation to perform a single task in a collective intelligence system. The second intersection (what and how) defines the task, and the strategy to accomplish it.

[7] The authors of the study employ the term genes doing an analogy from biology.

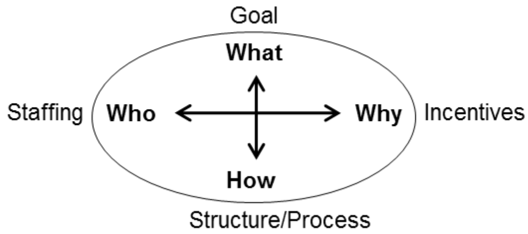


Figure 3.8 Building blocks of Collective intelligence systems (Malone et al., 2009).

The Table 3.3 describes each one of the genes that once combined can complete a collective intelligence system. About the genes (Malone et al., 2009) emphasize that:

- Crowd gene is a central feature of Web enabled collective intelligence systems.
- Collective intelligence systems rely on the genes of Love and Glory instead of Money as the motivation force.

Table 3.3 Genes description. Inspired from (Malone et al., 2009).

Question	Answer (Gene)	Gene description	Example
Who	Hierarchy	Someone in authority assigns a particular person or group of people to perform the task.	It is the operation of some open source projects. There is an authority to control the evolution of the project.
	Crowd	Activities can be undertaken by anyone in a large group who chooses to do so, without being assigned by someone in a position of authority.	Anyone can propose a new article or edit an existing article in Wikipedia.
Why	Money	The promise of financial gain.	Direct payments.
	Love	People can be motivated by their intrinsic enjoyment of an activity, by the opportunities it provides to socialize with others, or because it makes them feel they are contributing to a cause larger than themselves.	Wikipedia participants.
	Glory	The desire to be recognized by peers for their contributions.	Power seller on eBay, top reviewer on Amazon, programmers in many open source software communities.

Question	Answer (Gene)	Gene description	Example
What	Create	The actors in the system generate something new.	A piece of software code, a blog entry, a T-shirt design.
	Decide	The actors evaluate and select alternatives.	Selecting which T-shirt design to manufacture, deciding whether to delete a Wikipedia article.
How	Collection	Items contributed by members of the crowd are created independently of each other.	YouTube videos are created mostly independently.
	Contest	One or several items in the collection are designated as the best entries and receive a prize or other form of recognition.	Innocentive, IBM's Innovation Jams.
	Collaboration	Members of a Crowd work together to create something and important dependencies exist between their contributions.	Wikipedia.
	Individual Decisions	Members of a Crowd make decisions that, though informed by crowd input, do not need to be identical for all.	Individual YouTube users decide for themselves which videos to watch.
	Group Decision	Inputs from members of the crowd are assembled to generate a decision that holds for the group as a whole.	Threadless.

Besides the genes for building collective intelligence systems, academia researchers show interest on how online communities are fertile sources of innovation (Brabham, 2013). One way is the model to gather collective intelligence in Web application presented in Figure 3.9. The model represents the users' interactions, and how the user interactions are aggregated in models. The aggregation allows to learn from other 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 intelligence is information that the user provides directly in the application.
- Implicit intelligence is information the user provides either inside or outside the application (e.g. unstructured).
- Derived intelligence is based on the explicit and implicit information.

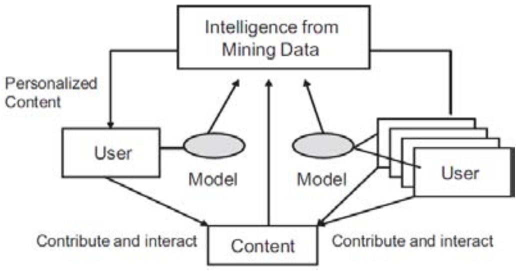


Figure 3.9 Architecture for a collective intelligence system (Alag, 2008)

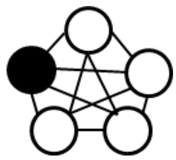
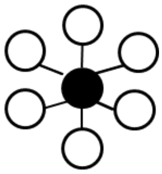
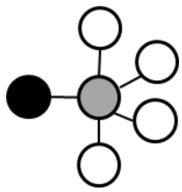
According to (Pérez-Gallardo et al., 2013) there is an interest about the use of collective intelligence in different domains such as: education, tourism, e-commerce or medical field. In the domain of innovation management, (Leimeister, 2010) argues that companies have new opportunities to improve creativity and innovation capabilities by leveraging their inherent collective intelligence. Some of these areas are: decision support, open innovation, crowdsourcing, social collaboration, control, diversity in-depth expertise, engagement, policing, and intellectual property. From these areas, crowdsourcing platforms are detailed because enterprises are using them as a mechanism to improve their innovation capacity.

3.4.3 Crowdsourcing platforms

Regarding to crowdsourcing services for implementing open innovation, they help to create a global market of ideas. Coined by (Howe, 2006), crowdsourcing is reported (Ren et al., 2014) as a search activity in which many individual intelligence simultaneously explore a problem space for novel and practical solution. In literature the terms innovation intermediary or brokering services are used as synonyms for crowdsourcing (Feller et al., 2012; Lytras et al., 2008; Majchrzak and Malhotra, 2013). Moreover, (Simula and Ahola, 2014) explain how the terms open innovation, crowdsourcing, collaborative innovation and collective intelligence are often used as similar concepts. Nevertheless, some minimal differences are observed. According to (Yankelevich and Volkov, 2013) crowdsourcing is "*the act of delegating (sourcing) tasks by an entity (crowdsourcer) to a group of people or community (crowd) through an open call. Individuals (workers) within the crowd are usually rewarded for completing a task*". Whereas, the broker or intermediary is the central element that makes the link between an innovation-seeker and the community that provides solutions (Nunez and Perez, 2007). Therefore, the difference between both terms is that crowdsourcing is an operation model, whereas the broker is a component (e.g. technological) that makes part of crowdsourcing operation.

A deeper understanding about how crowdsourcing can contribute to business and innovation activities needs to take into account the distinct operational configurations available. In (Simula and Ahola, 2014) a classification of four configurations is presented: internal crowdsourcing, community crowdsourcing, open crowdsourcing, and crowdsourcing via a broker. The Table 3.4 details each of these configurations.

Table 3.4 Crowdsourcing configurations. Based on (Simula and Ahola, 2014)

<table>
<tr><td rowspan="4">Crowdsourcing configuration</td><td>Internal to the firm</td><td>Internal crowdsourcing
</td><td>Leverages the expertise and heterogeneous knowledge of an industrial firm's employees. Typically, there is no selection mechanism and internal idea competitions are open to all employees of a firm. Serendipity increases when each and every employee is able to participate.</td></tr>
<tr><td rowspan="3">External to the firm</td><td>Community crowdsourcing
</td><td>Taps in the expertise of densely connected networks of experts working on a specific topic or challenge. A crowdsourcing community is formed from a specific crowd, comprising individuals and organizations with specific skills, knowledge, and other pre-qualifications. Participation can be restricted.</td></tr>
<tr><td>Open crowdsourcing
</td><td>Gaining access to the brightest of ideas by involving as many actors as possible in the innovation challenge, and making it as easy as possible for any actor to contribute. There is no pre-selection and the call to participate is open to everyone.</td></tr>
<tr><td>Crowdsourcing via broker
</td><td>Relies on a particular type of firm that connects potential problem solvers with organizations seeking new ideas or specific solutions to their problems.</td></tr>
<tr><td colspan="4">Components of the crowdsourcing configuration ● Focal firm ○ Contributor ◉ Broker</td></tr>
</table>

Considerations like products complexity, new innovation management paradigms, the need for external knowledge and time-to-market reduction influence the success of commercial crowdsourcing services. An analysis of (Feller et al., 2012) about the operation of these platforms identifies the processes necessary to "orchestrate" crowdsourcing: knowledge mobility and appropriability. The process of knowledge mobility implicates the ease of transferring solutions from providers to innovation seekers, and appropriability is the perception of capturing value from the crowdsourcing process.

The operation of most promising platforms for crowdsourcing innovation is limited to take a challenge formulated as a problem, and broadcast an open call to the crowd in order to propose a solution (Majchrzak and Malhotra, 2013). Despite this limitation, different companies are using collective intelligence to solve problems (Georgi and Jung, 2012), e.g. the InnoCentive platform provides service to companies such as: AstraZeneca, DARPA or the U.S. Air Force. According to (Georgi and Jung, 2012), the lack of systematization makes the use of collective intelligence an unpredicted process because: problem solvers on such platforms do not necessary constitute a virtual community (Frey et al., 2011), restrictions to capitalize existing solutions because of Intellectual Property, and the use of experts to formulate the problem.

Figure 3.10 presents the components, processes and actions in the operation model of crowdsourcing services. The operation involves three components: assigner, intermediation and provider. The workflow starts when the assigner submits a task to the intermediation platform, then the platform broadcast the task to providers. Intermediation creates also the link between the assigner and the providers; it has also rules to control the lifecycle of crowdsourcing. Providers interact with the assigner to inquire about some details of the task to support their works, or to negotiate over the requirements and rewards. At the end of the workflow, the assigner validates the solutions provided by provider as feedbacks.

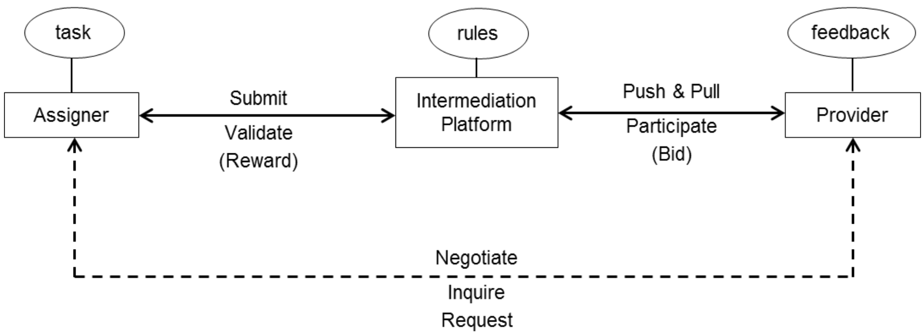


Figure 3.10 Crowdsourcing operation model (Zhao and Zhu, 2012)

Literature on crowdsourcing offers a description of the state-of-art of different commercial and academia solutions. According to (Feller et al., 2012), companies that do not have a dedicated Web platform to outsource innovation activities turn to platforms for open innovation intermediaries like Innocentive, NineSigma, YourEncore and Hypios.

- *Innocentive (www.innocentive.com)*. Service dedicated to crowdsource innovation solutions. They connect companies having technical problems (seeker) with solution providers (solvers). Usually the seeker post the problem in a form of contest, and the solver who provides the solution that matches the seeker requirements is awarded with an economical prize. According to the statistics given by Innocentive (January 2015) they have registered a total of 355,000 solvers from nearly 200 countries.
- *NineSigma (www.ninesigma.com)*. It is an innovation network that connects companies that have scientific and technologic problems with companies, universities, government and private labs, and consultants that can develop solutions (Huston and Sakkab, 2006). According to the information provided by *NineSigma* (January 2015), the innovation network is composed with more than 2 million solution providers who have submitted 35,000 proposals. Figure 3.11 presents the participation level in NineSigma.

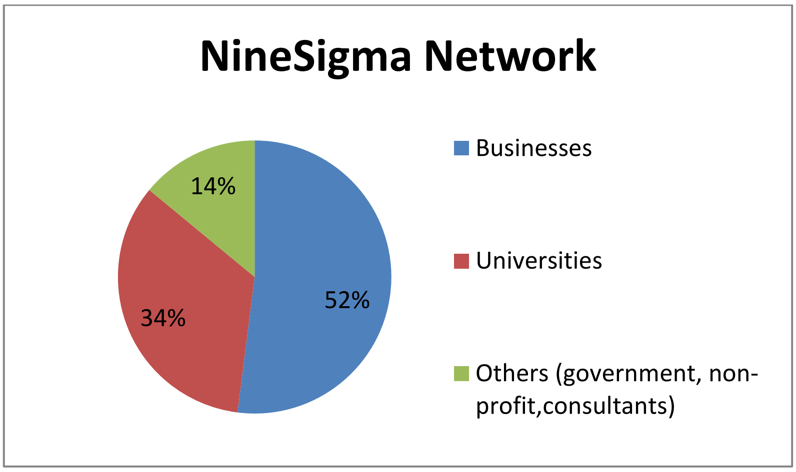


Figure 3.11 Participation in NineSigma innovation network

- *YourEncore (www.yourencore.com)*. The innovation network in YourEncore is maintaining with recently retired experts. According to the information provided by YourEncore (January 2015), the veterans network is composed with 8,000 members having an average of 25 years of industrial experience. The services of YourEncore are to match expertise and solutions to the requirements of the companies, in order to overcome R&D challenges and speed new and innovative products to market.
- *Hypios (www.hypios.com)*. Their objective is to help corporations solve complex R&D problems. According to (Stankovic et al., 2010), Hypios is the first social marketplace where the problem solvers are organized in a social network. The service differentiates from other providers, because it relies on software for in-depth semantic analysis of each problem, and competency discovery technology able to sound the web to find relevant experts.

Regarding academic developments about crowdsourcing services, the following works were identified:

- (Bücheler and Sieg, 2011) investigate: a) the applicability of Crowdsourcing to fundamental science and b) the impact of distributed agent principles from Artificial Intelligence research on the robustness of Crowdsourcing. Insights and methods from different research fields are combined, such as complex networks, spatially embedded interacting agents or swarms and dynamic networks.
- (Ramos et al., 2012) identify the crowdsourcing innovation facilities needed by SMEs, and present an architecture that encourages knowledge sharing, development of community, support in mixing and matching capabilities, and management of stakeholders' risks.
- (Chiu et al., 2014) propose a framework based on four major components of crowdsourcing: the task that is outsourced, the crowd which carries out the task, the crowdsourcing process, and the outcome evaluation . It supports various phases of managerial decision-making and problem solving.
- (Ren et al., 2014) develop a model for crowd-based search for new designs, consisting of three major forces: the problem domain, the actors, and the process.
- (Geiger and Schader, 2014) introduce a personalized task recommendation mechanisms for matching tasks and contributors' individual interests and capabilities.
- (Wooten and Ulrich, 2014) use two online contest websites to compare the performance of three different feedback treatments – no feedback, random feedback, and directed feedback.

Since crowdsourcing is an operation model, it requires sociotechnical systems to provide the services for harnessing the diverse potential of large groups of people via the Web. The *broker* is the pattern observed in most of the crowdsourcing services.

3.4.4 Broker pattern

For (Francu and Marsic, 1999), the broker pattern is a powerful solution when building distributed collaboration systems. The reason is because the broker allows, in a transparent way, the interaction between clients and service-providers through work request, broadcasting the request to available service-providers, and returning results to the client (Hayden et al., 1999). The broker architectural pattern is presented (Buschmann et al., 1996), as the structure for distributed software systems with decoupled components interacting through remote service invocation; its responsibilities are the coordination of communication, like forwarding requests, as well as the transmission of results. The broker interaction is represented in Figure 3.12. In this interaction, the service provider satisfies a request from the client.

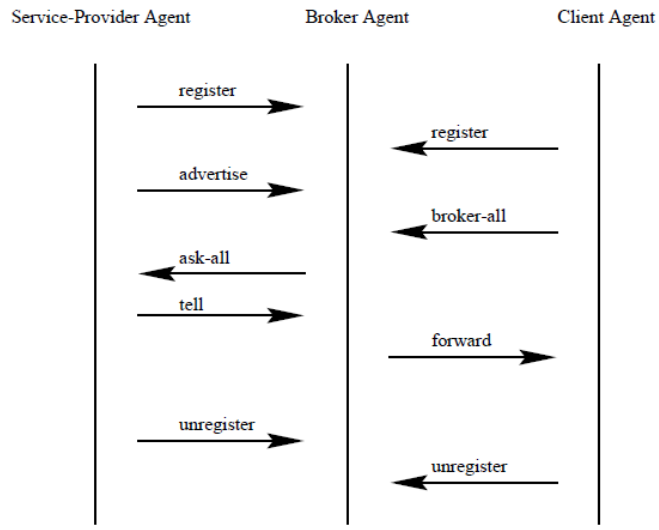


Figure 3.12 Broker interaction diagram (Hayden et al., 1999)

For the implementation of a broker system, we propose the architecture illustrated in Figure 3.13. As observed, the architecture integrates the Model-View-Controller pattern[8]. We argue that the integration of the patterns Model-View-Controller (MVC) and broker pattern is suitable to design flexible systems in heterogeneous computer network; a characteristic of this kind of systems is the capacity to evolve and adapt to new functionality. The graphical description in Figure 3.13 is an illustration of the combination of both patterns in a Web-based broker; the broker provides the infrastructure to propose distributed applications, and the MVC organizes the logical components in execution within Web applications.

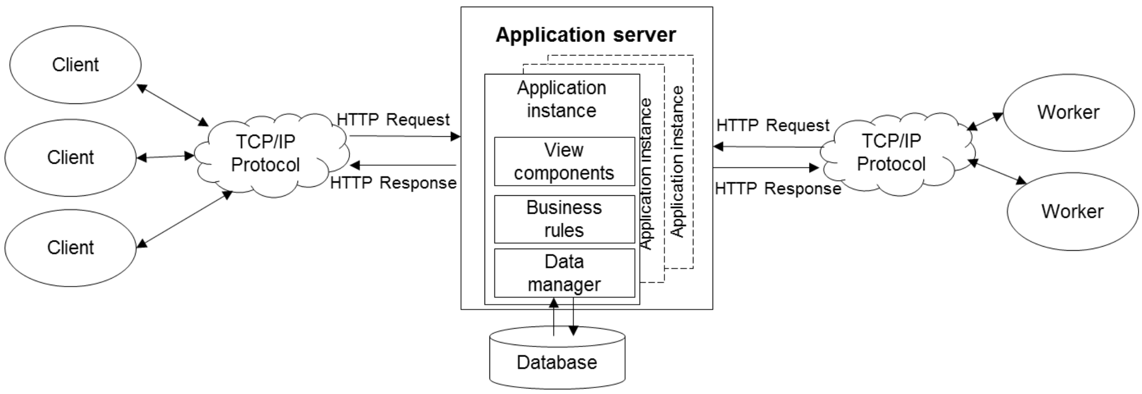


Figure 3.13 Web-based broker components (Own construction)

[8] The Model-View-Controller divides an interactive application into three components: (1) Model to include core functionality and data, (2) View to present information, and (3) Controller to handle interactions in the View (Buschmann et al., 1996).

Despite of the advantages of using the wisdom of the crowds to solve innovation problems, some drawbacks are observed:

- The problem solvers on such platforms do not necessarily constitute a virtual community (Frey et al., 2011).
- Reliance on the emotional states and motivation of participants.
- Difficulties to attract skilled people.
- Problems to control the quality of the generated content.
- Keep up the motivation of the community members.

3.4.5 The role of the Social and Semantic Web

As firms are increasingly engaging in outsourcing activities of the innovation process to large groups of external contributors, the integration of Web-based applications becomes necessary to provide a global accessibility, communication and interaction between users at a low cost (Frey et al., 2011). The cornerstone of applications that appeared after the dot-com era was the capacity to harness and utilize the contributions by users. For (Malone et al., 2009) the ecosystem of participation in the Web 2.0 enables the emergence of surprising new forms of collective intelligence. However, according to (Gruber, 2008) it is premature to apply the term collective intelligence to the class of web sites which are part of the Web 2.0, because the way to unlock the collective intelligence in the Social Web is through the use of Sematic Web. The Sematic Web provides the means to represent knowledge and to use reasoning techniques. An example is reported in (Esteban-Gil et al., 2012), where the authors propose the integration of Semantic Web concepts and the Web 2.0 to automatically create semantically-empowered relationships between the users in a platform based on their interaction.

3.5 Conclusion

The development of software-based information systems to assist the innovation process revels an opportunity to better understand such process; Computer Aided Innovation (CAI) leads the research field efforts. The research in Computer Aided Innovation was originated with the objective to make easy the use of TRIZ theory methods and tools. Consequently, different commercial tools exist in the market, most of them based on classical TRIZ methodology. In this chapter we have argued that commercial developments need to take into account recent developments in the TRIZ methodology, innovation management (e.g. open innovation), as well as state-of-the-art of collaboration technologies (e.g. Web 2.0).

As revealed in this chapter, academia has shown an interest to keep up to date CAI technologies. Examples of researches include tools integrating TRIZ with other techniques such as Product Life Cycle or Optimization, the use of knowledge representation (e.g. ontologies) or the use of virtual worlds. A more radical change in CAI evolution is proposed by the concept Open CAI 2.0. The concept Open CAI 2.0 looks to develop tools influenced by two recent developments in innovation management (i.e. open innovation), and collaboration technologies (i.e. Web 2.0). Despite the progress in industrial and academia solutions, we did not find reports of TRIZ-based computational tools covering aspect such as: the use of collective intelligence, Semantic Web or the integration of Open Linked Data.

In the same evolution trend of Open CAI 2.0, new services using principles of collective intelligence are emerging. These services create what we called a new market of ideas, which is mainly influenced by open innovation initiatives. In order to organize related literature, we proposed a three level structure composed by: collective intelligence as the research field, crowdsourcing as the operation mechanism and the broker as the implementing technological element. In the operation of this market, companies have access to services for outsourcing innovation activities (e.g. generation of ideas, resolution of creative problems). Participants use the Web 2.0 as a collaboration platform. However, the performance of such services is limited to take a problem and broadcast it to an unlimited number of persons. Consequently, users lack of tools to assist them in the creative process. In this scenario, we argue that the Open CAI 2.0 concept, with the systematic approach of the TRIZ, will help in the convergence of this new market of ideas with tools to assist the creative process.

Therefore, it is possible to highlight that future development of CAI solutions needs to take into account:

- The engineering and managerial approach for innovation.
- The use of a strategy or paradigm for innovation management.
- The innovation activities to cover.
- A supporting methodology to drive the creative process, or a combination of them.
- Recent advances in Information and Communication Technologies.
- Elements of collective intelligence in the new market of ideas.

To advance the evolution of CAI tools, in Chapter 4 we introduce the proposition for a conceptual framework in Open CAI 2.0 which take into account previous recommendations.

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Chapter 4 Conceptual Framework

Highlights
• To extend the conceptual foundations of the Open CAI 2.0 concept. • To outline the mechanism to gather the collective intelligence for solving inventive problems. • To introduce our proposal for a conceptual framework for Open CAI 2.0.

4.1 Introduction

"Je vais vous dire (si je puis, sans verbiage) le peu que j'ai pu attraper de toutes ces sublimes idées."

Lettres philosophiques (Voltaire, 1734)

Collaboration is the base in many industrial activities, and the innovation process is not an exception, because it improves the speed of the development of inventive products, and it allows to increase the level of inventiveness of the solutions proposed. Hence, understanding the mechanisms of collaborative behavior in groups of people is necessary for the development of an architecture of participation. Collective intelligence derived from this architecture of participation is a suitable mechanism for enhancing the collective resolution of inventive problems.

This chapter introduces our proposition of the conceptual framework for an Open CAI 2.0 solution. Then, it is developed each aspect of the theoretical basis. Firstly, the chapter recalls the previous proposition, describing the open innovation paradigm as the strategic driver, and the use of Web 2.0 as the technological driver. The chapter also details the mechanism to implement the open innovation paradigm in the enterprises, having a particular interest in the Open Innovation Networks. For the technological driver, the Web 2.0 is presented as a platform for collaboration; social network services are studied in details because of the advantages for collaborative participation in the industrial context. The Open CAI 2.0 is complemented with elements of collective intelligence to enhance the model of collaboration. Then, the chapter introduces a new element in Open CAI 2.0 solutions: a creativity driver. The creative driver is outlined as a problem resolution process.

4.2 Our proposal for a conceptual framework in Open CAI 2.0

4.2.1 Conceptual elements

In Figure 4.1, we present the conceptual elements of our proposition for an Open CAI 2.0 solution. Each principle was selected with the goal to configure a flexible conceptual framework capable to adapt to all the stages of the innovation process, not only the front end. In further section we will discuss the methodological operation of each of them.

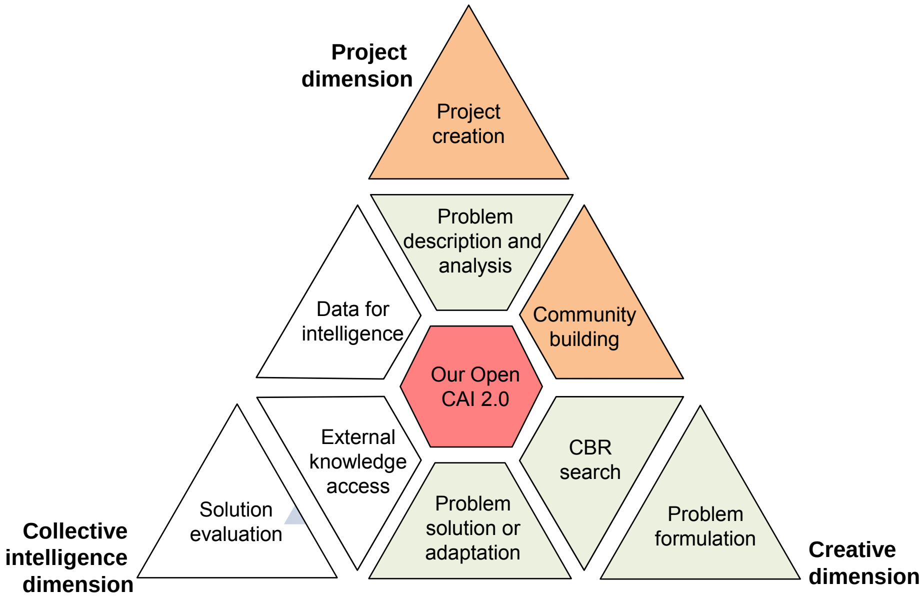


Figure 4.1 Conceptual elements for an Open CAI 2.0 solution (Own construction)

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, taps into the explicit and implicit knowledge generated during the collaboration. Below is described each conceptual element.

Project creation this requirement corresponds to the identification of collaboration situation. The stakeholder creates an instance of what is called a *project* to organize and store the information relative to the problem resolution process.

Community building is the requirement to form a team in the collaboration process. Building the community refers to locate the expertise necessary to solve the creative problems. It is the stakeholder the responsible of this requirement.

Problem description and analysis is where the participants provide relevant information for the problem resolution process. It is divided into problem description to detail the problematic situation, and to analyze where the participants have access to the analytical tools to better understand the causes and the resources available in the problem situation.

Problem formulation corresponds to the options for accessing the TRIZ tools to formulate the problem.

CBR Search is the functionality to look for past experiences with a certain similarity to the current problematic situation.

Problem solution or adaptation is part of the TRIZ-CBR model, when using the CBR search two options are possible; current problem match an existing case in the knowledge base, then the users should adapt the retrieved solution to the current problem. On the other situation, the user should propose a solution by using TRIZ solutions model.

External knowledge access is a functionality to help the participants in the resolution process for accessing external information that could be relevant to the problematic situation. It takes into account the problem description and the tags included in the project to make the request in Open Linked Data sources.

Data for intelligence refers to the implementation of Collective Intelligence techniques to better support the resolution process in collaboration. A recommendation system, creation of the user profile, review and the tag support are one of the techniques proposed.

Solution evaluation is a decision making activity. It is the stakeholder responsible to evaluate the best solution proposal; with the use of the community reviews (rating and comment) it could be easier for the stakeholder to make his selection.

The link between these key elements must be detailed to define the methodological framework of the tool.

4.2.2 Methodological Framework

In order to organize the different theoretical elements of the proposed framework, Figure 4.2 introduces a three level structure. 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. 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 Figure 4.1: Problem description and analysis, Problem formulation, CBR search, Solution proposal or adaptation.

- *Collaboration support*: this module includes 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 and Community building are the blocks of Figure 4.1 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. This level addresses with the Data for intelligence, External knowledge access and Solutions evaluation blocks of Figure 4.1.

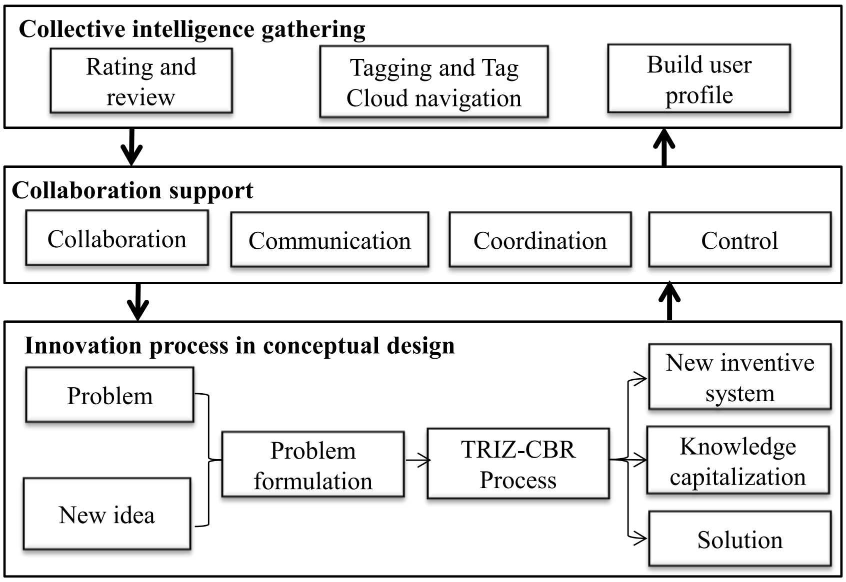


Figure 4.2 Organization of theoretical elements in our Open CAI 2.0 solution (Own construction)

One characteristic of the organization presented in Figure 4.1 and Figure 4.2 is that the elements can be easily replaced for other conceptual components, or the configurations can be easily scaled. These elements are based on the following theoretical aspects to propose the basis of our conceptual framework:

Regarding Open Innovation:

- To outline company policies while taking the decision to put in practice open innovation.
- To define a roadmap with the implementation mechanism, i.e. seven axes model. The seven axes model will be detailed in the section 4.4.2.

- To describe a collaboration mode, i.e. Open Innovation Networks.

Regarding the Web 2.0 as platform for collaboration:

- To select a collaboration pattern, i.e. Asynchronous.
- To have an architecture for active participation, i.e. Distributed Social Network.
- To studying the dynamic of online social networks.
- To gather data for intelligence.

Regarding the creativity driver:

- To have a common language to overcome imprecision.
- To define a logical sequence of activities to organize creativity as a problem resolution process.
- To take advantage of previous experiences.

The subsequent sections lay out the theoretical foundations of the proposed Open CAI 2.0 framework.

4.3 Foundations for an Open CAI 2.0 framework[9]

As indicated in Chapter 2, the process of innovation is a social phenomenon that requires the support of methods and tools adapted to the dynamics of modern industry. Then, Chapter 3 has underlined that Computer Aided Innovation is one active research fields to develop tools to assist the creative phase of the innovation process. This Chapter proposes the theoretical foundations for a framework based on the Open CAI 2.0 concept. Firstly, Figure 4.3 provides the elements constituting a previous proposition. This figure presents the characteristics of the open innovation as the strategic driver, as well as the characteristics of the technological driver. Later in this chapter, in the section 4.7, we adapt and improve this first proposition to integrate the creativity driver.

[9] A basic conceptional structure (as of ideas) - Merriam-Webster definition

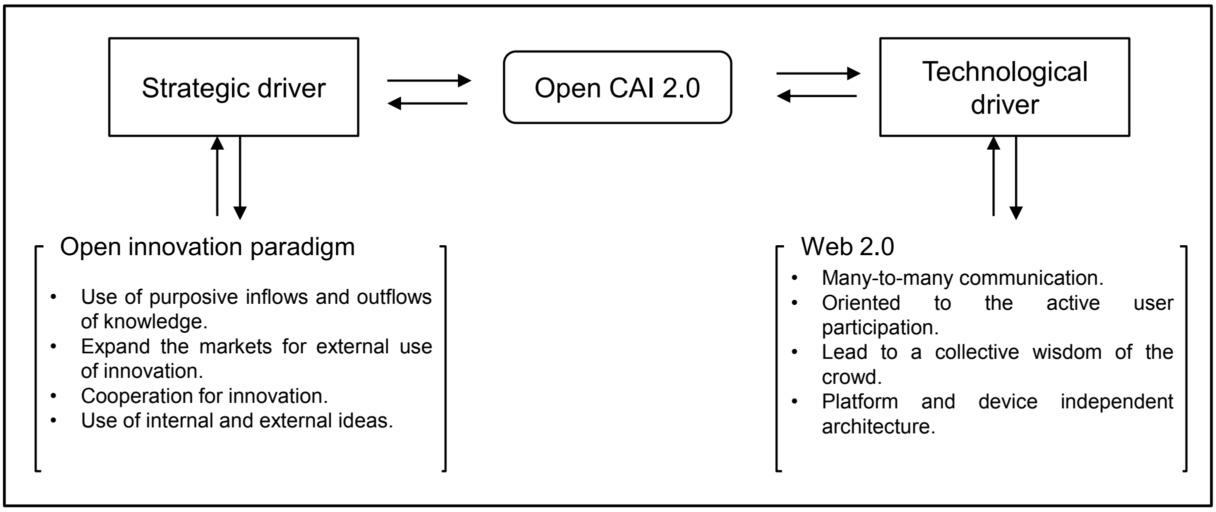


Figure 4.3 Open CAI 2.0 concept. Based on (Hüsig and Kohn, 2011)

From the theoretical elements in the original Open CAI 2.0 concept, we identified the following requirements for the implementation of a software solution:

- Expansion of the innovation community beyond the organization boundaries.
- Participation of external actors (customers, researchers and people interested).
- Increase of the creative potential.
- Reducing the time to generate ideas using the wisdom of the crowds.
- Evaluation of ideas and solutions by the community itself.
- The use of the Web as a platform for collaboration.
- Identification of external participants to create a relevant community.

4.4 The mechanisms to implement Open Innovation

As enterprises realize that the closed model of innovation becomes outdated in a globalized economy, they tend to include the participation of external knowledge and expertise. Consequently, many contemporary organizations consider the open innovation paradigm as a way to enhance their innovation capabilities (Mortara and Minshall, 2011). Nevertheless, while there are important debates on related concepts, and on benefits derived from the practice of Open Innovation (Huizingh, 2011), there is still a research activity regarding the mechanisms of implementation (Chiaroni et al., 2011).

In the context of this work, the open innovation implementation is outlined following the roadmap shown in the Figure 4.4. The objective of this roadmap is to define a strategy, starting from the principles to implement open innovation until a specific collaboration. As observed, the roadmap starts with generalities about changes inspired on the four principles. These changes are conceived at managerial and organization levels. Then, it continues with more specific mechanisms to put in practice open innovation at operational level in organizations. Finally, the collaboration mode is associated to the implementation (including the use of a technology) of one or more mechanisms. It is supposed that the implementation of this roadmap is adapted to other phases than the front end of innovation, because it covers a wide number of principles and mechanisms.

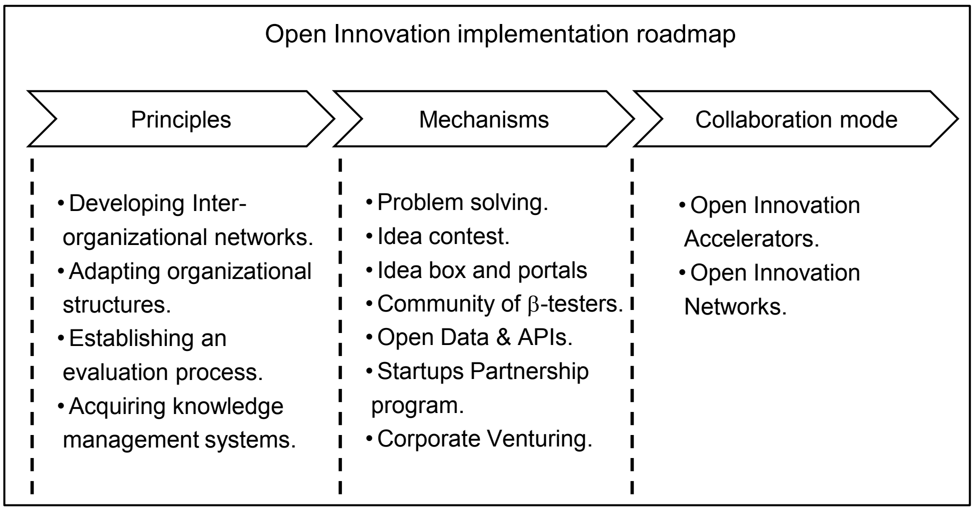


Figure 4.4 Open Innovation implementation. Based on (Chiaroni et al., 2011; Duval and Speidel, 2014)

The remainder of this section details the steps presented in the roadmap.

4.4.1 Principles to implement Open Innovation

Regarding the principles to implement Open Innovation, (Chiaroni et al., 2011) identify four principles described as follows:

- *Developing an inter-organizational networks*. In order to successfully implement open innovation, firms should be able to manage different partners including universities, research institutions, suppliers and users. Therefore, the establishment of collaboration networks offers twofold benefit: to in-source external ideas from a wide range of innovation sources, and to have more channels to market internal ideas.
- *Adapting organizational structures.* The "design over the wall" pattern is an obstacle to deploy open innovation in enterprises. Therefore, companies require an internal re-organization to successfully manage external acquired knowledge, as well as to follow the commercialization of internally developed ideas. This re-organization includes the development of complementary internal networks, the creation of independent open innovation business units, the establishment of organizational roles and the use of rewarding systems to support the new paradigm. A first study to identify, define and analyze the influence of the organizational structure in the interaction with the enterprise environment for the practice of open innovation is documented in (Steiner, 2014).
- *Establishing an evaluation process.* The explosion of the number of innovative concepts due to the openness of the process increases the difficulty to evaluate them. Thus, it is necessary to develop an evaluation process dedicated to identify potentially successful innovations. This

process encompasses metrics of evaluation and systematically inspections for available technologies in the external environment.

- *Acquiring knowledge management systems.* The introduction of the new paradigm requires the use of Knowledge Management Systems (KMS). This is explained by the use of purposive inflows and outflows of knowledge. Therefore implementing Open Innovation means to adopt KMS to effectively support different knowledge processes; e.g. knowledge exploration, retention, exploitation, reuse and creation of new knowledge within the firm, and between the firm and its environment. Moreover, KMS are necessary because the openness of the innovation process increases the generation and the use of new knowledge sources.

These principles indicate the general practices to outline company policies while taking the decision to put in practice open innovation. However, they are general and need specific implementation mechanisms. The next section introduces more detailed practices in a seven axes model.

4.4.2 Implementation mechanism: Seven axes model

(Duval and Speidel, 2014) present a model which is composed of seven axes for implementing Open Innovation practices. As shown in Figure 4.5, the mechanisms of this model are oriented toward the participation of internal enterprise actors, likewise to external collaborators. According to the authors, enterprises implementing the seven axes model improve the opportunities to develop an open innovation culture with a sustainable collaborative dynamic. In principle, such opportunities are based on adapting existing practices within the enterprise, for their internal and external use in a systematic innovation process.

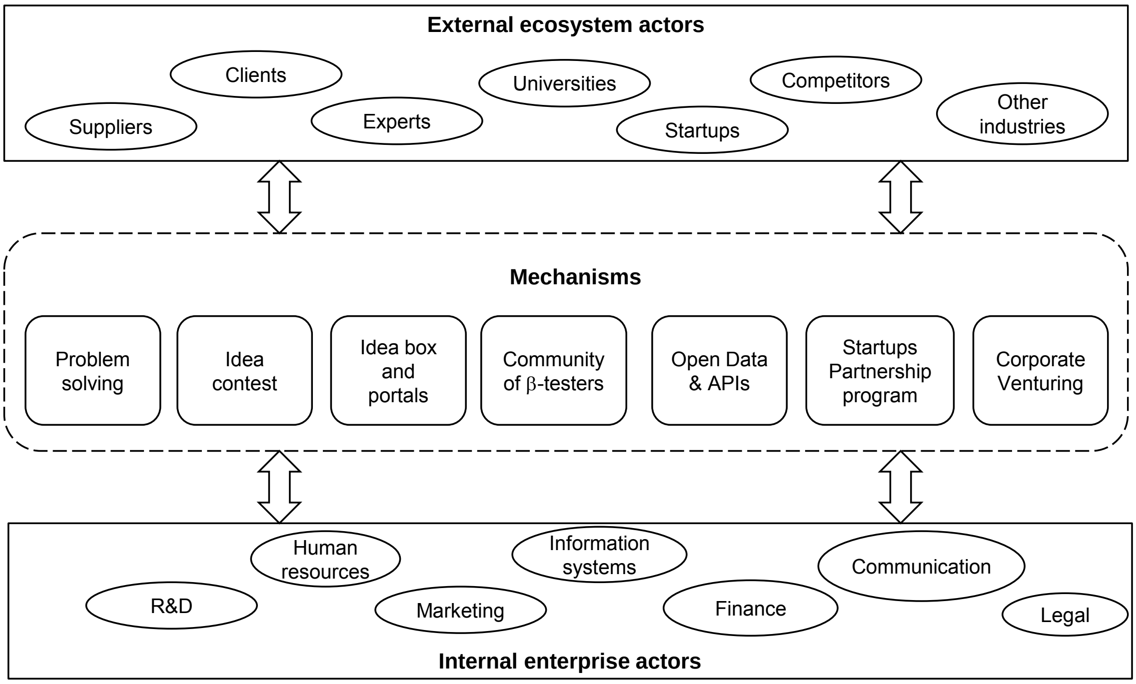


Figure 4.5 Seven axes model (Duval and Speidel, 2014)

Regarding the three first mechanisms (problem solving, idea contest and idea box), they promote the active participation of actors with different profiles and backgrounds. Although, their practices can be achieved without the use of Information-Communication Technologies (ICT), it is recommended to use web applications to accelerate the implementation. Community of β-testers is a selected group of users and clients who provide feedback about new products or services. The Application Programing Interface (API) and the Open Data are two mechanisms used by companies to provide software services and information for different reasons (e.g. enhancing the web traffic, pay-per-use or products diffusion). Startups and corporate venturing are mechanisms oriented toward the valorization of internal, as well as external generated technologies.

The advantages of the seven axes model are: the flexibility to adapt the mechanisms to different industries, they are based on existing practices within enterprises, and they rely on the use of digital platforms. This work focuses on the first two mechanisms (problem solving and idea contest), in order to put in practice the open innovation strategy. Although each mechanisms concerns different phases of the innovation process, the first two are specific for the creative development of new products.

The successful implementation of the selected mechanisms requires the definition of a collaboration mode. Open Innovation Accelerators in general, and Open Innovation Networks in particular are two modalities for creating ecosystems of participation to take advantage from external input in an efficient and effective way.

4.4.3 Open Innovation Accelerators

Recent web-based services are using the wisdom of the crowd to organize the open innovation practices (i.e. crowdsourcing services). In this perspective, the intermediaries between a specific company and the external actors are called Open Innovation Accelerators (OIA). (Diener and Piller, 2009) define OIAs as "*intermediaries that operate on the behalf of companies seeking to innovate in cooperation with external actors from the periphery. OIAs offer one or several methods of open innovation and, partly, supporting complementary services for the innovation process*". The OIAs methods (e.g. lead users, idea contest, and toolkits) are focused on new forms of collaboration such as the broadcast of open contests or the co-creation of new products.

Collaboration through OIAs helps the organization to decrease the time for developing a new technology or solving inventive problems, because with many information sources and participants the task for searching specialized knowledge can be very long. Since Small and Medium Enterprises (SMEs) have a limited capacity to tackle innovation activities (Lindermann et al., 2009), OIAs allow them to access intermediaries in order to accelerate their innovation process. Consequently, SMEs access to external knowledge and service providers, whereas they avoid difficulties associated with management aspects. However, a potential issue is the centralization of information, which is the control of the information by a central unit.

Open Innovation Networks are one particular type of OIAs. They are particularly interesting in the context of this work, because of the possibilities to create a community composed of innovation seekers and solution providers. The following section addresses in details the operation of this kind of service.

4.4.4 Open Innovation Networks

Open Innovation Networks operate as an intermediary between a seeker that broadcasts an innovation problem, and a community of solution providers. (Nunez and Perez, 2007) document the operation of these kinds of systems, and Figure 4.6 illustrates the operation.

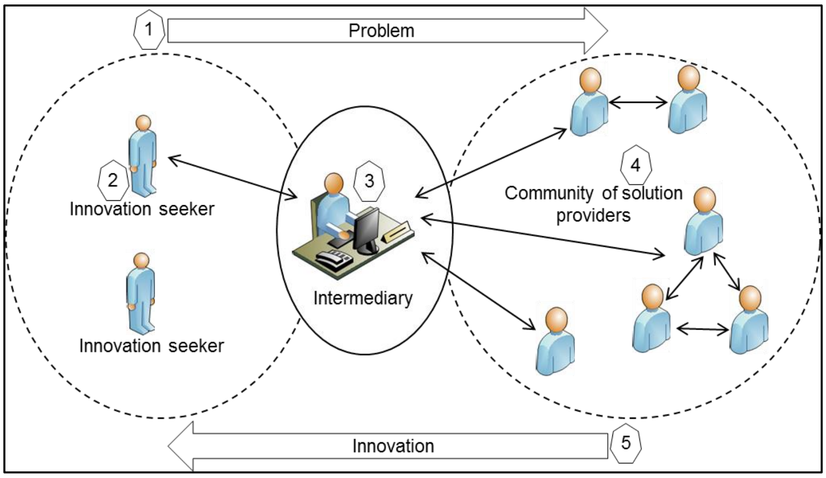


Figure 4.6 Architecture of an Open Innovation Network (Nunez and Perez, 2007)

Each element of the architecture can be described as follows:

1. Problem. It is a specific problem for which the innovation seeker requests help to solve it. The information is composed, but is not limited to the title, description, terms and conditions, end date, keywords and profile (taxonomy fields).
2. Innovation seeker. It is the entity (an individual user, group of users, legal entity, or group of legal entities) that is registered in the Open-Innovation Network and seeks to license or buy innovations.
3. Intermediary or broker. It is the entity that provides the workspace to the innovation seeker and the solution providers to source the development of innovative solutions, and organize for their delivery. It provides the mechanism for the correct transaction to license or purchase innovations, for example: verify innovation results, manage governance, ensure quality, create incentives for system participation, and establish methods by which solution providers can extract monetary value from the creation of innovative solutions.
4. Community of solution providers. It encompasses a plurality of potential solution providers, who are individuals or groups which have experiences and/or trainings useful to a specific industry and intent to develop and/or post inventive insights.
5. Innovation. It includes, but it is not limited to, the realization of a new or improved useful idea. The innovation is described in one or more documents (e.g. text, images, video, animation or audio files).

As (Ye and Kankanhalli, 2013) indicate, brokering capabilities of Open Innovation Networks reduces the gap between multiple domains and industries in order to create new products or services, because it transfers ideas from where they are known to where they are needed. Moreover, in this emerging collaboration models for the innovation process, the development of Web-based solutions favors the access to a marketplace of innovation providers. Therefore, the next step is the identification of the technological elements to develop the services of an Open Innovation Network.

4.5 The Web 2.0 as a platform for collaboration

The Web 2.0 as a technological driver is the other major component in the Open CAI 2.0 concept. In section 2.6.1, a description about the Web 2.0 technology was introduced. This section is more focused on the technological elements to implement, and to take advantage of its collaborative capacities. 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. But before talking about collaboration on the Web 2.0, it is necessary to make a semantic distinction between cooperation and collaboration. Often in literature the collaboration term is mistaken with the cooperation term, or both are used as synonyms. However to differentiate them, (Dillenbourg et al., 2009) give the following definitions:

- Cooperation: The division of labor among participants, as an activity where 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.

Based on the two previous definitions it is possible to point out that they encompass similar points such as sharing work, creating and sharing knowledge, communication and coordination. However, according to (Caseau, 2011) the main difference between collaboration and cooperation is the degree of organization of the activities between actors. On the other hand, collaboration is a fuzzier concept and the participants do not have a hierarchical organization, instead the work is guided by a common objective which is shared by all the members. Both cases require an orchestration of activities, which justifies the definition and the formalization of a process. The concept of process, as it is defined in the Business Process Management field, is an important tool because it orchestrates the tasks between participants. In order to detail the collaboration concept, a generic collaboration framework is described in the next section.

A generic collaboration framework

For (Campos et al., 2006; Sorli and Stokic, 2009), situations of collaboration in the industry seek to facilitate the participation of different actors in activities related to reach a common objective (e.g. solving a problem, designing a new product). Figure 4.7 shows a generic framework with the main activities to consider in collaboration whatever the situation and the collaboration purpose.

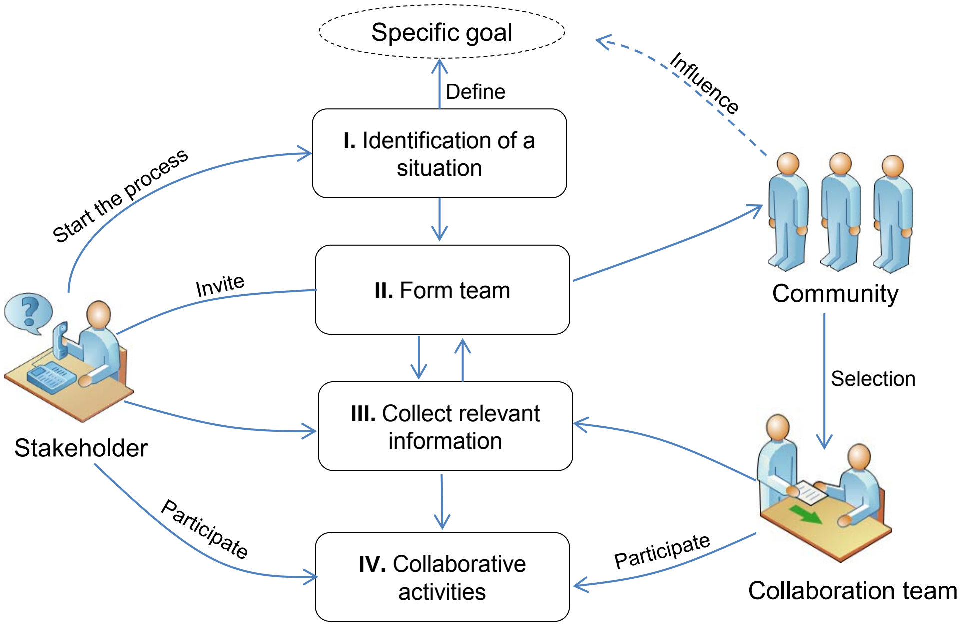


Figure 4.7 Generic model for industrial collaboration. Adapted from (Campos et al., 2006)

The activities presented in the collaboration model require:

I. To identify a situation. It is the stakeholder who identifies the situation that requires collaboration to meet a specific goal. The stakeholder is an individual or a group of individuals.

II. To form a team. The Stakeholder invites the members of a community to form the collaboration team. For a better result, a recommendation service enables to create a coherent and relevant collaboration team composition. The actors involved have the role of collaborators.

III. To collect relevant information. The participants provide the necessary information for the situation, by gathering knowledge from different sources, and the by processing and analyzing it.

IV. To participate in collaborative activities. According to the nature of the situation different tools and collaboration patterns will be necessary. It is required to register all contributions in order to keep a record of the collaboration process.

For implementing the above described framework, 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” relying on the Web 2.0. Therefore, it is important to define the concept of “architecture of participation” to deeply understand the collaborative features associated with the success of the Web 2.0. As (O’Reilly, 2007) indicates, the architecture of participation is a service acting primarily as a broker, by relating different participants to explicitly and implicitly generate content. This architecture provides the elements for developing collaborative tools such as blogs, wikis and social network services (Kane, 2009).

For (O'Reilly, 2006, 2007), two principles support the architecture of participation:

- Users added value. Users add value directly through active participation for instance. Consequently, the value of an application is proportional to the quantity and dynamism of the managed information. However, there is also added value as consequence of their interactions, e.g. rating or commenting the content generated by other users.
- Network effects improve the value. Network effects occur when a product or service becomes more valuable as the number of people using it increases. For (Katz and Shapiro, 1994), the value of membership is positively affected the more users join and participate in the network. For instance, in communication networks members find valuable the network as other users subscribe. In social networks, a user finds useful the service when most of his friends are subscribed.

The advantage of the Web 2.0 technologies for business purposes, or its use in the industry is because not only they provide a better communication between people in diverse groups and locations by breaking the time and the space, but also they provide lower-cost, easier-to-adopt and scalable solutions (O'Reilly, 2007; William Xu and Liu, 2003). Moreover, the Web 2.0 technologies enable different forms of collaboration patterns outlining the interactions among participants. According to (Campos et al., 2006) these patterns emerge from the necessity to share information and objectives, and to divide the work. A classification about these patterns is presented in Table 4.1.

Build on the Web 2.0 technologies, Social Network Services[10] create new forms of communication, interaction, information sharing and collaboration (Wilson et al., 2009). Social networks base their operation in the creation of relationships between participating members (e.g. social or family ties), through the use of ICT. For (Caseau, 2011), they are an emerging way to organize collaborative work in the industry, leading to what is known as Enterprise 2.0.

[10] Also known as Online Social Networks, Social Network Services or Social Networks.

Table 4.1 Generic collaboration patterns (Campos et al., 2006)

Pattern	Classification	Description
Temporal	Synchronous	Data is shared by team members in the same period of time. Modifications are observed by all members at the same time.
	Asynchronous	Each user works on data separately. The activities are achieved at distinct times.
	Multi-synchronous	Modifications occur in parallel.
Spatial	Locally	Collaboration team members are located physically in the same place.
	Distributed	Team-members are located in different geographical locations and workspaces.
Rules	Work rules	Defined by participants; can be negotiable, therefore removed, updated or replaced.
	Norms	Each group members is expected to respect these norms; usually known for all group members.
	Constraints	Not negotiable; usually established by external situations or by technical aspects.

For an in-deep understanding about the design of social network services, the following section documents different patterns and architectures. Indeed, the social network analysis technique is relevant to describe the behavior of members in social network services and online communities. This tool is included for studying the performance of collaboration, and it can be useful to uncover important knowledge arising from the users' interactions. Moreover, to promote participation is necessary to study the behavior of the involved actors. To recapitulate, the value of social networks is positively affected, the more users participate.

4.5.1 Collaboration in Social Network Services

In (Easley and Kleinberg, 2010), the authors define social networks as: "*the collections of social ties among friends*". The use of social network services for collaboration is not recent, there are different documented cases. For example the UK government department investigates how to deal with managerial and organizational issues by using social networks for supporting collaborative work (Rooksby and Sommerville, 2012). However, the adaptation of the use from the personal context to the organization context is not straightforward (Convertino et al., 2010).

In the innovation process, people are the central elements because they are the creative actors who transform information and knowledge into solutions. Thus, organizing collaboration between actors becomes the crucial point of the process. Social networks enable new form of collaboration by allowing the interaction of different users without the need to meet each other (Esteban-Gil et al., 2012). A simple representation of a social network is illustrated in Figure 4.8 with a graph model; where the nodes represent the members and the edge represent the relationships between them.

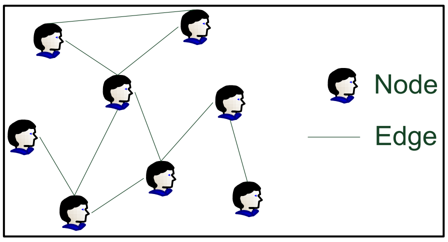


Figure 4.8 Graph model to represent a social network

According to (Abrams, 2006) the advantages of interacting through social networks are:

- It is more comfortable for the interaction with strangers.
- It reduces the risks of rejection, deception, and even danger in some cases.
- It enhances efficiency of the process.
- It increases the level of quality in relationships established.

On the other hand, disadvantages about the use of social networks are:

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

Design of social networks

To create opportunities for the better design of social network services, it is necessary to understand their evolution patterns, the users' behavior and the collaboration architecture. The next paragraphs describe these elements.

Regarding the evolution patterns in social networks, (Kumar et al., 2010) identify that they follow the same evolution as offline networks, that is: rapid growth, and then slow but steady growth. They also argue that this pattern is due to the activity of leader users who actively are discovering and exploring the service, whereas they invite new users. Then, there is a period of rapid growth with new members joining the service. Finally, there is a period of ongoing organic growth in which membership and linkage increase slowly.

Most of the content in social networks is user generated. For (Benevenuto et al., 2009), the quality of the content generated is directly correlated to the users' behavior. (Kumar et al., 2010), classify the behavior based on the users' interactions and activity as follows:

- Passive members or *Singletons:* The main characteristics of this kind of members are: they do not have connections with other participants, they do not participate actively in the network or they have recently joined the service.
- Inviters or *Middle region* members: This kind of participants encourages offline friends to join the service, they form isolated communities where there is a single charismatic individual linked other users who have very few connections.
- Linkers or *Giant component* members: They fully participate in the social evolution of the network, these users are connected directly or indirectly to a large fraction of the entire network, and typically they are the high active and gregarious individuals.

The evolution of the structure within social networks characterizes users' behavior according to their participation. However for an effective collaboration, it is required to define an organization model. According to (Nguyen et al., 2012), a collaborative group (or community) is a subgraph of a social network, and the architectures for organizing the collaboration among community members are: centralized, distributed and decentralized as shown in Figure 4.9.

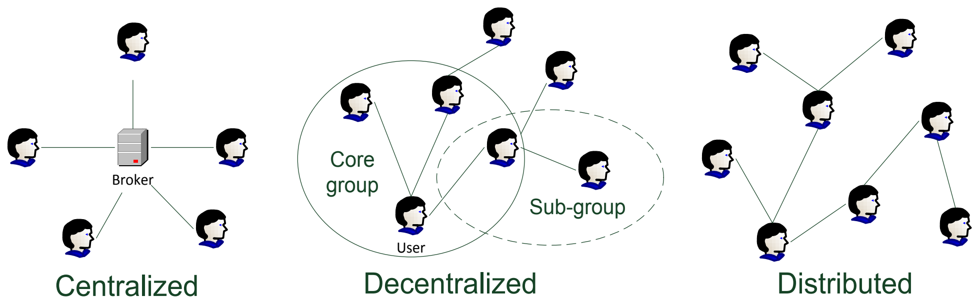


Figure 4.9 Collaboration organisations (Nguyen et al., 2012)

These three types of collaboration organization can be described as follows:

- Centralized. A central unit controls participations and information flows. Participants depend on the central unit to access information (send and receive). Characteristics of this organization are: users do not have much control over how their own generated information is disseminated (Trieu and Pham, 2012); communication becomes more complex as groups increase in size; authority becomes hierarchical (Forsyth, 2010).
- Decentralized. These groups derive from centralized ones; they divide tasks and assign them to smaller groups. The main characteristics identified (Trieu and Pham, 2012) for this organization are: information is always available; direct exchanges, connection between two

users is established directly; quick responsiveness to share information; and scalability, when participants can connect directly to the others, new friendship is easy to build. However, it is possible to have nodes having central positions in the sub-groups.

- Distributed. This model is a variation of decentralized groups but they do not have central positions. All the participants are linked in the bases of equality, independence and cooperation. This model makes easy the composition of self-organized communities. However, conflicts and decision making need to take into account the opinion of all participants in a sub-group.

For (Forsyth, 2010), small groups with centralized organization perform better than decentralized, because it takes less time to perform tasks, sent fewer messages, and the correction of errors is easier. However, decentralized networks outperformed the centralized ones in more complicated tasks (i.e. problem solving). For (Forsyth, 2010), this situation is due to the *information saturation*; the more information is managed by the central unit, a saturation point can be reached for which information is handle inefficiently. Despite the advantage of decentralized networks, the fact of having different centralized sub-groups can result in the same problems as the centralized ones. In the case of distributed organizations, they perform better to create self-organized communities, however a consensus is required because the different visions of participants provide different solutions to the same problem (Kozierkiewicz-Hetmańska, 2012).

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 selected to organize collaboration in our Open CAI 2.0.

Online communities

By using implicit or explicit relationships (Kwak et al., 2010), users integrate virtual communities for collaborating to create content or to establish relationships. According to (Cliquet, 2010) a community is a group of people that are linked either by obligations, common interests, opinions or common personalities. However, despite the technological advantages observed in collaborative web-based applications, only a small number of participants are active contributors. As demonstrated by (Iba et al., 2010; Priedhorsky et al., 2007) in Wikipedia community only the top 10% participants create about 86% of its valuable content. And the top 0.1% of the members contributes to 44%.

Studying the dynamic of online social networks is useful for the better understanding of collaboration and collective intelligence in web-based applications. Collaboration and collective intelligence are part of the requirements for services to support the Open Innovation paradigm.

4.5.2 Analyzing the dynamic of Social Networks

Members in online communities behave the same way as traditional or offline (face-to-face) communities: developing norms, admitting new members, identifying goals and experiencing conflicts. A community is formed with two or more individuals, but in practice they have on average between 2 and 7 members (Forsyth, 2010). Understanding how the users behave when they participate in on-line communities allows to evaluate the performance of existing systems and leads to a better services design (Benevenuto et al., 2009). Social Network Analysis is a group of concepts and methods inspired from mathematics, mainly from Graphs Theory, for the analysis of relational data arising from social systems. Social Network Analysis is useful to study the dynamic of users' participation in on-line communities because it is feasible to represent those interactions as graph information or in the form of matrix. Indeed, social networks data consist of a two dimensions matrix of measurements. The rows are the cases or observations (i.e. community members). The columns are the same set of cases or observations. And each cell in the column describes a binary relationship between them (Hanneman and Riddle, 2005).

The graph theory is widely used to represent the structure and interaction in social networks (Caseau, 2011; Easley and Kleinberg, 2010; Wilson et al., 2009). The fundamental data required for a Social Network Analysis consists in an adjacent matrix or a graph made up of individuals (or organizations) called nodes, which are connected by links (also called edges, vertex or ties) representing interactions or relationships between the nodes. In order to represent the information two options are identified (Hanneman and Riddle, 2005), the use of a graph model and the use of matrices; the reasons to represent social network information with mathematical methods are:

- Matrices are compact and systematic.
- Matrices allow to use computers to analyze data.
- Matrices have formal mathematical notation.

With this introduction to the representation of social network information for its analysis, let's consider the metrics to find relevant nodes in a Collaboration Graph. Collaboration Graphs (Easley and Kleinberg, 2010) are useful to record who works with whom in a specific task, for example, co-authorship among scientists or patent citations. Concerning indicators, *centrality* refers to one of the metrics widely used to determine the relative importance of a node within a network. Therefore, centrality is an important concept in analyzing collaboration in social networks because it helps in finding active contributors. Besides other measures such as the user's reputation, centrality is also useful to detect potential collaborators in the process of collaborative innovation.

Centrality metrics

Centrality measures are crucial to perform analysis in networks such as: social, co-authorship, biological, communication, and transportation (Brandes and Fleischer, 2005). It was Freeman (Freeman, 1978) who initially proposed the methods to calculate the metrics. In the work of (Takemoto and Oosawa, 2012), authors summarize the most common metrics for centrality, and among them:

- Degree Centrality. It is the simplest measure for centrality, it represents the total number of connections incident upon a node. It is viewed as an important index of its potential communication activity. Using the correlation between the centrality of node *i* and the degree of node *i* (K_i), the degree centrality *i* is calculated as

  $$C_D(i) = \frac{K_i}{N-1}, \tag{4.1}$$

  where *N* is the network size.

  For directed graphs, degree centrality is usually separated in two sub-categories: in-degree and out-degree. As (Hanneman and Riddle, 2005) remark, in-degree is the sum of connections directed to the node, and it is linked to its influence. Out-degree is the number of connections that the node directs to others.

- Closeness centrality. This measure emphasizes the distance of a node to all others in the network by focusing on the distance from each node to the others. It is based on the shortest path length between nodes *i* and *j*, *d(i, j)*. When the average path length between a node and the other nodes is relatively short, the centrality of such a node may be high, therefore the metrics is expressed as

  $$C_C(i) = \frac{N-1}{\sum_{j=1, j\neq i}^{N} d_{ij}} \tag{4.2}$$

  One difficulty with this metric is when there are isolated components resulting from unreachable node pairs; in this case closeness centrality is not calculated appropriately. In the case of co-authorship networks, closeness centrality represents how close an author is to all other authors (Liu et al., 2005). An author with a high centrality has many, short connections to other authors in the network.

- Betweenness centrality. This metric indexes how central is a node by identifying the shortest path between every other pair of nodes. Betweenness centrality of a node *i* considers the fraction of shortest paths that cross *i.* thus the metric is defined as

  $$C_B(i) = \sum_{s\neq t\neq i} \frac{\sigma_{st}(i)}{\sigma_{st}}, \tag{4.3}$$

where $\sigma_{st}(i)$ and σ_{st} are, respectively, the number of shortest paths between nodes s and t, on which node i is located, and the number of shortest paths between nodes s and t. For normalization, the betweenness centrality is finally divided by the maximum value.

- Eigenvector centrality. This metric is not part of the three original metrics that Freeman proposed, nevertheless it is presented as a higher version of the degree centrality (Takemoto and Oosawa, 2012). To be calculated, it can consider the centralities of neighbor nodes. In the following equation, let $C_E(i)$ be the centrality of node i; $C_E(i)$ is proportional to the average of the centralities of the neighbors of node i,

$$C_E(i) = \lambda^{-1} \sum_{j=1}^{N} M_{ij} \cdot C_E(j), \tag{4.4}$$

where M_{ij} is an adjacency matrix. $M_{ij} = 1$ if node i connects to node j, and $M_{ij} = 0$ otherwise. λ is a constant. For instance, eigenvector is used to measure the prestige of web pages, web pages represent the nodes and hyperlinks are the edges (Liu et al., 2005). The google's PageRank algorithm, which is a variant of the eigenvector centrality, illustrates the importance of this metric.

In the Figure 4.10, Takemoto and Oosawa explain graphically the differences between the centrality for each metric.

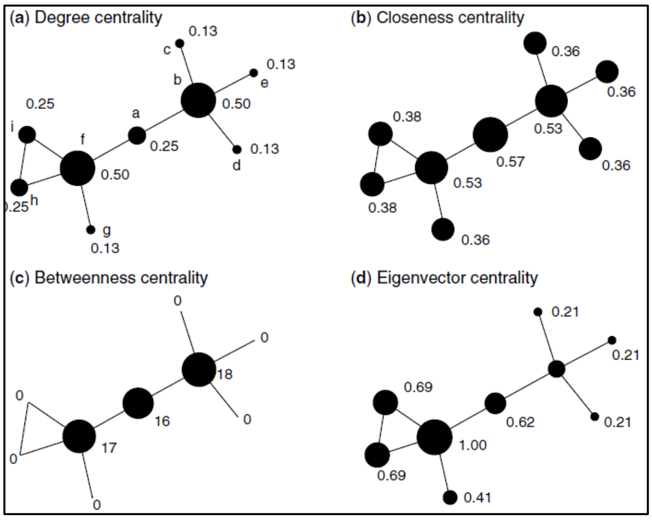


Figure 4.10 Principal centrality metrics (Takemoto and Oosawa, 2012)

Besides, centrality finds how many connections a person has; it also identifies his or her position within a network itself (Forsyth, 2010). Important information such as the most active collaborators is easily derived with the degree centrality. With degree centrality, for example, it is possible to identify nodes with high communication capacity, or high influence within a network. This kind of analysis is also valid to uncover hidden knowledge in other information structures such as patents citation networks.

The technological elements, organization and the tools to promote the collaboration in the Web 2.0 were previously introduced. We propose the Figure 4.11 to organize them for the design and implementation of an Open CAI 2.0 solution. In the pyramid, the lower levels correspond to more technical aspects, and the upper levels represent a higher abstraction for collaboration support. It highlights that social network services are built on the support of the Web 2.0, and they are at the same level as collective intelligence. This is because collective intelligence is understood as an element to enhance the innovation process, which results from the collaboration through social network services. The next section 4.6 describes the way collective intelligence improves collaboration.

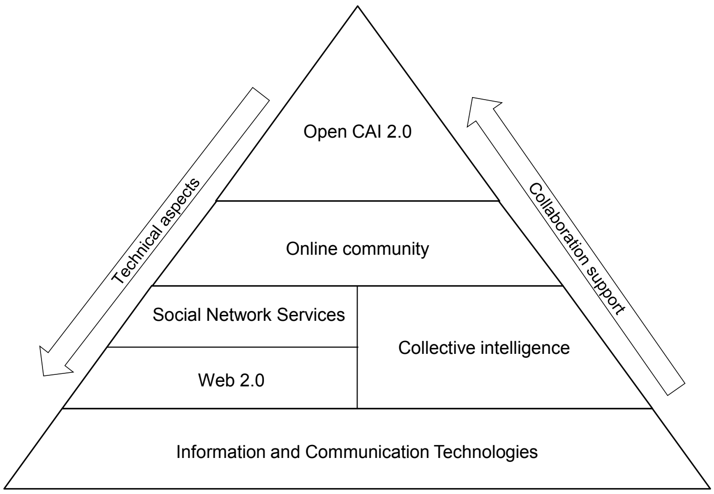


Figure 4.11 Organizing the technological elements for collaboration (Own construction)

4.6 Collective intelligence approach to improve the innovation process

In a distributed architecture for organizing collaboration, the innovation process has the option to allow the participants to express their creativity in a more open way. Nevertheless, if not handle correctly, there is a risk to lose information and the huge amount of knowledge produced during the process. The human creative effort in community in combination with the power of computer algorithms can lead to what is known as Collective Intelligence.

Not only the organization of the collaboration process should allow participants to express their creativity with the less restriction possible, but also it is required to include in the architecture for participation techniques to take advantage of the collaborative participation. Therefore, this section introduces the algorithms and techniques in current use to develop the Collective Intelligence concept in Web 2.0-based solutions. These algorithms are oriented to self-organized communities for organizing collaboration. To illustrate the use of collective intelligence functions in the collaborative innovation process, the Table 4.2 lists the requirements that we must take into account for an Open CAI 2.0 solution.

Table 4.2 Collective intelligence requirements for the collaborative innovation process (Own construction)

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

The detail for each function is described next.

4.6.1 Gathering data for intelligence (collective intelligence techniques)

In the architecture of participation of social network services, it is possible to combine the user-generated content with sophisticated algorithms in order to exploit explicit and implicit information in web-based applications. By combining user-generated content with such algorithms, the applications improve their performance as more users take part. In previous section 4.5 the characteristics of Web 2.0-based software to promote user collaboration were exposed, the next section documents the techniques to enhance these kinds of applications with the collective contribution from the users. (Alag, 2008) introduces these techniques to harness data for intelligence in web applications.

Tag integration

Tagging facilitates to add keywords to classify items (e.g. pictures, videos, articles, profiles). Tag and tag cloud navigation are part of dynamic classification of content through terms generated using one or more of the following techniques: machine-generated, professionally-generated, or use-generated. According to (Esteban-Gil et al., 2012), in collaborative environments tagging is useful for indexing purpose, facilitating search and navigation of resources. Figure 4.12 is an example of the tag-based navigation to filter the items according to the selected tag, and the classification of an item using keywords the users generate. The example is from a project created in our developed prototype.

Figure 4.12 Tag example

Build user profile

The profile represents the users' membership into the social network service. As (Lytras et al., 2008) observe, the profile serves as an online identity within the environment. Therefore, the ability to create and maintain the users' profile is a basic functionality to keep a record of his previous participations in collective environments.

The content to build the user profile is originated from different sources:

- Personal information. It concerns the biographic and professional information of the user. Most of the time, this kind of information is explicitly indicated and the user has the control to update it.
- Tracking user activities. Typically it is a record of the participations of the user within the service.
- Reputation. It is a mechanism for scoring the participations of users. It helps to encourage participation and to prevent abuses. Ranking[11] and review are two of the most common ways to get the feedback for implementing a reputation system.
- Content associated (i.e. tags).

The previously sources to build the user profile, take into account common information found in services promoting participation in community. Personal information allows the user to introduce himself with other community members. Information recovered from user participations helps to track activities and content associated. And, reputation is the evaluation provided by the community to the user contributions.

Figure 4.13 graphically outlines profile elements. The figure illustrates a general organization to compose and present the principal elements of a user profile.

[11] Also known as voting

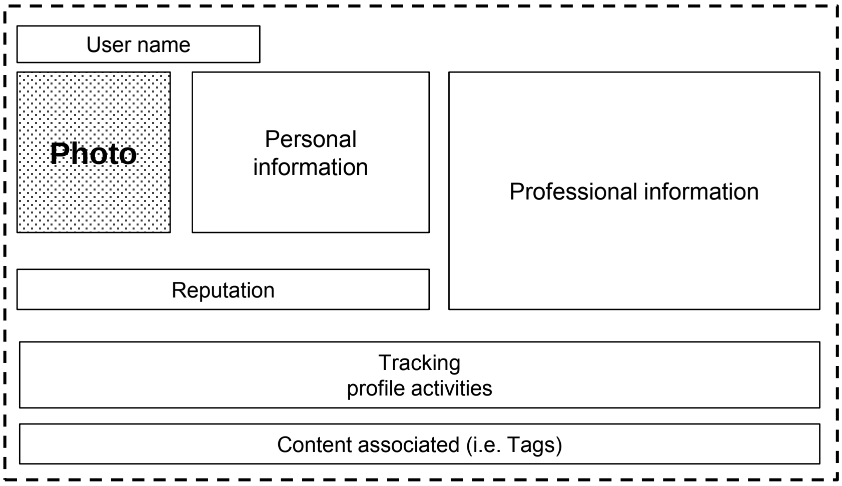


Figure 4.13 Elements of user profile (Own construction)

Harness external content

It is a mechanism to provide relevant information from external sources. Harnessing sensitive information in the context of the problematic situation improves the process of problem resolution, even if the information comes from a different domain. The Web as an information system is acknowledged as an unlimited source. However, most of the information is unstructured or is hidden to search engine indexers. Semantic web technologies are an attempt to overcome this problematic. The objective is to create a web where the information has a semantic meaning. Open Linked Data is an effort to create services for providing data in an open way using semantic web technologies. DBpedia[12] and Freebase[13] are two open linked data services created by a worldwide community. Therefore, it is possible to connect those services using the tags associated to a project, in order to harness external sources to provide the users with information associated to the problematic.

Review

Review is an opinion that users express about an item (product, service or other user). Opinions are often formulated either in a numerical way (e.g. rating) or in a textual way, and they could influence others in order to take decisions. For (O'Reilly, 2006) tags, comments and reviews are mechanisms that allow the users to enrich the information in many of the most successful content and media sites. It was Amazon.com one of the pioneers in using this mechanism in order to enhance the information of the products with the opinions from the buyers.

Information from reviews is also useful as an input to algorithms for a recommendation system. The Figure 4.14 is an example of the review component in the site of www.ideastorm.com. In the example

[12] www.dbpedia.org
[13] www.freebase.com

it is observed the rating review and the textual review, from online “brainstorm” service to share ideas and collaborate with one another.

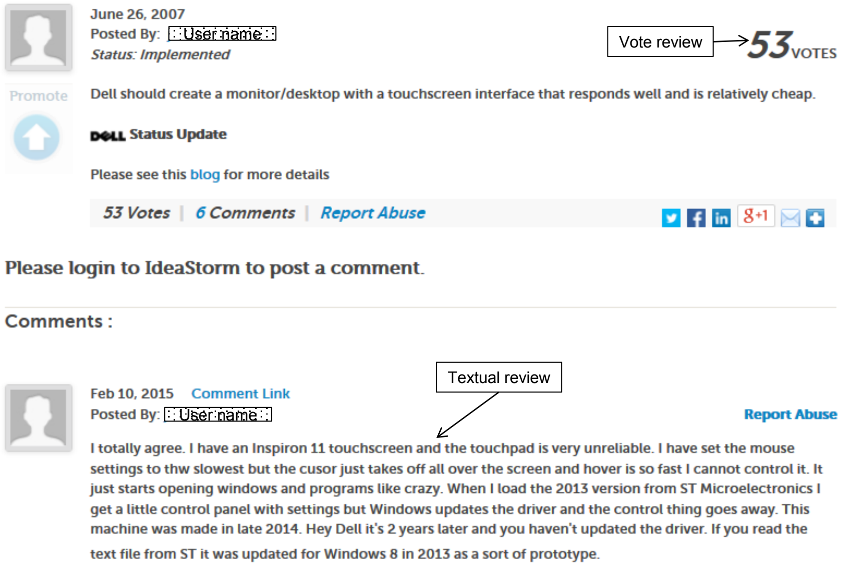


Figure 4.14 Review example. Screenshot from http://www.ideastorm.com/

It is worth to mention that 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 this user-generated content with sophisticated algorithms to exploit explicit and implicit information. Figure 4.15 describes the relationship between the stakeholder formulation and the community. The figure also includes the support to gather content with collective intelligence algorithms.

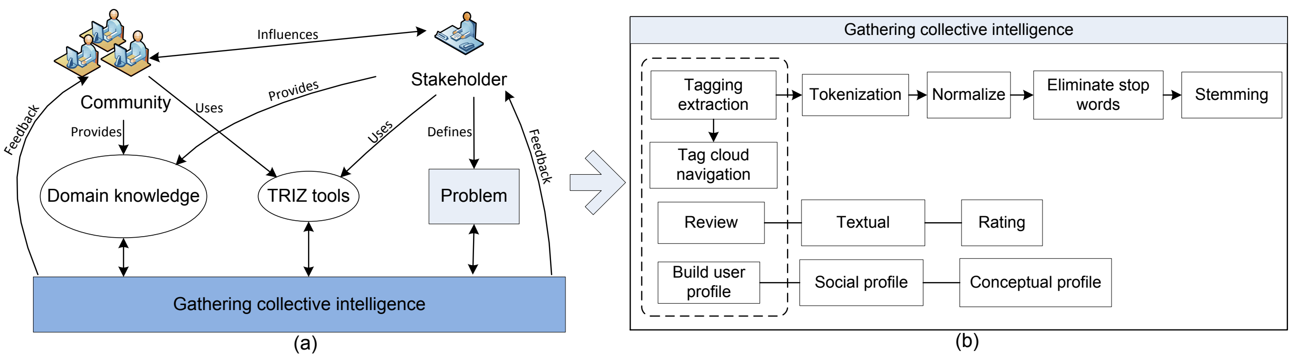


Figure 4.15 The use of collective intelligence in Open CAI 2.0 (Own construction)

As revealed in this section, gathering collective intelligence from social networks is a mechanism to enhance collaboration. Among the benefits, it facilitates to take advantage from user contributions, or to connect with external sources of information. Another benefit is the evaluation by the community of user generated solutions (e.g. using the review). In a distributed architecture is important to have a consensus for the evaluation of solutions, because users can have different visions about the same problem and solution.

In summary, the elements for the design of collaborative solutions based on the Web 2.0 were addressed in this section. These elements are: (a) generic collaboration patterns, (b) design and fundamentals of Web 2.0-based solutions, (c) the use of social network analysis as a strategy to study the structure and network behavior in the process of collaboration, and (d) the incorporation of algorithms to gather the collective intelligence resulting from the collaboration.

Identifying and evaluating strategic partners is an important decision in the successful development of collaborative innovation. The next section therefore aims to present the fundamentals for a service to guide strategic collaborators selection.

4.6.2 Discovering collaborators

In Open CAI 2.0, the identification of relevant actors to form a community is complicated because it relies on experts' judgements. To overcome this situation, recommendation systems are software-based solutions that can be applied to expertise locating (McDonald and Ackerman, 2000). However, due to an initial lack of information (e.g. not enough registered users) the recommendation system is ineffective to make any recommendation; this problematic is referred as the cold start problem (Bobadilla et al., 2012). According last authors, the cold start problem represents a serious issue since it can lead to the loss of participation in a collaborative platform.

Knowledge diffusion is facilitated by information encompassed in documents such as research articles or patents. Consequently, those documents are rich in information. Specifically, the identification of inventors in highly cited patents, suggest the idea that they can have a valuable role as complementary expertise in the innovation process. Patent citation is a good indicator of the importance of a patent, since a highly cited patent is likely to contain an important technological advance (Chang et al., 2009; Karki, 1997; Leu et al., 2012). Therefore, patent citation analysis could be useful in the design of an expertise recommender while overcoming the start cold problem.

Therefore, social network analysis is a useful tool to provide expertise recommendation system with information by identifying highly cited inventors. A previous work (Choe et al., 2013) shows the feasibility of this approach, as illustrated in Figure 4.16, although some limitations remain in phases 2 and 3. For instance, it does not take into account the inventors of the patent in the network analysis.

However, it is easy to include them since the information is gathered in the documents from the USPTO[14] database.

In the network analysis, the number of citation, or co-citation, for each patent can be assessed through mathematical measures, i.e., centrality measures. 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 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 the analysis step. Furthermore, the patent citation network is not the only significant network to analyze. 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.

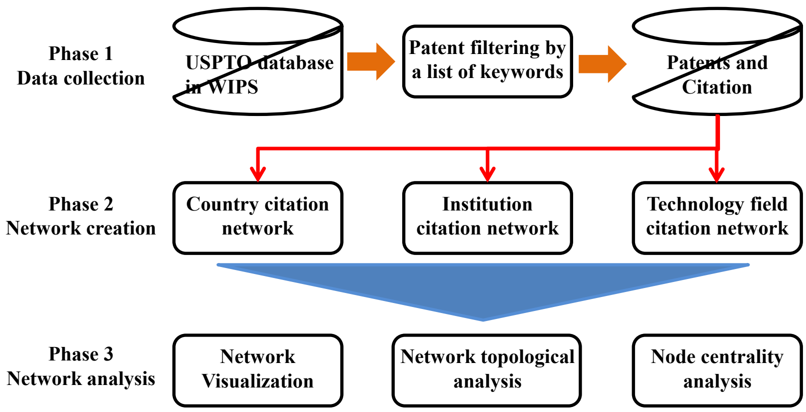


Figure 4.16 Phases in network analysis of patents citation (Choe et al., 2013)

Until now it has been presented the mechanisms to implement Open Innovation, as well as the technological components, and services to develop collaboration activities. In this work we formulate the hypothesis that in order to complete the Open CAI 2.0 approach, it is necessary to include the use of a creativity driver. This work proposes to include the creativity driver as a means to abstracts the operations to assist in the generation of creative solutions to inventive problems. In the following section are presented the details.

[14] U.S. Patent and Trademark Office

4.7 A creativity driver

Regarding the previous Open CAI 2.0 proposition, it addresses only the strategic and the technological drivers. To overcome this limitation and take a step forward, we propose extend the Open CAI 2.0 concept by including a creativity driver. The objective is to better assist participants in the collaboration process, as well as fostering creativity in the front end of innovation. Figure 4.17 introduces our proposed Open CAI 2.0. As illustrated, the original concept is complemented with a method to accelerate inventive design. This approach has two advantages: it offers to deploy the open innovation while guiding creativity, and to foster the implementation of problem resolution process with the collective effort of experts community composed with different skills.

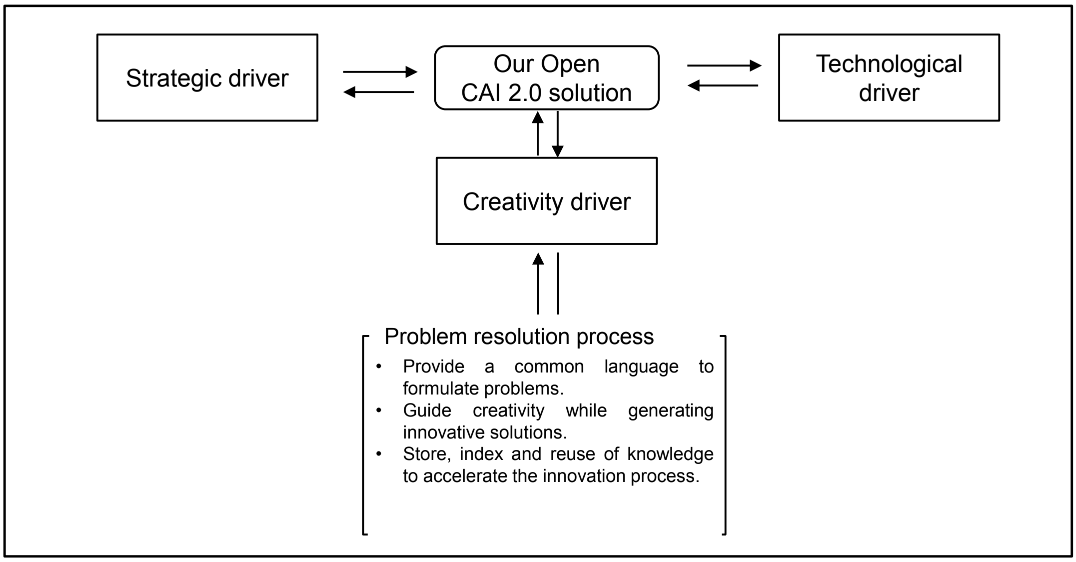


Figure 4.17 Our proposition for an Open CAI 2.0 framework

As observed, our proposition is oriented to improve the creative abilities of the human participants. We support the idea that the development of an Open CAI 2.0 solution should not be totally oriented on creating information–based software with the capacity to replicate the human creativity. Instead, this kind of solutions should look at providing the tools to develop creativity of staff working in collaboration. For (Nattrass and Okita, 1983), persons and computers form a symbiotic relationship in product design. In this relationship human beings outperform computers in thinking spontaneously, relating disjointed facts and are creative by association. On the other hand, computers are faster, more accurate, tireless, and they are better to process vast quantities of engineering data at a time. In the experience of (Pollack et al., 2003), persons should be engaged in higher-level forms of creativity, while computers are suitable for lower-level details of design. Since the front-end of innovation requires developing solution with a high degree of inventiveness and creativity, it is reasonable to expect that persons are the most qualified for this task.

Furthermore, as (Giachetti et al., 1997) highlights engineering design is characterized by a high level of imprecision, vague parameters, and ill-defined relationships. Therefore, the principles for the creativity driver need to take into account the imprecision [15] level in design. As observed in Figure 4.18, imprecision is more important in early stages of design. Early stages typically begin by a description in terms of natural language statements. At this level, linguistic imprecision arises from the qualitative descriptions of goals, constraints, and preferences made by humans (Giachetti et al., 1997).

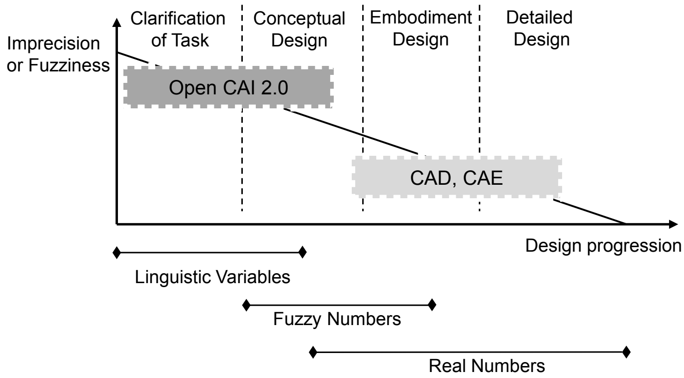


Figure 4.18 Imprecision level in Open CAI 2.0 (Giachetti et al., 1997)

Profiles diversity in collaboration environments is another element to take into account in the creativity driver. Consequently, it is important to have a shared technical language which enables participants to bridge the gap between their backgrounds and problem abstractions. Moreover, the complexity of inventive problems requires a clearly-defined language, and a step-by-step procedure to transform the problematic initial situation into a solution.

For previously revealed reasons, our creativity driver requires a language to overcome imprecision for defining inventive problems, as well as it requires a logical sequence of activities to organize creativity as a problem resolution process.

4.7.1 The problem resolution process

According to (Ilevbare et al., 2013), different visions exist about TRIZ, either as a methodology, a toolkit or a science. Consequently, the multiple approaches leads to confusion on its definition. Moreover, in practice TRIZ is particularly challenging because the engineering nature of the methodology makes difficult to adapt for application in a wide range of situations. The lack of standardization in the application also makes difficult the practice of TRIZ. The Algorithm for Inventive Problem Solving (ARIZ) is considered as one of the most powerful algorithm of TRIZ to

[15]Authors (Giachetti et al., 1997) define imprecision as the preference a designer has for a particular value but will accept other values to a lesser degree.

guide the problem solving process (Savransky, 2000). For this author, ARIZ is a sequence of logical steps to analyze ill-defined initial problem/situations and leads to the formulation of a solution by using TRIZ concepts and tools.

ARIZ

According to (Fey and Rivin, 2005) ARIZ can be used for three purposes: problem formulation, braking psychological inertia, and combining TRIZ tools.

Problem formulation. The proper problem formulation can lead automatically to a solution. Usually, the formulation may include a system analysis, and the formulation of a contradiction, either physical or technical. ARIZ guides the problem solver to the understanding and clarification of the initial situation. Therefore, the first goal of ARIZ is to reformulate the initial problem; and the solution comes much easier.

Breaking psychological inertia. ARIZ is mainly focus on humans, and for that, it integrates a set of tools to break the effect named “psychological inertia” of the problem solver. (Cameron, 2010) defines the psychological (or mental) inertia as: “*the assumptions, usually subconsciously about a problem, resources and solutions*”. Other negative effect of psychological inertia is the fact that it avoids searching for a solution on a different problem domain, because it leads to believe that the solution is found only in a given area of knowledge, the same of the problem.

Combining TRIZ tools. Because TRIZ is composed of different methods and tools, which can be used randomly, ARIZ combines them in a sequential process to create an algorithm for the resolution of inventive problems.

Although, ARIZ brings together most of the fundamental concepts and methods of TRIZ (Fey and Rivin, 2005), it is not commonly used for the following reasons (Cameron, 2010; Rantanen and Domb, 2002; Savransky, 2000):

- It is a long step-by-step guide.
- It is considered as an analytical approach, rather than a problem solving process.
- It is exhausting, especially when inventors do not have much time for solving a problem.
- It is required for less than 1% of all technical problems.

For the previously revealed reasons, this work proposed the use of TRIZICS roadmap to organize the process of problem resolution.

TRIZICS

In practice, TRIZ tools are organized depending on the problem situation. In this case, is particularly difficult for inexperienced users to select and apply TRIZ tools. In (Cameron, 2010), the author proposes a standard process to guide the user from the beginning of a problem solving process to the end. This process is named TRIZICS. As shown in Figure 4.19, TRIZICS roadmap is composed by six sequential steps which structure a systematic problem solving process:

1. Identify the problem
2. Select Problem Type
3. Apply Analytical Tools
4. Define Specific Problem
5. Apply TRIZ Solutions Tools
6. Solutions and Implementation

Each of these six steps provides a formal model to define the problem, specify the limitations, establish deadlines for a solution, review assumptions, define the cost, resources, and the implementation plan.

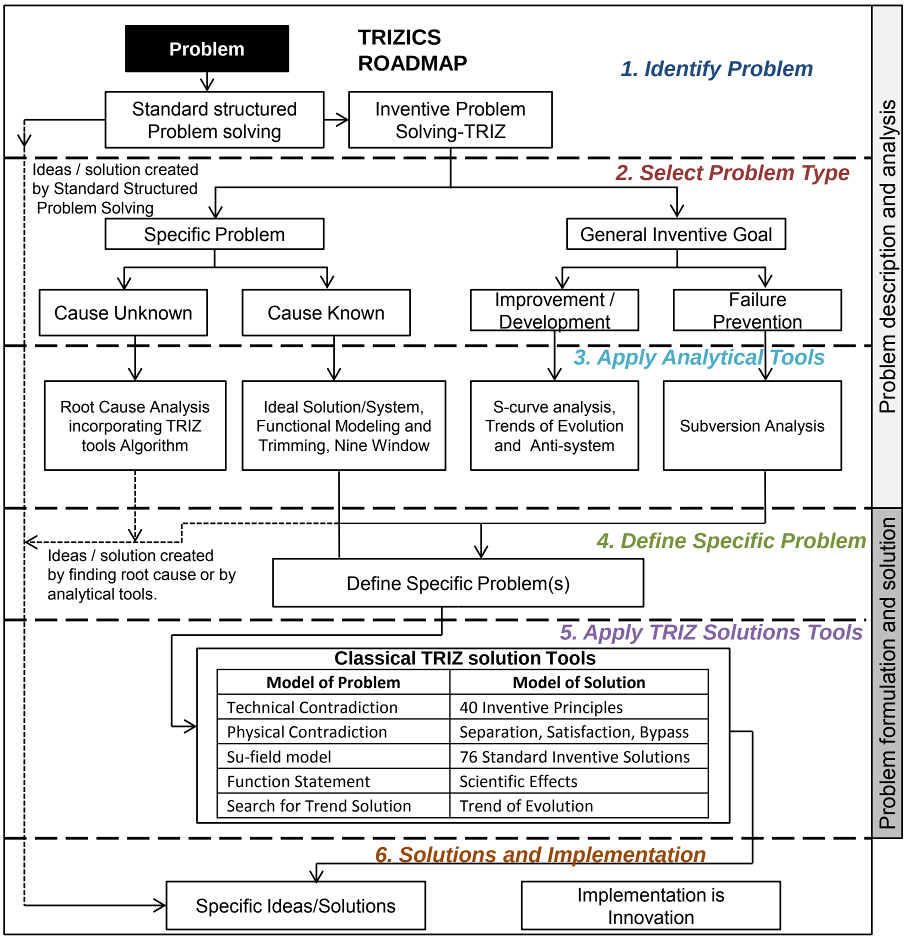


Figure 4.19 TRIZICS Roadmap (Cameron, 2010)

In this work we take some of the elements of the TRIZICS roadmap to propose a simplified version to organize the TRIZ tools in two phases: problem description and analysis, and problem formulation and solution. The potential benefit of dividing the application of the tools in the two phases is to allow the participation of TRIZ inexperienced users, as well as TRIZ experts in the same roadmap. As illustrated in Figure 4.20, problem description and problem analysis include the use of tools oriented to a larger audience of non-TRIZ practitioners. Problem formulation and problem solution are tools that require an expertise in the use of TRIZ. This versatility in the roadmap aims to create the conditions to promote active participation of the two types of users. Additionally, the workflow is affected by the CBR cycle, as it was previously described in section 2.3.3 about the model TRIZ-CBR.

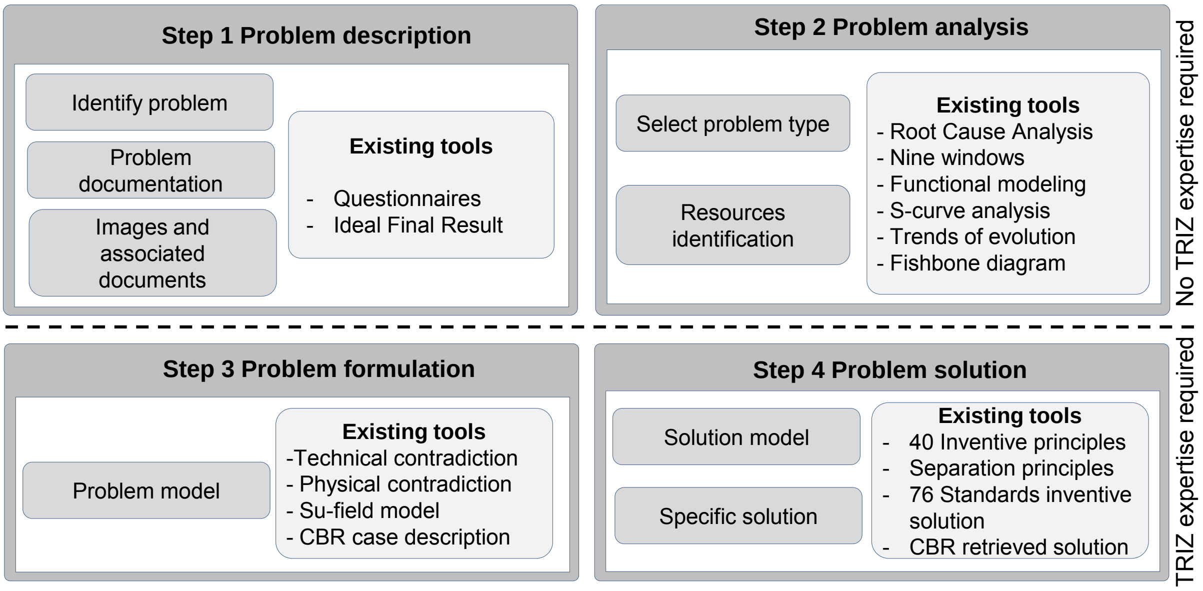


Figure 4.20 Problem resolution roadmap. Adapted from TRIZICS (Cameron, 2010)

4.8 Conclusion

The development of Open CAI 2.0 solutions is an opportunity for the industry to better understand the innovation process when it is approached in a collaborative way because it comprises to take into account the study of management methodologies, while at the same time it encourages the use of a technological driver to put in practice the concepts developed in the theoretical part.

In this chapter we have proposed a conceptual Open CAI 2.0 framework comprising three dimensions: project dimension, creative dimension and collective intelligence dimension. Until now, the previous Open CAI 2.0 concept as it was conceived by (Hüsig and Kohn, 2011) did not consider a systematic methodology to drive the creative part of the innovation process. Therefore, we propose to include a creativity driver (i.e. TRIZ-CBR) to enhance the development of innovative solutions while exploiting previous experiences. On the other hand, TRIZ methodology is difficult to learn for newcomers, that is why the participation architecture proposed in the Open CAI 2.0 solution integrates non practitioners with expert TRIZ users in a straightway.

Based on the architecture of participation, the incorporation of techniques to harness the collective intelligence resulting from the collaboration is an opportunity to enhance the problem resolution process. The use of collective intelligence techniques in commercial websites like amazon.com or ebuy.com has demonstrated its relevance. In addition, dedicated services for crowdsourcing the resolution of innovative problems demonstrate the interest of companies for solutions using the wisdom of the crowds.

Finally, locating expertise is a problem in collaborative workspaces. The use of social network analysis is a reasonable solution to recommend highly cited patent inventors, due to highly cited patent inventors could be considered as major innovators.

The development and implementation of the conceptual framework are further detailed in the Chapter 5.

Chapter 5 Development of a software-based Open CAI 2.0 tool

Highlights
• To cover the general overview of the collaborative workspace operation. • To outline the workflow of the problem resolution process. • To document the aspects of the technical development. • To document the incorporation of the service to discover collaborators in patents database. • To report the operation scenarios of the framework.

5.1 Introduction and general overview

"Ainsi souvent lorsqu'on dort, et même quelquefois étant éveillé, on imagine si fortement certaines choses qu'on pense les voir devant soi ou les sentir en son corps, bien qu'elles n'y soient aucunement."

Les Passions de l'âme (Descartes, 1649)

In this chapter we present the development and implementation of the conceptual framework proposed in Chapter 4. First, we present the general overview of the modules that make the core of our proposed Open CAI 2.0 solution. This overview provides an insight of how some non-functional requirements are addressed and how the different modules interoperate. Then, we present a process flow in Business Process Model and Notation (BPMN) to illustrate the principal functionalities of the software-based framework: the collaborative workspace operation and the problem resolution process. The software-based framework implementation starts with the general design; we use Unified Modeling Language diagrams to document functional requirements, and domain data model. Two sections complete the implementation aspects: one dedicated to technical details and the other focused on usability elements. In addition, the Social Network Analysis implementation to discover potential collaborators is explained. Finally, a section presents a summary of the current state of development.

The conceptual elements and the methodological framework proposed in section 4.2 are transformed into specific functionalities. The details and the description of the functionalities start with the presentation of the general usage of operation in the Figure 5.1. The logical basis of the collaborative resolution process consists of orienting the interactions of the involved participants in such process with a common language; specifically, the problem formulation tools provided by the systematic approach of the TRIZ methodology.

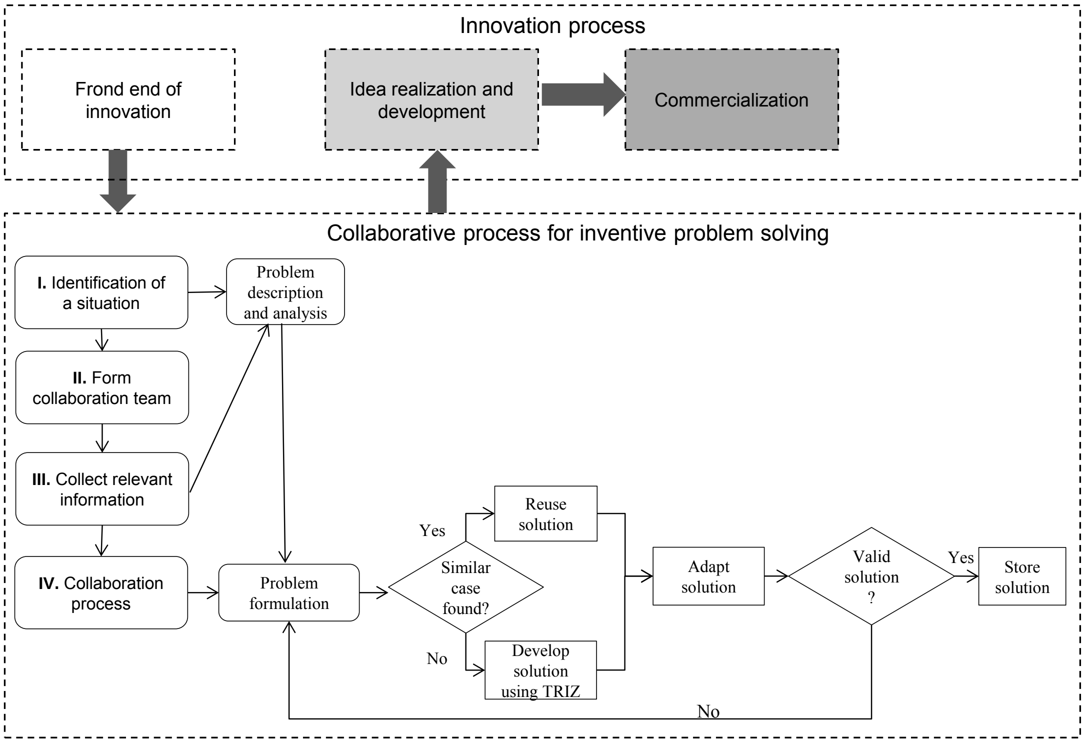


Figure 5.1 General usage of the collaborative process for problem solving (Own construction)

The description of the operation of the general use case is presented next:

I. The first activity –identification of a situation- corresponds to the description of the problematic situation. The basic information to describe and analyze the problem are:
   a. Project name and general description.
   b. Clear problem statement.
   c. Images and documents related.
II. The second activity is the composition of the collaboration team. This situation requires identifying specific experts for the problem faced. Two types of search are possible:
   a. Among the group of registered users.
   b. Outside the platform, looking in other sources for the required expertise.
III. Collect relevant information helps to provide details to make clear the problematic situation. Once the collaboration team is composed, the participants have the option to review and complete the information about 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.

The advantage of using the TRIZ-CBR model in the collaboration process is because the TRIZ theory is an approach that provides a common language to communicate the problem formulation (Ilevbare et al., 2013). For instance, contradiction and Su-field model are very well defined patterns with a high level of abstraction. Consequently, they facilitate the creation of problem models which are independent from a specific technical domain. Moreover, the proposed collaboration model aims at facilitating the interaction between TRIZ beginners and experienced TRIZ users.

Despite Figure 5.1 presents the functional aspects in a general use case, details about the development of the proposed framework are addressed in the next sections.

5.2 Architecture of main services

Crowdsourcing services are currently used to implement open innovation activities. In our case, they are socio-technical systems capable to link together people having inventive problems (stakeholder), with a community of solution providers. The Figure 5.2 provides a description about the operation of the crowdsourcing services in our proposed Open CAI 2.0 framework.

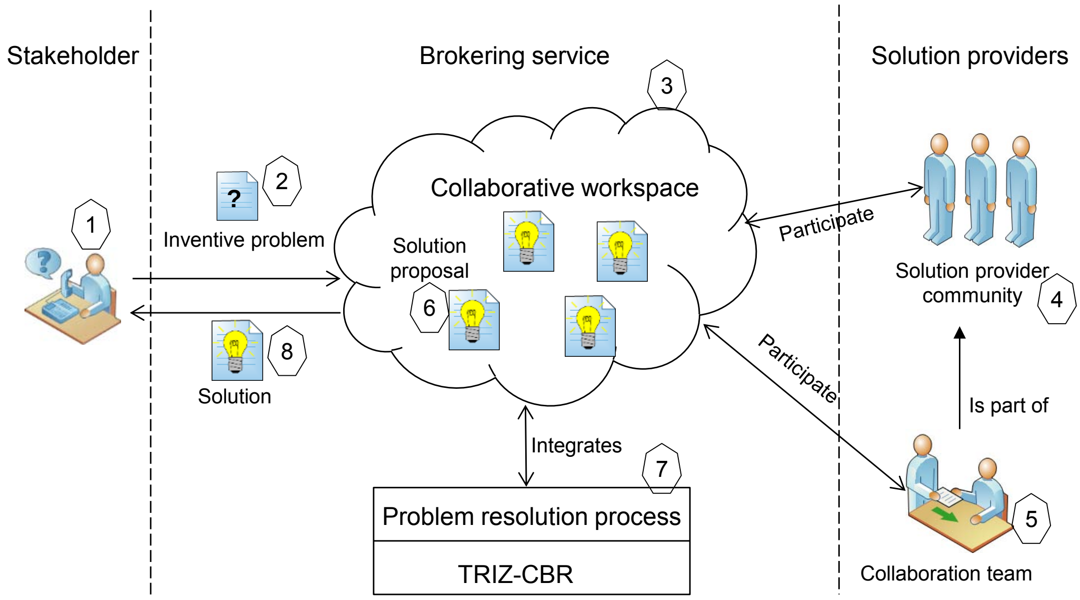


Figure 5.2 Elements of the crowdsourcing service (Own construction)

[1] “Stakeholder” – includes, but not limited to, the individual or group of individuals having inventive problems. The stakeholder is the responsible to start the collaboration process by sharing an idea or an inventive problem.

[2] “Inventive problem” – refers to need or idea imagined by the stakeholder and which is formulated as an inventive problem. An inventive problem is a complex situation that required the transformation of existing technical knowledge for the formulation of new concepts.

[3] “Collaboration workspace” – it is the virtual workspace that relates stakeholder with a community of solution providers. This workspace includes the workflow to formulate the problem, and to develop one or multiple solution proposals following the problem resolution process. It takes into account the collaboration aspects previously addressed in section 4.5. In addition, the collaborative workspace

implements the mechanism to communicate, coordinate, and control the contributions from the involved participants.

[4] “Solution provider community” – includes, but not limited to, the group of individuals with the potential to participate in the workflow of the problem resolution process. The community is composed with members having different technical profiles, likewise TRIZ practitioners.

[5] “Collaboration team” – composed with members who are part of the solution provider community. They are a selected to participate to the resolution of a specific problem according to the user profile. It is the stakeholder who forms the collaboration team; optionally the broker service includes mechanism (e.g. recommender system) to identify potential participants by using the problem description or relationships created from past collaborations.

[6] “Solution proposal” – is the formulation of a possible solution for a specific inventive problem. They are formulated through the different phases of resolution process. In order to promote participation, the collaborative workspace allows for one inventive problem to have multiple solution proposals.

[7] “Problem resolution process” – it is the sequence of steps that coordinates the search for a solution to a problematic situation. In this work, the process is organized following the principles of the tools proposed in the TRIZ theory, and the model TRIZ-CBR.

[8] “Solution” – is the creation of new concepts or new relationships between existing concepts to propose new conceptual design of product, process or services. It is the stakeholder who takes de decision about the solution that best fits the requirements for his specific inventive problem. The stakeholder has access to the evaluations that the community makes on the solution proposals in order to take the decision.

The operation of the virtual workspace for collaboration is described using a BPMN diagram. The collaborative problem resolution workflow starts with the creation of a resource called *projec*t. The project is an entity that organizes all the information related with an inventive problem, and the workflow to solve it. The fields included in the project information are presented in the Table 5.1.

Table 5.1 Project information

Field	Description
Project id	It is a unique identifier of the project in the system.
Project name	The project title.
Project description	It is a general description about the inventive problem situation. It provides to the participants an introduction to the nature of the problem.
Estimated release	The date limit to participate.
Problem description Id	Reference to the problem description.
Comment list	List of comments on the project.
Collaborator list	The list of solution providers that collaborate in the resolution of the problem.
Tags	They are free text introduced by the stakeholder to quickly add meta-information to the project.
Profile id	It is the unique identification of the profile linked to stakeholder that creates the project.

A description of the operation of the collaborative workspace and the problem resolution services are presented next.

5.2.1 Collaborative workspace service

BPMN diagrams provide a common language to communicate processes clearly. Figure 5.3 describes the operation of the collaborative workspace. The actors involved in the process are: the stakeholder (project creator), the solution provider(s) and the control system. After the project creation, the stakeholder is responsible to share the project, either to all the community, or a collaboration team. Then, the mechanism to share the project is realized through an invitation generated by the stakeholder. One important requirement on collaborative workspaces is to maintain information integrity; therefore, the control system blocks the project when a solution provider is working on it. The mutual exclusion finishes when the user ends the edition, or by the mutual exclusion control when the timer is over.

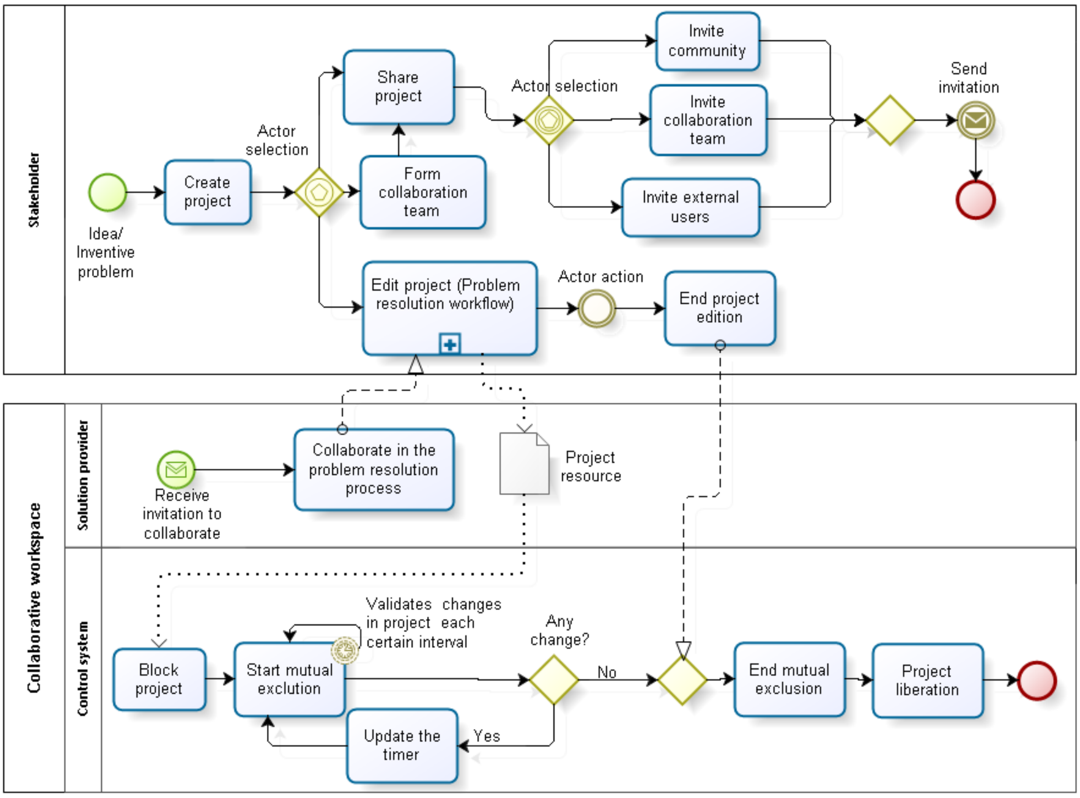


Figure 5.3 Workflow of the collaborative service (Own construction)

The project is a structure that contains all the information related to a problem. Once a project is created the owner describes the problem situation, adds relevant documents and specifies the problem background. The objective of this first step is to provide as much as possible information to describe and analyze the problematic situation. In the following steps, the stakeholder and solution providers deploy the problem resolution process as explained in section 5.2.2. It is worth to mention that the way users declare all the information is via dialog forms, most of theme composed by free-text inputs. Free-text dialogs are a common way to communicate in social network services, whereas they give to the users the means to express in the imprecise first stage of conceptual design. About the operation of the collaborative workspace presented in Figure 5.3, it aims to control information integrity when different participants collaborate on the same project. Consequently, it takes into account the following aspects:

- To coordinate the activities performed by users.
- To allow users to create, edit and share projects.
- To allow the creation of collaboration groups.
- To ensure information integrity and to keep the progress tracking.

5.2.2 Problem resolution service

The problem resolution process aims to provide the logic sequence in order to assist in the search for a solution. The goal of this process is to assist the creative development with: (1) a sequence of activities to document and analyze the problematic situation, (2) formulate the problem using a common and comprehensible language, (3) and to propose one or several solutions. Finally, the process provides the mechanism to select and document the solution retained. The workflow of this process is detailed in Figure 5.4. As the diagram suggests, there is a set of activities inspired from the TRIZICS roadmap (Cameron, 2010) which are organized following the TRIZ-CBR model. The condition to start the process is the existence of an entity of Project. The details for each activity are provided below.

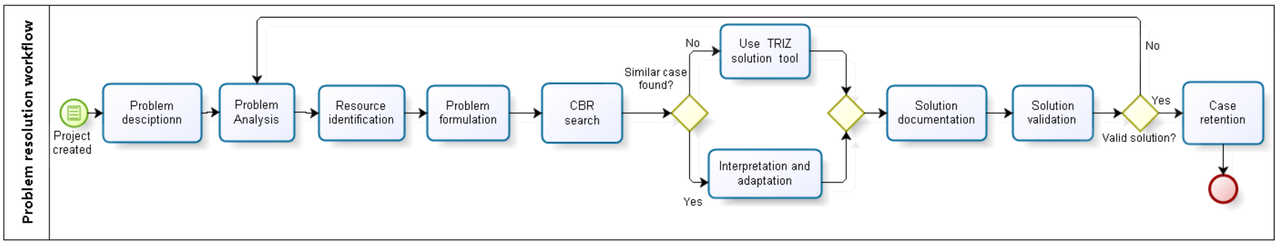


Figure 5.4 Problem resolution service (Own construction)

- *Problem description*. It helps to document information related to the inventive problem situation. The information about the problematic situation is divided into three parts: Problem documentation, Images and documents, and Comments.
  For the problem description the fields included are described in Table 5.2. These fields are common information to problems in different domains. Unlike existing crowdsourcing platforms, which provide a problem redaction service, in our proposition, stakeholder and collaborators have full control to edit the project information (i.e. problem description and analysis, problem formulation). Indeed, this kind of operation is to promote the open participation likewise it avoids the situation of information saturation. The operation model is related to an open crowdsourcing pattern.

Table 5.2 Problem description

Field	**Description**
Problem description Id	It is a unique identifier of the Problem description in the system
Problem statement	It is a textual description about the problem. It is the stakeholder who enters the information trying to make a clear description.
Name of the technical system	Description of the technical system in which the problem is observed.
Main useful functions	The principal functions of the technical system.

Images and media are digital documents that help to better describe the problematic situation. Currently, the framework treats two kinds of documents: Images and text documents in format such as PDF, Microsoft Word or TXT.

About the comments, they are free textual opinions expressed through the entire process. The fields observed in the comments are expressed in Table 5.3.

Table 5.3 Comment fields

Field	**Description**
Comment Id	It is a unique identifier of the comment in the system.
Author Id	It is the Id referencing the profile that creates the comment.
Title	A title for the comment.
Description	It is the option expressed in the comment.
Date	The creation date.

- *Problem Analysis*. After the problem documentation, the following phase in the process is the problem analysis. Problem analysis proposes the use of analytical tools according to the type of problem; in our case it is the user who does the identification, but in a future development the framework should be capable to identify the nature of the problem from the background information. Natural Language Processing is one technique which could identify the nature of the problem from the textual problem description .As the analysis tools to apply depend on the type of problem (Cameron, 2010), in the problem resolution workflow the user identifies between specific problem (root cause know and root cause unknown) and general inventive goal (improvement and failure prevention).
    - *Specific problem.* For this type the user has access to Root Cause Analysis, Ideal Solution and Nine Window tools. These tools are suitable, because they help to identify (or validate) the cause of the problem[16] , to identify the optimal functionality for the technical system, and to release psychological inertia.
    - *General inventive goal.* For these types of problems, the recommended tools are S-curve analysis, trends of evolution or subversion analysis (failure prevention). These tools are useful to describe the lifecycle, anticipate the evolution, or predict future failures of technical systems.

[16] Other useful tool for the analysis is the fishbone diagram.

- *Resources identification*. Here the users select existing resources in the context of the problem. For (Barragan Ferrer, 2013), problem resolution uses available resources. Last author proposes a modeling technique for the resources identification, which includes the nine window tool. Such technique is implemented in this framework because it allows to identify in resources available not only in the system, but also it includes the subsystem and the super-system.
  The selection is supported with a list of predefined resources which are recovered from (Trotta, 2012). Below is presented the classification for the list elements, the complete list of resources is included in Appendix III .
  - *Material*
  - *Energy*
  - *Signal*
- *Problem formulation.* It is an important phase in the problem resolution workflow, as well as it is a difficult phase to tackle. In order to assist the users , the framework includes the following TRIZ-based tools to formulate the problem or a part of the problem:
  - *Technical contradiction.* The information required to formulate the problem as a contradiction is presented in Table 5.4.

Table 5.4 Contradiction fields

Field	Description
Problem formulation Id	It is a unique identifier of the problem formulation in the system.
Author Id	It is the Id referencing the profile that formulates the problem.
Positive characteristic	It is the technical parameter that needs to be improved.
Positive characteristic description	A textual description about the positive parameter. It is a way to explain the interpretation of the parameter.
Negative characteristic	It is the technical parameter that is in conflict
Negative characteristic description	A textual description about the parameter in conflict with the positive characteristic. It is a way to explain its interpretation of the problematic situation.

  - *Physical contradiction.* The information required to formulate the physical contradiction is the same way as the technical one; it is classified as a physical contradiction when the improving and degrading parameter are the same. Consequently, it is necessary to identify the contradiction type to propose the appropriated resolution tool (inventive principles or separation principles).

  - *Su-field model.* A preliminary graphical tool to formulate the problem using a Su-field model is introduced. This development is very basic and requires improvements.

  It is worth to mention that the framework allows the users to make the formulation of more than one problem. For example, it is possible to have in a project the formulation of more than one contradiction or the combination of different types, or problem formulations (contradictions and/or su-field models). The justification for this functionality is to promote the participation, and because each participant can have a different vision of the same problem. With the same idea about promoting participation, the community effectuates the evaluation of the problem formulation (i.e. rating or textual review). For instance, rating review facilitates to order problem formulation according to feedback each one receives, accelerating the decision-making process.

- *CBR search*. The next step is to look for similar case(s) on the knowledge database. In a CBR system, similarity between query case and stored cases is calculated with similarity functions. Similarity functions computes and choose the most similar case(s) to the query. In the context of this work, similarity is calculated with the k-nearest neighbors algorithm using the implementation of the library named jCOLIBRI (Recio-Garía and Díaz-Agudo, 2007). As required by a CBR system the cases need for a description, the Table 5.5 presents the characterization of a case in the framework. The attributes and the weight are in experimentation phase. The weight for each attribute was assigned in a panel of TRIZ experts according to the following criteria: problem formulation is the principal model to describe the problematic situation; a 50% ponders this importance. Problem solution includes the use of available resources; consequently a 25% comprises the expected impact of resources for the problem description. Tags are meta-information related to the textual description, they are used to try to overcome the imprecision level associated to the problem description, and a 20% is a value that tries to take into account this consideration. A 5% for the problem type is a value that tries to measure the impact of this attribute in the selection for the analysis tools. As previously mention these weighs are in experimentation, and it is possible to adjust them, allowing to the users specifying their own values.

Table 5.5 CBR case characterization

Attribute	Weight
Problem formulation	50%
Tags	20%
Problem type	5%
Problem resources	25%

The retrieval of cases has two possible results, a case (or multiple cases) matching the similarity criterion, or there is not a case matching the query case.

- *Case found*. In this situation, the framework retrieves the matching case or cases and presents the details associated to the project related to each case. As presented before, the project is the entity that aggregates the information in the process of problem resolution. A user has the option to print a report either in PDF or HTML format. From the information on the report, the user can start to develop the solution to the current problem.
- *Case not found*. When there is not a similar case in the knowledge base, the CBR-TRIZ model proposes the use of TRIZ solving tools.

- *Solution documentation*. Once the problem has an initial solution, the next step is to document it. For this option, the framework includes dialogs to provide the most possible details about the solution proposed. In addition, the user can attach related documents.
- *Solution validation*. As the framework allows multiple problem formulations this option is dedicated to validate only one solution; in the framework a problem formulation has only one solution associated which is selected with the consensus of all participants. The consensus uses the evaluation mechanism in the implementation of collective intelligence (i.e. rating, review). The stakeholder can complement the information about the implementation details.
- *Case retention.* It is performed once the stakeholder has validated the solution, then the framework creates a case instance in the CBR database.

5.2.3 Social network analysis service

The service of social network analysis is conceived to be deployed in two modalities: (1) to locate the most active users within the framework, and (2) to locate external collaborators in patent databases.

To implement this service, the NodeXL (Hansen et al., 2010) complement for Microsoft Excel (see Figure 5.5) is included. It is an easy to use and to implement Social Network Analysis (SNA) functionality. NodeXL is included as analysis tool because it is widely known, some of its most relevant features are:

- Graph Metric Calculations: It incorporates the algorithms to calculate the metrics degree, betweenness centrality, closeness centrality, eigenvector centrality, PageRank, clustering coefficient and graph density.
- Flexible Import and Export: It has the facility to incorporate or export information in other formats from existing SNA solutions such as UCINET, GraphML or Pajek. In addition, it allows importing an adjacent matrix from an Excel Workbook.
- Direct Connections to Social Networks: It provides a plugin to connect directly with Social Networks (Flickr, Twitter or YouTube) to import information relative to tags network, user's network, search network or video network.
- No programming required.

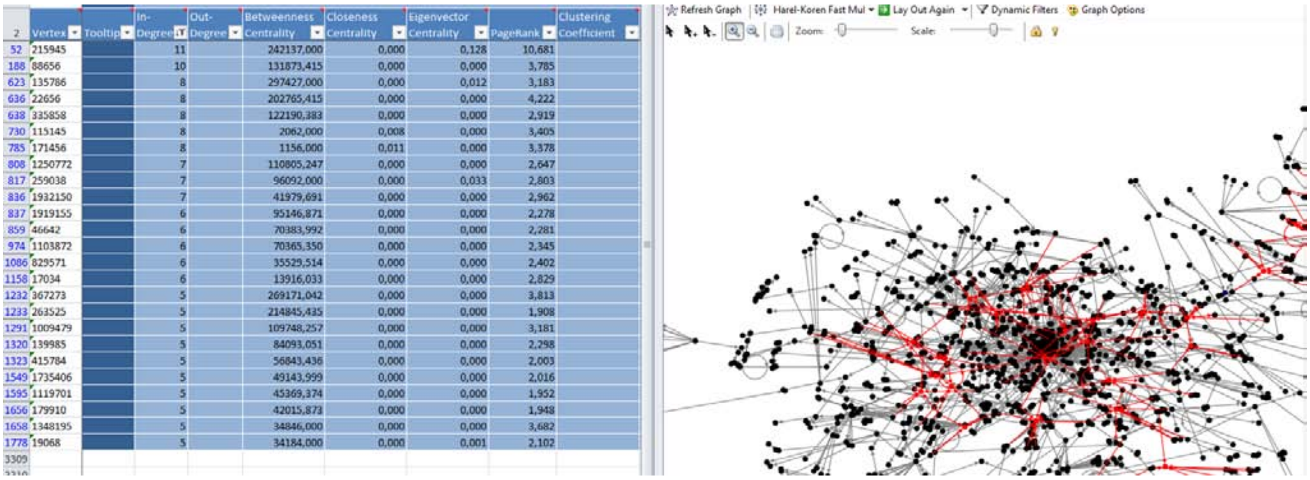


Figure 5.5 NodeXL example

Although the NodeXL implementation for SNA simplifies the metric calculation, certain limitations are observed (Smith et al., 2009):

- Dependency on the installation of Microsoft Excel.
- Limited to the spreadsheet size.
- Network visualization can become easily unintelligible.
- Clusters of nodes are difficult to identify and represent.
- Large scale data sets remain hard to display.

Despite the limitations prior mentioned, it remains an acceptable solution because the expected number of elements to be analyzed is reduced. For instance, the number of patents analyzed in the experimental phase was less than 9,000 patents.

Internal users analysis

To make the analysis of internal users, the information is extracted from the users' interactions via the classes Collaboration, Profile, Project and Tag; their relationships are illustrated on Figure 5.6. The information is retrieved from the database, and then saved as network edge list in a worksheet before using the centrality metrics.

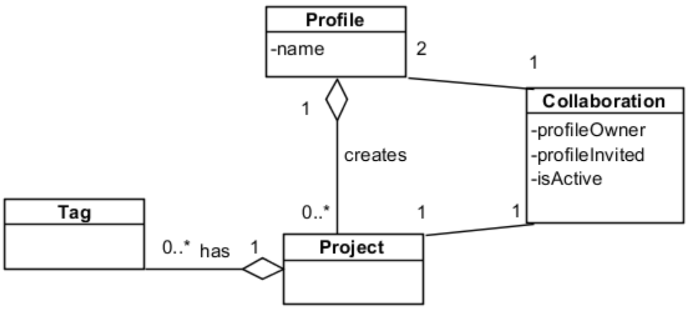


Figure 5.6 Collaboration class model

The Figure 5.7 provides an example of the query for retrieving the information. The *C.profile_invited* property corresponds to the user who collaborates in a project, where the stakeholder is represented in the *C.profile_owner* property. The *SEARCH_TAG* is a parameter representing the tag keyword which is related to the expertise required.

```
SELECT C.profile_invited,
       C.profile_owner
FROM   project PJC
       INNER JOIN project_tag PT
               ON PJC.project_id = PT.project_id
       INNER JOIN tag T
               ON PT.tag_id = T.tag_id
       INNER JOIN collaboration C
               ON PJC.project_id = C.project_id
WHERE  T.NAME LIKE '%SEARCH_TAG%'
       AND C.is_accepted = 1;
```

Figure 5.7 Query example to get the collaborators network

Search for collaborator in patent databases

The Figure 5.8 presents the workflow we propose to discover potential collaborators based on Social Network Analysis in patent citation.

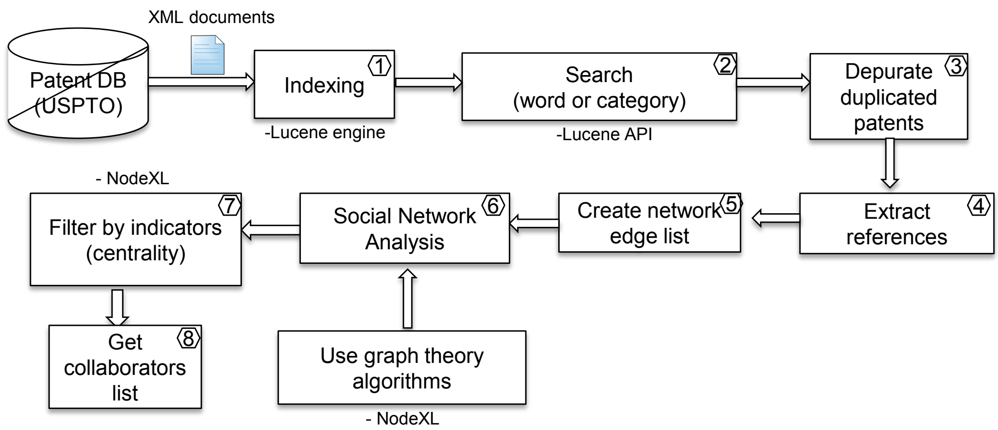


Figure 5.8 Patent citation analysis with SNA (Own construction)

The workflow starts by indexing the patent database, in this case the US Patent and Trademark Office (USPTO). The next step is to retrieve the documents using specific keywords or a patent category; the keywords are free text introduce by the users to describe and categorize the problematic situation. A pre-treatment consisting in the elimination of duplicated patents is required, since in the USPTO database there are repeated patents with different numbers. The next step is to identify the "referenced by" patents in order to create the adjacent list. The adjacency list is formed with the source patent and the patents that reference the source patent. Finally, the last step is to recover the collaborators list applying the filter indicators provided in NodeXL, in our case the Degree Centrality

5.3 Functional and logical aspects

The software development was mainly inspired in Agile Programming practices; the Appendix IV details the development workflow. In this section, we present the models related to software engineering for documenting the framework implementation.

The section is divided into three subsections. The first section, deals with the framework design aspects and with the system architecture. Then, we present use case diagrams to describe the dynamic functionality. Class diagrams are also included to describe the data organization in static diagrams. The second section, deals with technical details related to programming language, third parties frameworks, and details about the deployment of our tool in a server. The third section covers usability aspects, which include the considerations for the design of the Graphic User Interface (GUI).

Through the different aspects of the technical development, the capacity to evolve the application was stressed. For instance, the framework design is based on the Mode-View-Controller pattern (Buschmann et al., 1996), which facilitates escalating the application to include new functionalities. New functionalities comprise: modifications on the collaborative workspace operation, or including a new problem formulation tool.

5.3.1 Framework design

The Unified Modeling Language (UML) is often used to document the design of a software system. In order to present describe the software-based framework two types of diagrams are included: use case diagrams to document functional requirements, and class diagrams to communicate the java classes model.

5.3.1.1 Functional design

The functional requirements express the behavior of the system. For our framework solution, the general functional requirements are illustrated in the use case diagram of Figure 5.9. As observed in the figure, it is possible to identify three types of users' roles: Stakeholder, Participant and TRIZ practitioner. This differentiation is because the operation of the framework requires at least the competences from these three categories of actors. As previously mentioned in section 5.2, the Stakeholder is the user who proposes an inventive problem. The Participant is a user having specific domain knowledge or training (i.e. an engineer); his participation is justified due to the expertise he has acquired. Finally, the TRIZ practitioner role is a person having received training in the use of TRIZ tools. Currently, the framework design allows users to play the three roles without restriction.

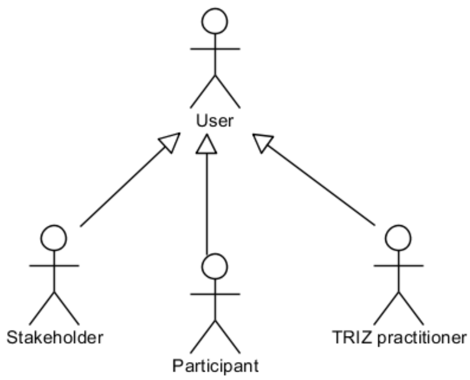


Figure 5.9 Framework general use case diagram

The principal use cases that involve the three users are:

- ***Create Account***. This use case deals with the creation of credentials to authenticate in the system; an account is useful to create a unique identity. Then, the user profile is automatically created, and both entities are associated. Hereafter, all the content the user creates is associated to its profile.
- ***Project Management***. It refers to the functionalities for creating, editing and sharing the resources known as projects.
- ***Collaborate***. It is the action to participate in the resolution of inventive problems from other users.

The use case manage project (see Figure 5.10) refers to the possible options that the user can access to create, modify and share project resources. Once the user logging on into the system, the first operation with the projects is the creation. During the creation, the system associates the project with the user profile, and creates a notification. After the project is created, the user has the option to share or edit it according to functionality of the collaborative workspace (section 5.2.1) or the problem resolution process (section 5.2.2) respectively.

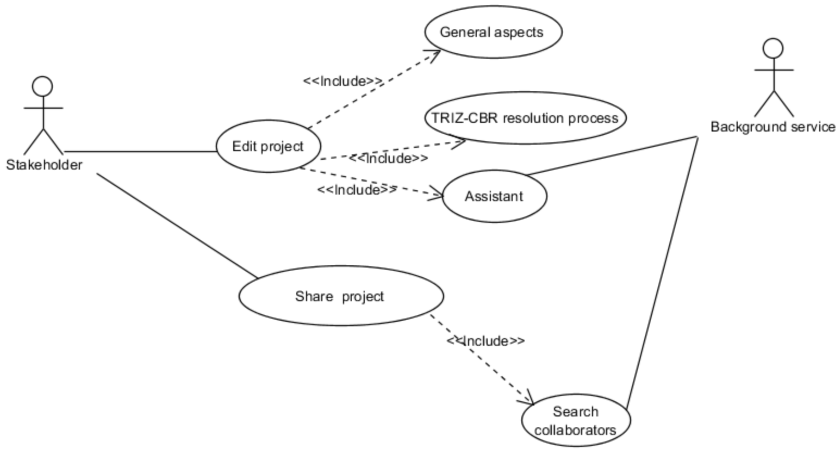


Figure 5.10 Manage projects use case diagram

Functionality about project management and collaborate has been covered in previous section about main services (5.2). Functionality for External knowledge access and Data for intelligence is covered by Assistant use case and Search for collaborator use case respectively.

Assistant use case

As it is observed in Figure 5.10, the use case Assistant and Search collaborators have a background service, because they require internal operation to accomplish these activities. The Assistance is conceived to provide the users with information sources related to the subject of the problematic described in the project. To fulfill this requirement the use case diagram in Figure 5.11 presents the functionality associated.

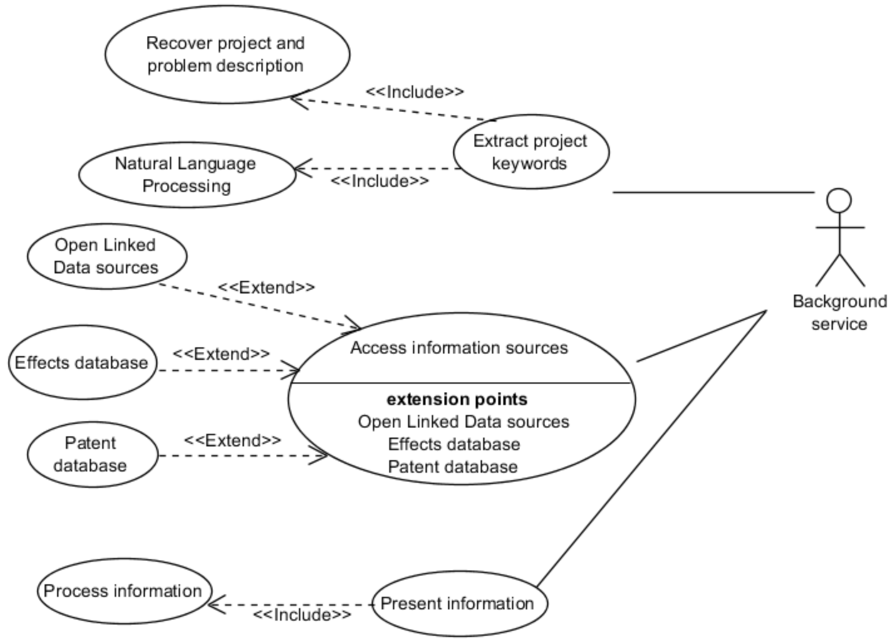


Figure 5.11 Assistant use case diagram

Search for collaborator use case

Search for collaborator functionality detailed in Figure 5.12 is an attempt to overcome the problematic of expert finding in collaborative environments. In our software-based framework, the expertise location is divided into internal and external search. In the internal search the candidates are users registered in the platform. However, the profile search is based on the affinity between the user profiles and the problem profile by using the project keywords. In the section 5.2.3 is explained the mechanism for the internal search.

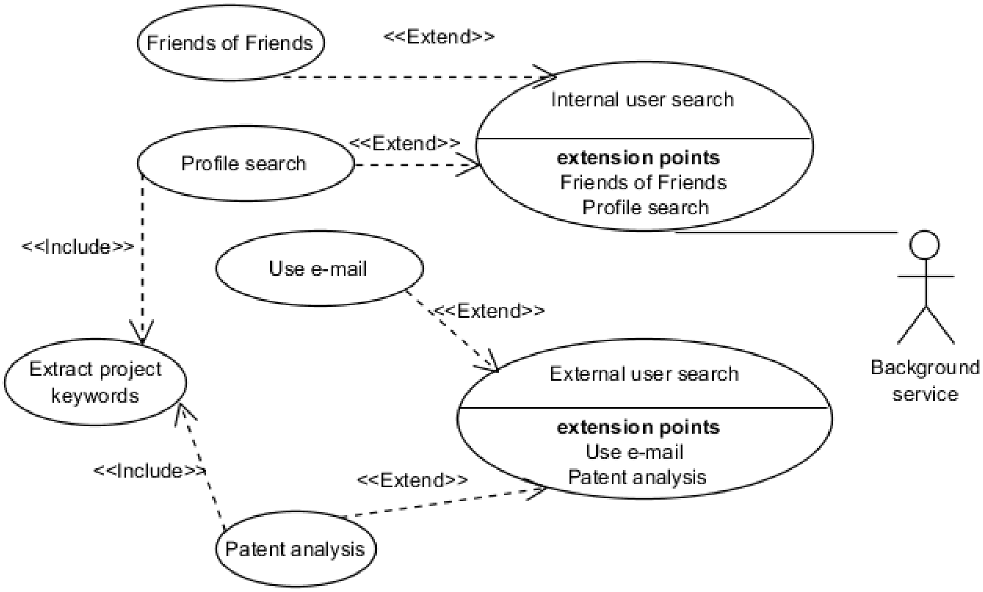


Figure 5.12 Search for collaborators use case diagram

5.3.1.2 Classes domain modeling

The domain data modeling is useful to identify the main business entities and the relationships between them. Figure 5.13 shows the base business classes in our framework using a UML class diagram. This design is useful because on the one hand it helps to describe the domain classes; and on the other hand, it allows to elaborate the physical design of the data base from it. The model in Figure 5.13 shows how the Profile – Project is a relationship that is a pivotal for the other classes; the relationship is established either when the user creates a project, or when the user collaborates in other projects. A dictionary describing the principal classes is found in Appendix V.

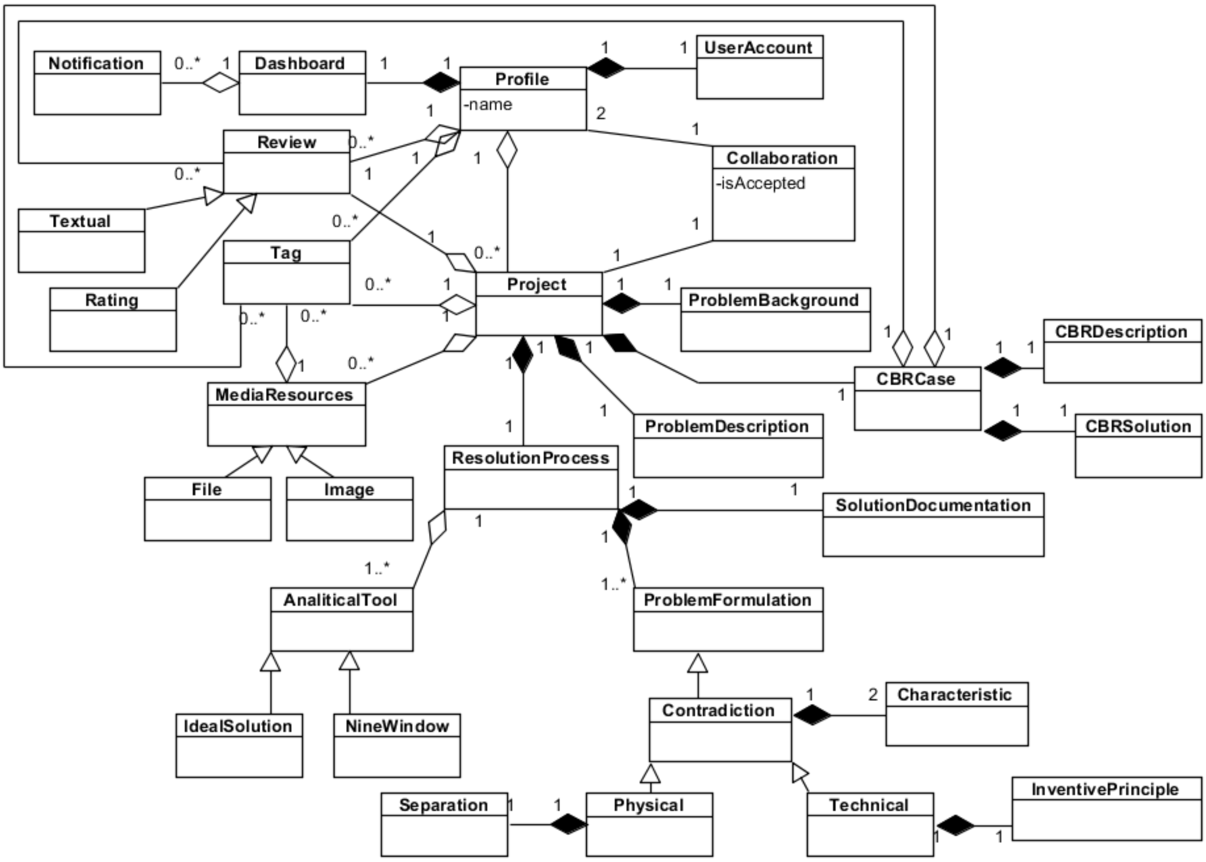


Figure 5.13 Java class diagram

5.3.2 Technical development

This section addresses the technical aspects of the collaborative platform. Programming language is the first important choice in the construction of any software. In our case, Java is the programming language selected. The justification for this choice is because Java is a generic programming language, with an Object Oriented paradigm and platform independent.

Another element to take into account is the software pattern. The architecture patterns help to define the structural organization for software systems (Buschmann et al., 1996). In this development we structure the software architecture based on the pattern Model-View-Controller (MVC), because it is suitable to develop interactive applications. The MVC pattern divides the interactive application software into three elements: Model, View and Controller. The typical MVC operation is as follow: the Model encapsulates the core functionality and data, the View refers to the components useful to display information to the user, as well as the interface to capture information, and finally the Controller handles the user requests and connects the View with the Model.

The Figure 5.14 presents our implementation of the MVC pattern, the details of the operation are provided below.

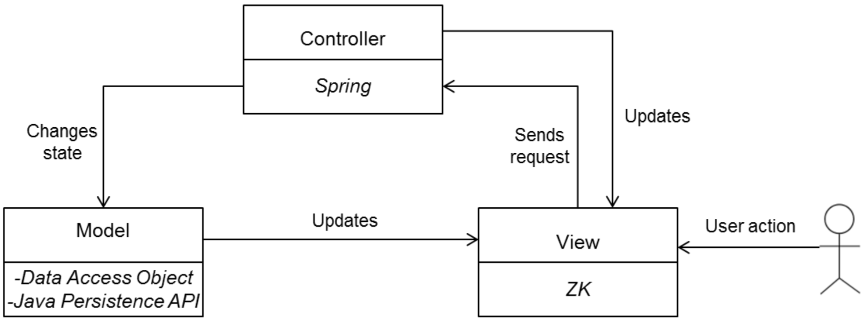


Figure 5.14 MVC implementation

- ***Model***. For the Model we have used the pattern Data Access Object (DAO). According to (Alur et al., 2003), the DAO pattern allows to encapsulate the operations (save, update, get or delete) for accessing to data from a persistent store or an external system; by using this pattern, it is possible to build more flexible applications. In addition to the DAO pattern, the Java Persistence API (JPA) interface is included for the specific tasks of accessing the information in the database. The JPA implementation is the Hibernate Annotations 3.4. The advantage of using the JPA interface is the facility to modify the typical business classes with specific annotations to make them persistent objects. With this technology it is possible to have persistent business objects, and it is a solution to reduce the gap between entity-relational databases and the Object-Oriented paradigm.
  The combination of the DAO pattern and the JPA interface provide a flexible and efficient way to access and modify the information, as well as this coupling promotes the independence of database.
- ***View***. Regarding the implementation of the View components, the framework includes the ZK framework in the version 7.0. ZK is a Java-based framework for building enterprise web applications with little programming. This framework is retained because it offers[17]:
  - Support to build applications with AJAX functionality
  - MVC architecture
  - Transparent server push
  - Rich number of components
  - Availability of a development environment for Eclipse named ZK Studio
  - Wide range of supported browsers (e.g. Firefox, Internet Explorer, Chrome, Safari, iOS Safari, Opera)
  - Internationalization support
  - For security reasons no business logic exposure at client

[17] The list is part of the ZK features found in http://www.zkoss.org/whyzk/features (Accessed on Jun 2014)

- ***Controller***. In the case of the Controller component, the Spring Framework provides the infrastructure support to integrate the Model implementation and the View components. According to its documentation[18], Spring Framework is a solution conceived to support different configuration scenarios, from embedded applications to full-fledged enterprise applications. For our development, it is useful as a middle-tier by linking up the business logic using an *ApplicationContext* implementation in combination with the *ZK GenericForwardComposer* component.

An extended description about the operation of the MVC implementation is presented in Figure 5.15. This extended vision presents the interaction of the client (web browser) with the application. The application is executed in the Servlet Container; which is suitable for managing the lifecycle web applications based on Java language. For the computer-human interaction, the web browser manages the requests and responses using AJAX technology, which is implemented in the ZK framework. The server side operation is according to the pattern prior explained.

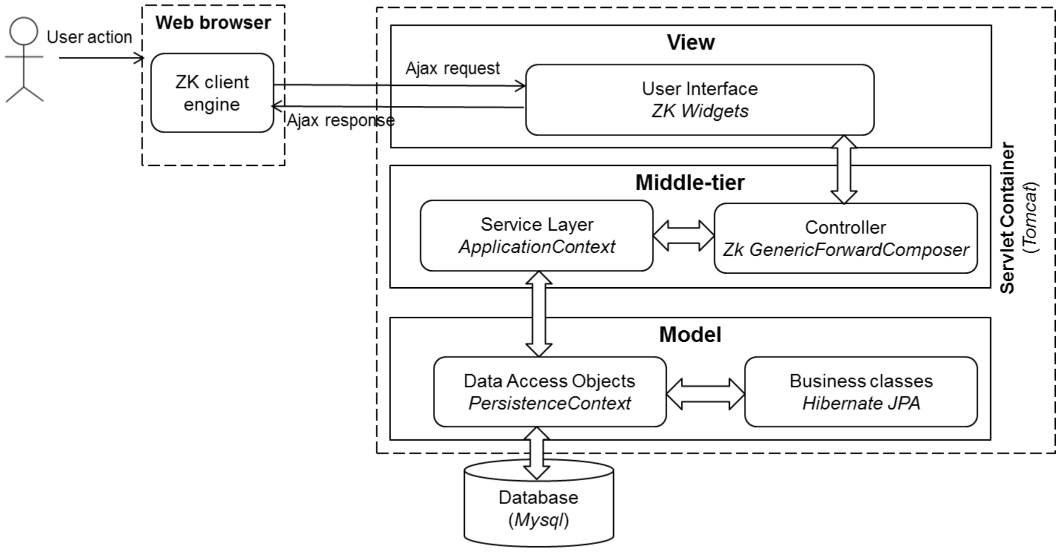


Figure 5.15 Extended MVC implementation (Own construction)

To summarize the technical aspects, the Table 5.6 presents the technological elements and their versions.

[18] http://docs.spring.io/spring/docs/current/spring-framework-reference/html/overview.html (Accessed on Jun 2014)

Table 5.6 Technological elements

Element	Software	Version
Programming language	Java	1.7
IDE	Eclipse	4.2 (Juno)
Application Server	Apache Tomcat	7.0
View component	ZK framework	7
Controller component	Spring framework	3.2
Model	Hibernate Annotations	3.4

The usability aspects are related to the View layer in the MVC pattern, they are oriented to improve the user experience while interacting with the Graphic User Interface. The next section addresses the guidelines followed in the development of our framework; namely Spring Framework allows configuring a software solution by integrating third-party frameworks.

5.4 Human-computer interaction

The emergence of communication systems and social networks has changed the way people interact through digital media. Although remote collaboration has been applied for several years, the immediacy and feedback capabilities offered by new technologies allow the creation of more effective and efficient systems.

In order to accomplish it, the systems development of collaboration teams should allow information exchange through a friendly and ergonomic visual structure. This structure must have a functional design focused on facilitating collaborative means and design considerations to promote its adaptation to any potential user.

Collaboration systems are composed of elements that allow the exchange of information at different levels. This information enables each user to understand the proposals and contributions from the other members within the team or the community. Then, the development of several Web 2.0 components could enable more accurate monitoring of the projects and its objectives.

The term usability is defined as the degree of effectiveness and efficiency derived from the subjective satisfaction of a user to manage a product within a particular environment and targeted (Taken from ISO 9241-11).

Therefore, the level of usability of a system can be measured only when it is evaluated by users interacting with it. However, in the initial part, there are guidelines and indicators that can be included on a preliminary study; they will aim to define some of the features to be included, such as: the basic user information, their knowledge and motivations of web usage, operating and navigation habits, use of application-specific modules and finally, their aesthetic preferences (Bian et al., 2010).

Extracted from a list of design principles to improve usability (Seraj and Wong, 2012), this work outstands seven elements as a starting point to adjust a system and to make it easier to use:

1) *Short navigation***.** Three clicks to access any feature or section. Making the most relevant contents easily available on the first sections of the system.
2) *Reduce scrolling***.** The structure of the screen could be designed to be adjustable or to show wider ranges of information in new Windows or sub sites.
3) *Intuitive navigation*: The user must know the basic elements of the system after the first minutes he uses it.
4) *Location of tools*: Classification of different elements must be made in order to present menus with similar options.
5) *Display Flexibility*: In order to organize information depending on the reading device.
6) *Visual information*: The use of several infographics would make faster readings of contents through the page.
7) *User control for the learning application*: The capacity to customize the workspace and align tools

The robust system functionalities are available after the user has created a “new project”. As the basic workflow and explication continued, the need to establish a background on the TRIZ theory became clear and the inclusion of the following characteristics was made:

- Introduction video to the system: Presentation of the general objectives of the system, its tools and one example of a resolved problem by its methodology.
- General Process Diagram: Set of icons or images showing the steps the user has to follow to use the system and solve the problem defined on the project.
- TRIZ theory links: Section dedicated to bibliography or useful links to give new users and introduction to TRIZ as a contextual frame to the system. For a future development this functionality can be integrated directly in the problem resolution workflow.
- Navigation Map: A basic navigation map to show users all the sections on the site / system.
- Workspace Integration: Incorporate into a single screen all the workspace utilities, allowing the user to access all the information from a single place.
- Social Network Gadgets: Buttons to allow users to share the page or its advance, through their accounts in several media.

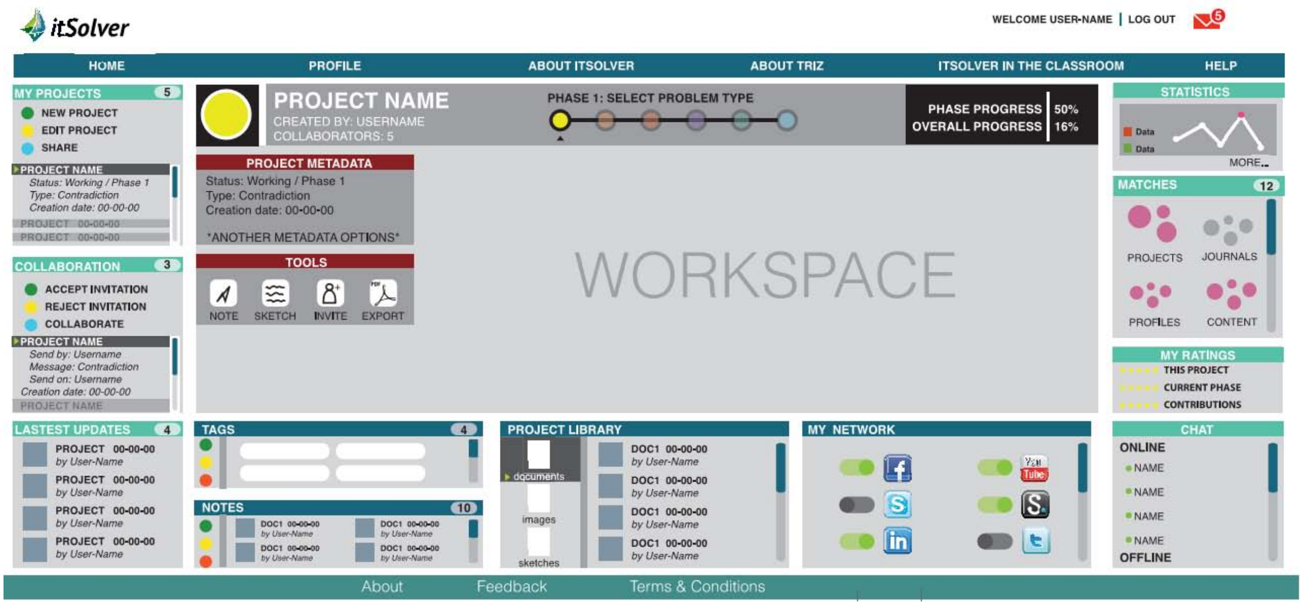
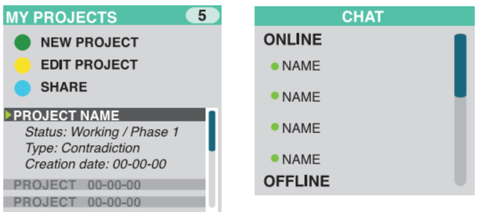
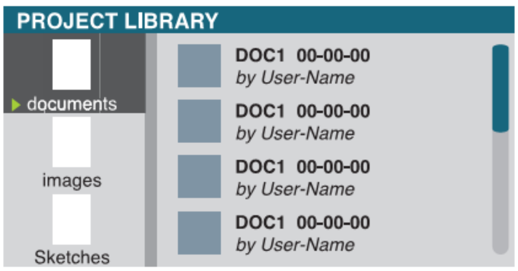
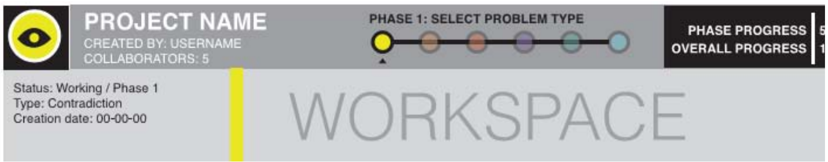
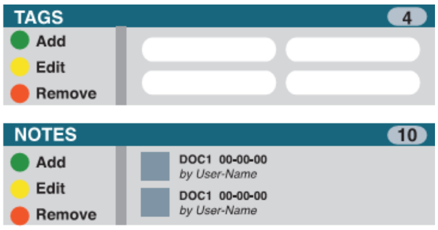


Figure 5.16 Usability design

About the sections composing the principal GUI, the Table 5.7 presents a description for the more relevant elements.

Table 5.7 Principal GUI components

Description	Element
Principal menu. Elements to promote learning and usability links.	
Principal system sections and information exchange components. All the components are designed to present a summary of information that can be displayed in a sub-screen.	
Information exchange components. The option is to have online personal storage of documents, and also the exchange of files between groups and communities.	

Information exchange components that also promote learning. The workspace includes a marker of progress and color indicators of the current section the user is in.	
Components to reduce communication errors. These components allow users to make contributions in all the phases of the process. In addition, Tags are part of the collective intelligence implementation.	

Besides the prior design propositions, made specifically to some stages of the system, a general set of tools following the characteristics determined in the investigation are also considered to make the process of use clearer to any user:

1) Email updates related to the stages of the projects
2) User capacity to send invitation emails to potential collaborators
3) Diagram to indicate the current completed level on the project phase
4) Explication and help notes in key questions or actions through the process
5) Feedback videos explaining differences between the different types of projects

5.5 Status of development

With regard to the current operation of the framework, we report the development status for the functionality documented in this chapter. Currently, the proposed Open CAI 2.0 solution is operational and it has been already tested in academic cases, the evaluation and analysis are presented in Chapter 6. Meantime, the list of the operational scenarios in the framework is:

- Control the users' access (through an account creation and a Login mechanism).
- Management of projects (creation, edition and sharing).
- Participation in other users' projects.
- Incorporation of a problem resolution process based on the logical approach of the TRIZ-CBR model.
- Implementation of a collaboration mechanism to control information integrity

- Incorporation of collective intelligence practices in Web applications, to assist the users in the problem resolution process, for example with the recommendation of external information sources or the creation of a user profile.
- The use of SNA to discover potential collaborators, either within the internal registered users or from a patent database citation analysis.

As an example of the operation, the GUI in Figure 5.17 presents the first contact users have with the framework. It covers the options to create an account or to Login.

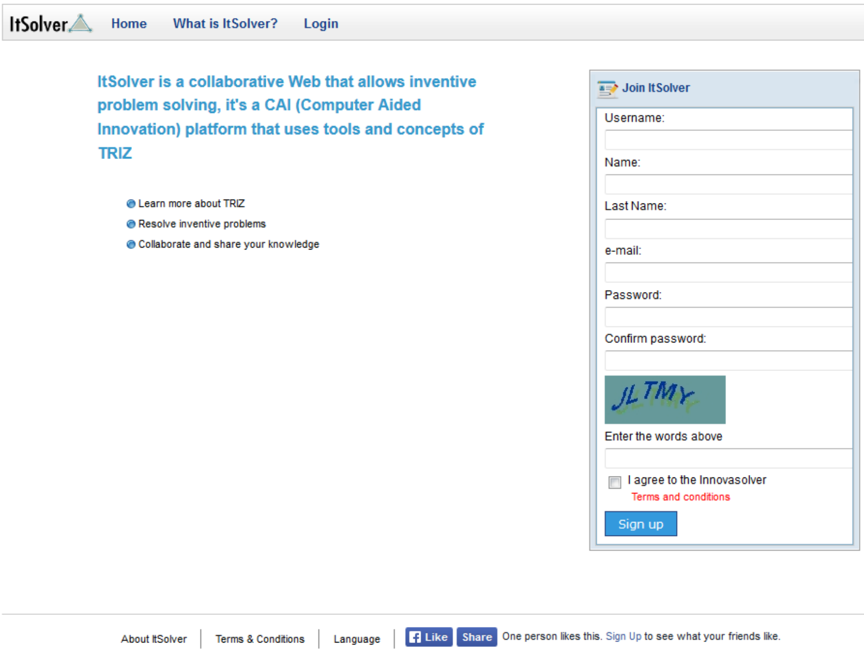


Figure 5.17 First contact with the framework

5.6 Conclusion

The software-based framework proposed in this work is an attempt to implement ongoing requirements of the Open CAI 2.0 concept. Recall the theoretical foundations were previously exposed in the Chapter 4. The objective of this chapter was to present the practical implementations. Thus, the development of the prototype has contributed:

- To define the pattern for collaboration activities. The implementation of a crowdsourcing service was the cornerstone in the collaborative workspace operation.
- To include the model TRIZ-CBR workflow in order to coordinate the activities of the collaborative workspace, as well as to have a common language to formulate and communicate problems.
- To enforce the correct operation of the collaborative workspace and to ensure information integrity, a control system was implemented. The control system follows the principles of a mutual exclusion system.

- To take into account principles for software architecture design. In order to propose a scalable application, the development followed the Model-View-Controller pattern. In addition, the Data Access Object pattern has speeded up the development of tasks related to store and retrieve information from a database.
- To stablish guidelines for the development of collaborative systems. The guidelines comprise ergonomic components that allow participants to interact, communicate and exchange information.

Although the prototype requires further development, with the current state of advance is possible to provide the preliminary conclusions:

- State-of-art in ICTs provides the technological elements to develop new solution to take the CAI to the next step named Open CAI 2.0.
- The Web 2.0 technology allows to implement collaboration patterns identified for industrial activities.
- To improve success opportunities in Open CAI 2.0 software-based tools, it is necessary to take into account usability aspects for Web 2.0 applications.
- NodeXL allows implementing Social Network Analysis in total simplicity.
- Patent databases are a rich source of information. Currently, we have explored the citation information with Social Network Analysis for expertise finding.
- The architectural design of the services facilitates the future development and integration of new functionalities.

Chapter 6 Evaluation and analysis

Highlights
• To expose the capacities of the proposed framework in a case study of Process System Engineering. • To report results and experiences from the evaluation.

6.1 Introduction

"Blâmer ou louer les hommes à cause du résultat, c'est presque comme si on louait ou blâmait les chiffres à cause du total."

Quatrevingt-treize (Victor Hugo, 1873)

This chapter presents an overview of the prototype in operation, namely ItSolver developed on the aforementioned conceptual framework. Firstly, it is described the general context of the problem statement. The case study is focused on the conversion of biomass into energy through thermo-chemical processes, particularly on the gasification process. It is used to illustrate the method and tool capabilities in the chemical process industry. Secondly, it is presented the process to create the community of solution providers. This part explains the mechanism to select the collaborators. Thirdly, the problem resolution includes problem analysis and formulation. In addition, it details the selection of a solution based on the wisdom of the community.

The case study does not present all the software-based framework operation; instead it is dedicated to evaluate the elements concerning collaboration and the method and tools for problem formulation, resolution. Other elements, such as the collective intelligence algorithms (e.g. building profile or content recommendation) require a longer operation of the software-based framework to provide relevant results.

6.2 Case study presentation

In recent decades, concerns about energy reliance on exporting countries, climate change, fossil reserve dependency and depletion, greenhouse gas emission, petroleum prices fluctuation are increasing the use of renewable resources for energy and chemicals substitution or complement. In the same time, several countries, *e.g.* European Union (European Commission, 2009), have set mandatory minimal targets to reduce the threshold of their greenhouse gas emission with the following milestones: 35% from 2012, 50% from 2017 and 60% after 2018. Furthermore, another directive has established that in the transport sector, 10% of the energy should be produced from renewable resources by 2020. This commitment is enrolled in a context of a growing worldwide demand of energy (International Energy Agency, 2012), thus viable energy alternatives are urgently needed to anticipate the future energy requirement.

Amongst the various possibilities, biomass as renewable energy will definitely be on the rise in deciding countries energy mix. Biomass is unique among renewable energy sources in that it can be easily stored until needed. In comparison to fossil fuels such as natural gas and coal, which take millions of years to form, biomass is easy to grow, collect, utilize and replace quickly without depleting natural resources. Biomass has not only the potential to contribute to fill the energy needs for many countries and to ensure their energy independence, but also to combat global warming and climate changes. The main advantage of biomass is its worldwide availability due to its diversity of sources: vegetation, energy crops, animal fats, wood and agricultural residues, municipal and industrial wastes. This work is more focused on terrestrial biomass and Figure 6.1 shows a number of major conversion pathways from terrestrial and aquatic biomass to intermediates and to final biofuel products (Yue et al., 2014).

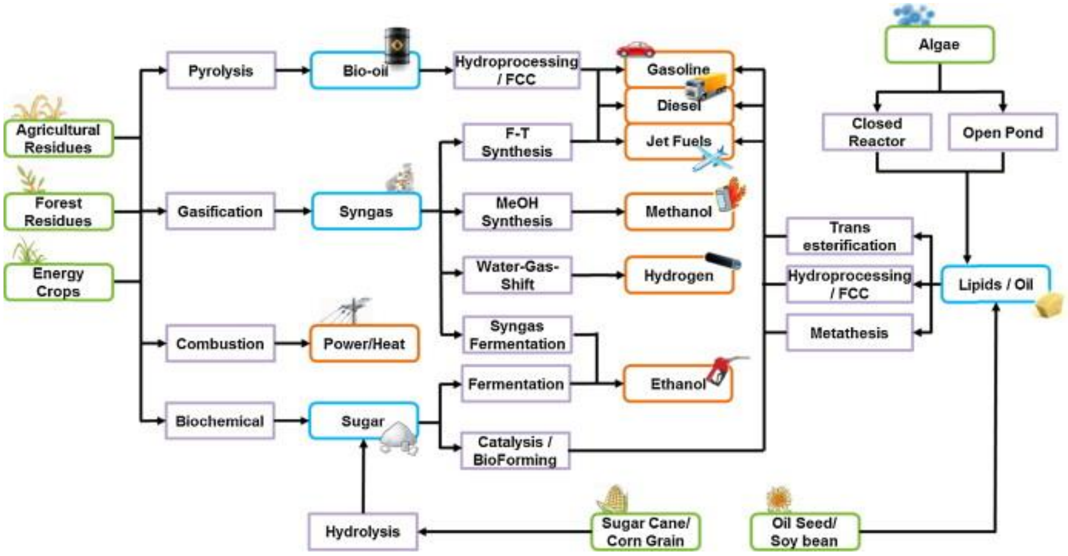


Figure 6.1 Selected conversion pathways from terrestrial and aquatic biomass (Yue et al., 2014).

From the chemical perspective, terrestrial biomass is a renewable resource that acquires carbon by photosynthesis derived from the reaction between CO_2, air, water and sunlight to produce carbohydrates during its growing cycles. The chemical bonds of structural components of biomass store the solar energy. Consequently, the value of a particular type of biomass depends on these chemical bonds (McKendry, 2002). Common sources for terrestrial biomass are woody and herbaceous species. According to last author, they have 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 can be converted into energy via various biological and thermo-chemical processes such as: combustion, pyrolysis, and gasification. Among the different pathways of Figure 6.1, we focus our attention more specifically on syngas production by gasification. Syngas is a gas mixture composed mainly of CO and H_2. Syngas can then be utilized by the Fischer–Tropsch synthesis, including a collection of chemical reactions, to produce hydrocarbon liquid duel products. Alternatively, methanol and hydrogen can be produced from the syngas via methanol synthesis and water–gas-shift process, respectively. Additionally, syngas can also be used as a fuel for heat supply. The hydrogen is useful for hydro treating operations, necessary to upgrade fuels and to remove impurities. In the gasification pathway, the lignocellulosic biomass resources are fed into a gasifier, where they are thermally decomposed (700–1300◦C) with limited oxygen, and then oxidized to yield a raw syngas. The raw syngas may contain some contaminants, including tars, acid gas, ammonia, alkali metals, and other particulates.

Biomass gasification gathers several endothermic reactions between carbon and reacting gas resulting in production of several gases such as: carbon monoxide, hydrogen and traces of methane. Figure 6.2 shows schematically the distinct mechanisms that take place in the 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 depends on many parameters such as the biomass properties the outlet requirements, e.g., syngas valorization and the power required. Fluidized bed reactors are considered to be the most advanced technology with several reactor configurations proposed in the literature. In (Warnecke, 2000) is documented in detail the four principal configurations for biomass gasification reactors. In the case study, we decided to improve the fluidized bed reactors technology, and among the reactor configurations, the circulating fluidized bed because it is more industrially established (with processes in Austria, Sweden and Finland) due to its biomass conversion rate, its thermal efficiency, and its capacity to tolerate wide variations on fuel quality.

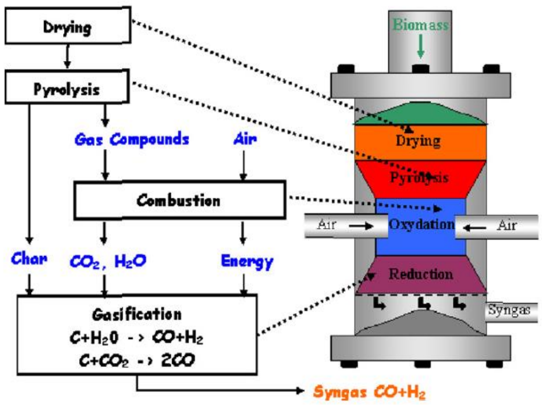
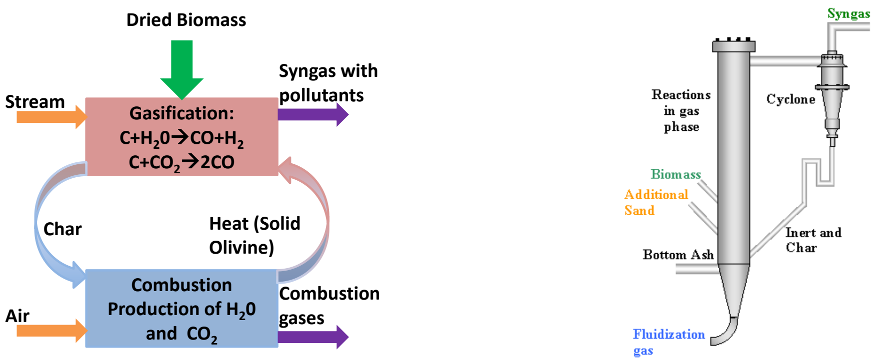


Figure 6.2 Biomass gasification process (Barragan Ferrer et al., 2012)

The fluidized bed 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, Figure 6.3. 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.



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

Figure 6.3 Gasification operation (Barragan Ferrer et al., 2012)

The three major drawbacks of circulating fluidized bed reactors for biomass gasification are: (i) the production of ashes, tars and pollutants in the outflow syngas, (ii) low heat recovery, and (iii) difficulty to operate with different biomass moistures and more particularly with moisture content greater than 20%. The first weakness was treated in the work of (Barragan Ferrer et al., 2012). The two other ones are the subject of this case study.

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 exchanges 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 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.

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 6.1.

Table 6.1 Biomass sources properties (McKendry, 2002)

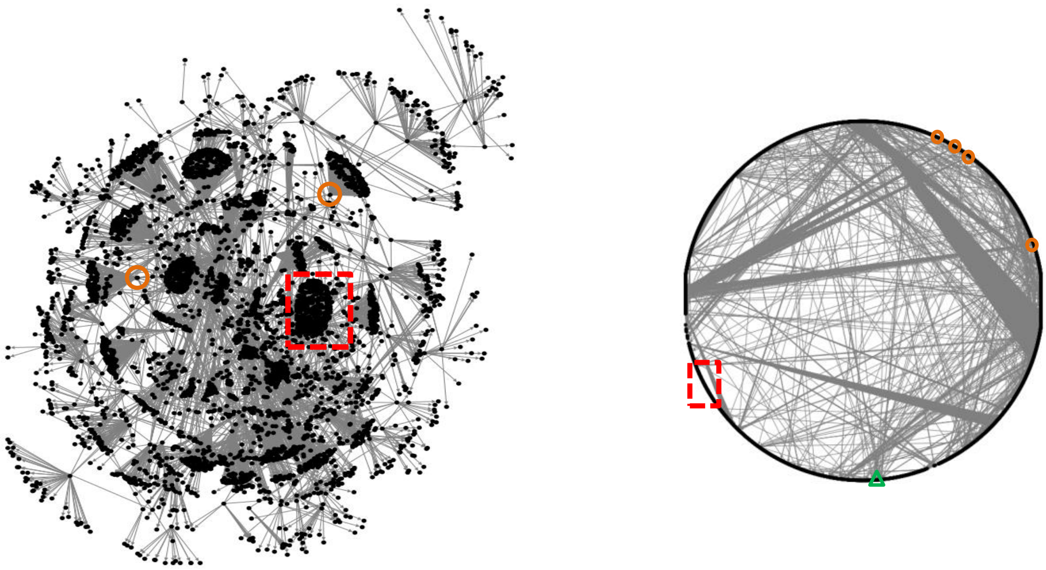
Biomass	**Moisture (%)**	**VM (%)**	**FC (%)**	**Ash (%)**	**LHV (MJ/kg)**
Wood	20	82	17	1	18.6
Wheat straw	16	59	21	4	17.3
Barley straw	30	46	18	6	16.1
Lignite	34	29	31	6	26.8
Bituminous coal	11	35	45	9	34

As observed in previous table, biomass sources have different intrinsic moisture contents. Therefore, the gasification process needs to adapt to the different moisture values.

Once the problem context has been exposed, the following is to describe the process of collective resolution using our approach.

6.3 Community members

This part highlights the software tool to examine patents as a mean to reduce the number of patents to browse to identify the knowledge flow, the important skills and the potential members of a community. A first set of 8,400 documents were extracted from patents database based on the word 'biomass', then this first list was reduced by filtering patents with respect to the centrality measures. As a consequence it remains only all the most important patents.



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

Figure 6.4 Community members

Figure 6.4a represents the citation network for the remaining patents, this graph is helpful to detect the different clusters of knowledge and how they interact. On this figure, we can identify groups of patents, like in the dashed rectangle, that gather studies based on much closed subject of interest. The links between different groups put in highlight the knowledge flow in the network. The patents in the boundary of this network, are predominantly patents with solution with a low level of inventiveness or very recent patents, this is why there are few cited. For the latter the results of the centrality analysis do not allow to retrieve recent patents bringing a breakthrough technology on the subject studied. Nevertheless with this centrality analysis expanded to the entire network, we can extract patent with important breakthrough as they give access to sub part of the graph (circles on figure a). These patents are at the origin of numerous other discoveries. The inventors of these patents have relevant skills and are potentially interesting people to encompass in the community provided to complement this information with network of inventors.

Figure 6.4b puts in highlight the collaboration between inventors. Each point on the outside circle represents an inventor and each edge is a link between two coauthors 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 at least to more than 3 patents. As a result inventors with no incident edge are those who collaborate with people coauthors 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 on Figure 6.4b). While they can be considered as experts because of their involvement in numerous patents, by analyzing more deeply this category, we can see that these people mostly interact with members of their firms. Consequently, they have a collaboration mode oriented toward closed innovation probably because of the strategy of their firm. (iii) the last category gathers people who are involved in numerous patents but with coauthors belonging to different firms (triangle on Figure 6.4b). Compare to the previous category, they are more in a logic of open innovation. The people belonging to the two last categories are relevant to create a community with a preference for those in the third category because already sensitized to external collaboration.

Unfortunately to test our prototype, we cannot afford to have a wide and diversified community with industrial, academics etc. As a consequence for the preliminary tests of the platform, we create a small community composed of researchers in universities with the different profiles as described in Table 6.2 (people belonging to the same country are not in the same university).

Table 6.2 Participant features

Country	**Field of expertise**	**TRIZ Practitioner**	**Participation to external collaboration**
Mexico	Industrial Engineering	Yes	Occasionally
France	Chemical Engineering	Yes	Regularly
France	Computer Science	No	Regularly
Lithuania	Mechanical	Yes	Occasionally

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. Here, the goal of this evaluation 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.

6.4 Problem resolution

6.4.1 Problem analysis and formulation

After the composition of the community, the next step is to deploy the resolution process. In this part, the process is detailed, presenting the crucial phases and sub phases. The attention is focused on the input data necessary for the resolution and the description of the retained idea.

The methods and tools developed in the Section 5.2.2 about the resolution process afford to have a deeper and detailed analysis of the problematic situation to reach the following problem features necessary as input information for the resolution:

Project details

Project name	Conceptual design for a fluidized bed gasifier.
Nature of the problem:	This project is about the conceptual design of a circulating fluidized bed process to improve heat recovery, and to facilitate the operation with biomass moisture greater than 20%.
User generated tags	fluidized bed ; gasifier ; heat recovery; moisture; biomass.
System generated tags	fluidized bed ; fluidized bed process; combustion chamber; gasification chamber; biomass gasification.

Problem description

Problem statement	The circulating fluidized bed 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.
What is the name of the technical system or technical process in which the problem resides?	Circulating fluidized bed process.
Describe the main useful function of the technical system or technical process	Biomass gasification.
What is the impact or cost of not solving the problem?	Low energy efficiency.
What is the 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).
What are the limitations and requirement	Temperature in combustion chamber cannot be upper than 1000°C. Drying chamber operation does not exceed 150°C to avoid risk of ignition of the biomass.

Problem type

Failure mode common to	machine
Specific failure mode	Fluidized bed gasifier
Problem type	Improvement

Resources analysis

Resources	• Material
	  o Gas
	• Energy
	  o Translational energy
	  o Heat rate
	  o Temperature

Problem formulation

Positive characteristic	Negative characteristic	Associated parameters
17 Temperature	39 Productivity	- 15 Dynamics - 28 Mechanics substitution - 35 Parameter changes
20 Use of energy by stationary object	39 Productivity	- Segmentation - Universality
22 Loss of energy	17 Temperature	- 19 Periodic action - 38 Strong oxidants - 7 Nested doll
39 Productivity	33 Ease of operation	- 1 Segmentation - 28 Mechanics substitution - 7 Nested doll - 10 Preliminary action
22 Loss of Energy	36 Device Complexity	- 7 Nested doll - 23 Feedback

Through the process, details about problem description, analysis, problem formulation and solution documentation are documented in Graphic User Interfaces (GUI) like the one exemplified in Figure 6.5. As observed the different components are organized according to the guidelines for human-computer interaction previously presented in section 5.4.

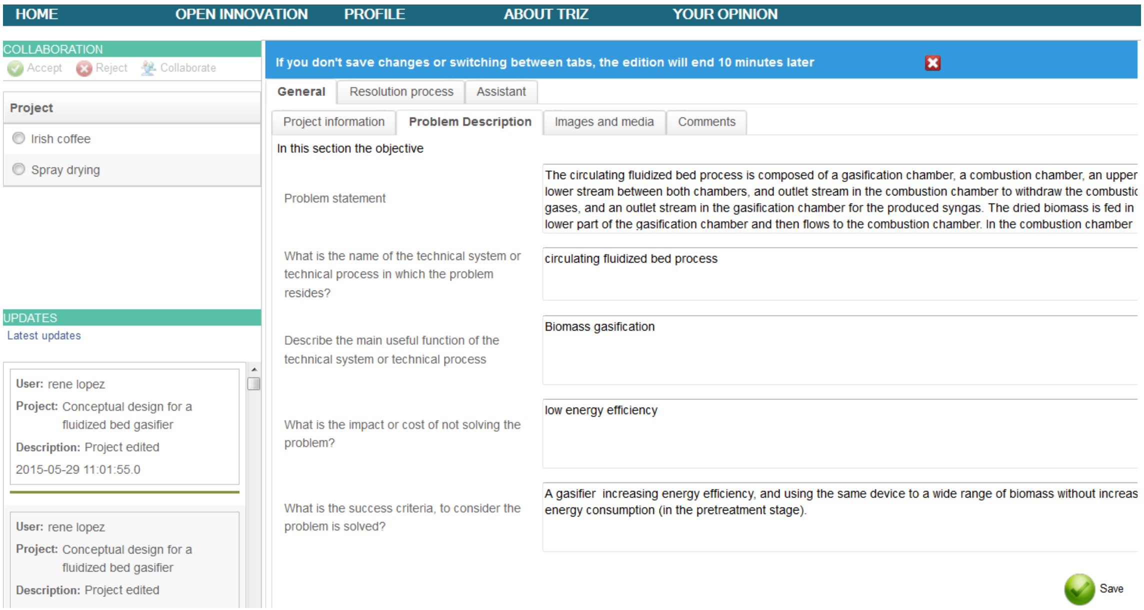


Figure 6.5 Problem description GUI

6.4.2 Solution selection

Several ideas were generated but only the retained one is presented here. This concept was chosen with the opinion that the community members expressed in a numerical way, i.e. rating, which is also useful as an input to the algorithms for a recommendation system. 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 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, two-round process was used to extract the most promising idea, 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.

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 current 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 serval 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. Figure 6.6 presents the elements related to the conceptual solution for a new fluidized bed gasifier.

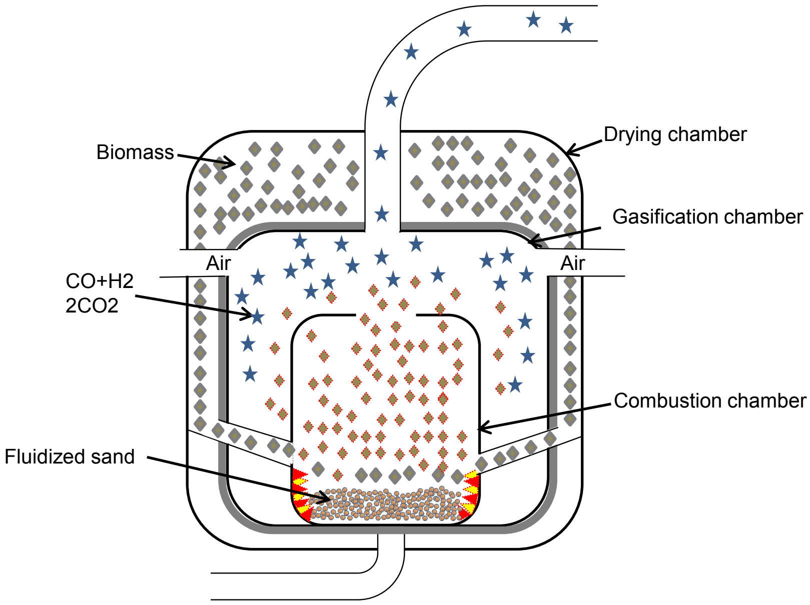


Figure 6.6 Nested-doll gasifier

Nevertheless, in a traditional gasifier, the hydrodynamic and thermal behaviors and the produced gas are closely related to the first reaction that occurs when the biomass is fed in 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 as the devolatilization phenomenon has a strong influence on the local hydrodynamic of the fluidized bed.

6.5 Discussion

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

- 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 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. Furthermore it can be easily handle by new practitioners.
- The use of collaborative technologies implicates the access to an undefined number of numerous sources of knowledge. Consequently our method based on the coupling between TRIZ and Case Based Reasoning enables to store and to easily reuse this knowledge for future problem resolution episode.

- An Open CAI must gather a documents analysis method both for creating a community of experts and to extract relevant information for problem formulation, while avoiding to browse the huge amount of documents available.
- 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.
- 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:

- The success of collaborative innovation is mainly determined by the selection of appropriated participants. Even if the documents analysis part of the tool enables to identify community members, the analysis is not deep enough to identify exactly the skills of each member to form the most efficient community. Moreover, to a priori anticipate if the collaboration between members will work is not an easy task.
- The huge amount of information generated by users makes difficult the identification of applicable ideas. It also raises the question of the knowledge maintenance as the knowledge base grows sharply. Another important question to address is how to create new knowledge by combination of the knowledge stored.
- The example treated is limited because academic, but in a real industrial environment 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).
- Difficulties to attract skilled people (correlated with the previous point).
- Two related elements an economic model and the intellectual property on the ideas generated are still a not covered issue in our approach.

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Chapter 7 Conclusion and outlook

Highlights
• To discuss the overall implication of this work. • To summarize our contributions. • To provide an outlook of limitations and perspectives.

7.1 Contributions and conclusion

"Pitié pour nous qui combattons toujours aux frontières de l'illimité et de l'avenir."

La jolie rousse (*Apollinaire, 1919*)

The initial motivation for this research work was to propose to take the evolution of Computer Aided Innovation tools to the next evolutionary step named Open CAI 2.0. For this evolution, we studied recent advances on innovation management paradigms, as well as the implication of the Web 2.0 as a technology for collaboration. In addition, we addressed a number of problems related to the systematizing of creativity in inventive problem solving. The use of the collective intelligence in combination with the TRIZ-CBR model was proposed to improve the capacity of a community to develop, evaluate and select a solution for inventive problems.

The first contribution of this work was to understand the mechanism related to the innovation process, specifically when it happens in a collectivity. The research conducted to the Open Innovation paradigm as a model to prone the active participation of internal, as well as external actors to the enterprise boundaries. Moreover, it valorizes internal generated knowledge through different channels and it promotes the integration of knowledge external sources in the innovation process.

With the increasing amount of information and the challenge to coordinate participants placed in different geographical areas, it becomes necessary to have adapted computational tools to assist the different activities. One technology widely implemented and widely accepted in the industry is the Web platform. Specifically, the Web 2.0 as a platform for collaboration has multiple advantages such as:

- Not expensive technology.
- Supporting different collaboration patterns.
- Accessible from different locations and different devices.
- Employees are familiarized.

After the study of innovation mechanism and collaboration technologies, the second contribution was to analyze existing tools related to the field of Computer Aided Innovation. In this work, we simply classified existing solution in two categories: industrial and academic developments. It was observed that current trends in the CAI field are related to the use of the collective intelligence (i.e. crowdsourcing services) for the implementation of Open Innovation practices. Despite the wide acceptation of these services, certain drawbacks were identified. The drawbacks lead to propose a conceptual framework complementing the Open CAI 2.0 concept previously proposed by (Hüsig and Kohn, 2011) with a creativity driver. The creativity driver is based on the systematic approach of the TRIZ-CBR hybrid model. 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 at different level of abstraction.

The third contribution was to propose a methodological framework for Open CAI 2.0, to our knowledge this is the first development including a creativity driver. The framework is organized according to three core levels. The lower one concerns the Innovation process and it is mainly focused on ideas generation and selection. To manage the large amount of knowledge deployed in open innovation while continuing to generate rapidly innovative ideas we have developed a dedicated methodology based on the most utilized TRIZ tools combined with Case Based Reasoning. The proposed approach allows the exchange of knowledge between disciplines. It offers the possibility to create new knowledge, it facilitates the transfer of technological solutions avoiding some pitfalls, thanks to information on the implemented solution. The intermediary level is focused on the collaboration and the way to create a collaborative environment to facilitate knowledge exchange. This is done by taking advantage of the benefits of on line Social Network. In this level we also address the question of the creation of community with relevant skills for the problem treated. To discover potential community members, we propose to use scientific documents and to analyze them through the network analysis of the graph theory. Different kinds of networks and different types of measure 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 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 interaction.

Once defined the conceptual and methodological framework for a solution of type Open CAI 2.0, the fourth contribution was to develop and implement a software-based prototype. The validation of the methodology and this prototype was in the field of Process System Engineering, with a problem about a new conceptual design for a circulating fluidized bed reactor. We observed that for processing engineering, Open CAI 2.0 becomes an important research domain with the purpose to support the entire innovation process. Open CAI 2.0 systems provide methods and tools for each step of the innovation process, i.e. from the creative stage to the transformation of invention into successful innovation.

Throughout the development of this work we observed that organizations need to introduce new advanced applications to impulse innovation, and to acquire and manage efficiently knowledge. Indeed in innovation, knowledge management is one of the central issues to force innovation, but also to adapt rapidly to a changing environment. One way to boost innovation is to reinforce collaborative practices with also positive impacts on ideas and products quality. This is the purpose of open innovation to expand collaboration outside the firm boundaries. In open innovation the knowledge is exploited in a more collaborative ways 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 especially with Web 2.0 which offers the technologies framework to facilitate relationship between people, and the exchange of knowledge and interests. Both drivers amplify the benefits of the incorporation of a logical approach (i.e. TRIZ-CBR) to drive the creative generation of solutions during the inbound process.

The preliminary results from the conception, development and implementation of the proposed Open CAI 2.0 allow us to highlight the following facts:

- Although most open innovation literature focuses either on a management (Chesbrough, 2006) or an economic perspective (Enkel et al., 2009), it is important to include an engineering viewpoint; specially, regarding the generation of creative ideas and inventive problem solving in the front-end of innovation.
- The use of collaborative technologies implicates the access to an undefined number of numerous sources of innovation (Enkel et al., 2009). However, existing crowdsourcing solutions to foster open innovation practices are limited to take a problem and broadcast it to a community of solution providers (Majchrzak and Malhotra, 2013).
- For (Majchrzak and Malhotra, 2013), existing crowdsourcing services lack of collaborative mechanism among participants to construct a common solution.
- The use of TRIZ methodology as a common language to formulate technical problems facilitates collaboration within a community of problem solvers.
- The Web 2.0 collaborative technology provides the elements required to implement a generic collaboration model such as the one proposed in (Campos et al., 2006). Moreover, for the industry the social web services help to unlock the potential of the collective intelligence.
- The advantage of using Web 2.0 technologies for collaboration is that the framework can be accessible to a wide range of users, which can result in reducing the gap between newcomers and TRIZ practitioners. In addition, the preliminary implementation of the software-based framework is planned to be used in academic context in order to spread the interest in the methodology.

Finally, our findings suggest that it is necessary to overcome several barriers in order to achieve a real collaborative innovation in an open context. In this manuscript some of them have been tackled: social interaction, knowledge management and the definition of an innovation process based on problem resolution. A solution that integrates these elements using the Web 2.0 platform was described. The concepts from collective intelligence expose the possibilities to improve participant’s creativity in the phase of conceptual design. The collective intelligence provides a way to expose knowledge that is otherwise hidden in a collective environment, for example, bubbling up interesting content or dynamic content classification.

7.2 Limitations and perspectives

Despite the positive aspects observed in the preliminary results, it is worth to mention that certain limitations -open research problems- are also observed:

- The problem solvers on crowdsourcing services do not necessarily constitute a virtual community (Frey et al., 2011). To constitute a virtual community requires to have properly motivated (e.g. money, glory) the participants, and the profile selection according to the type of problem.
- The success of collaborative innovation is mainly determined by the selection of appropriated participants (Geum et al., 2013). In our Open CAI 2.0 this was approached with an expert system recommender. But because of the reduced number of participants in our community, it was not possible a deeper validation.
- For (Martínez-Torres, 2013), the huge amount of information generated by users, makes difficult the identification of applicable ideas. The members of a community may have a different opinion about the same idea or solution. Consequently, it is required to have mechanism for the consensus in solutions evaluation.
- Reliance on the emotional states and motivation of participants. Since our approach is oriented to improve the creativity of humans involved in the innovation process, the emotional state and the motivation play an important aspect in the performance of the Open CAI 2.0 tool.
- Difficulties to attract skilled people while constructing the community of solution providers (Stankovic et al., 2012). The construction of the community needs to take into account the problem domain, and the incorporation of TRIZ practitioners. This was relieved in the evaluation of the case study that needed to have skilled people in the PSE and mechanical domains.

After the first evaluations in the case study, it was observed that a limitation in the form of a contradiction exists in the proposition of a generic and specific domain Open CAI 2.0 tool. On the one hand, a generic Open CAI 2.0 reduces the implementation time of the tool, as well as it may facilitate the transfer of solutions between multiple domains. However, it complicates the adaptation of a generic solution to a specific domain solution. On the other hand, a specific domain Open CAI 2.0 provides the elements (e.g. modeling tools, specific databases) to reduce the problem resolution time. But, it may lose the opportunity to discover existing solutions in other domains.

Regarding the current state of development of the software-based prototype and the methodology, further developments are required to improve our Open CAI 2.0. As perspectives of this work we have:

- The development of the software-based prototype requires modifications to control the access and modifications on the project resources. Currently, in the framework the users have the liberty to modify any part of the project without restriction. However, the stakeholder should have the options to accept or reject modifications to ensure the quality of information. Another technical requirement is to simulate the use by a considerable number of users, in order to measure the performance of the application. The results of the simulation will allow to prepare the software for a production environment. Finally, the development concerning the functionally of collective intelligence requires future development. For instance, the users profile needs to be complete it with an option to see an edit its features; or the assistant functionality needs to connect with information sources (e.g. Open Linked Data).
- The methodology must be enlarged by integrating a simplified version of the workflow proposed in (Barragan Ferrer, 2013) for problem formulation and resolution. Regarding the use of the contradiction matrix, its utilization is not easy and relies on the user's skills. This limitation could be overcome using an automatic method in order to scan free-text and find the specific technical parameters to formulate the contradiction (Wei Yan, 2013). The solution to assist in the formulation of contradiction implicates the use of domain ontology. Ontologies are a suitable technology to explore the corpus of the problem description to try to identify the positive and negative parameters. Other formulation tool is the Su-Field model. Although a first prototype has been developed, it needs to be improved. Another axe to enlarge the methodology includes 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.
- The presented approach for open innovation is based on the outside-in sub-process but the other one, i.e. the inside-out, could be included to improve invention valorization and to generate additional value. Thus another perspective regards the business model. Besides the affective or recognition motivations to participate in crowdsourcing platforms, solution providers look for a monetary reward. Thus, the virtual community in which people with inventive problems looking for solutions, and the people who provide those solutions became a crowdsourcing marketplace. Derived from the monetary exchange, a business model is necessary to generate an economic outcome from the accepted solutions. Therefore, this work should look forward to include a business model capable to valorize users' participations. Moreover, the business model will be part of a strategy to protect the Intellectual Property generated with each solution. We think that the business model and the Intellectual Property

are interrelated concerns. For developing this perspective it is recommended the collaboration with people from business and management research field.

- The first tests to the framework were to solve technical problems. However, TRIZ has propagated to non-technical fields (Ilevbare et al., 2013) such as marketing, psychology, sociology and education. In the near future we are planning to extend the application of the framework to non-technical fields.
- Regarding the implementation in Process System Engineering, the proposed Open CAI 2.0 requires future development to adapt it with traditional tools for design (e.g. simulation, optimization).

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Appendices

Appendix I Scientific communications

Book chapter

1. Lopez Flores, R., Belaud, J.-P., Lann, J.-M., Negny, S., Cortes Robles G., 2015. Collaborative framework in Open Computer Aided Innovation: a contribution for inventive problem solving. (Currently in preparation).

Peer reviewed journals

1. Lopez Flores, R., Belaud, J.-P., Lann, J.-M., Negny, S., 2015. Using the Collective Intelligence for inventive problem solving: A contribution for Open Computer Aided Innovation. In *Expert Systems with Applications*. doi:10.1016/j.eswa.2015.08.024
2. Lopez Flores, R., Belaud, J.P., Negny, S., Lann, J.M.L., Open Computer Aided Innovation to promote innovation in process engineering. In *Chemical Engineering Research and Design*. doi:10.1016/j.cherd.2015.08.015

International congresses

1. Lopez Flores, R., Belaud, J.P., Negny, S., Le Lann, J.M., 2015. "A next evolutionary step for computer aided innovation in chemical process engineering" in *10th European Congress of Chemical Engineering*.
2. Lopez Flores, R., Negny, S., Belaud, J.P., Le Lann, J.M., 2013. "Collective intelligence to solve creative problems in conceptual design phase". in *TRIZ Future Conference 2013.*
3. Lopez Flores, R., Negny, S., Belaud, J.P., Le Lann, J.M., 2013. "Interoperability in innovation 2.0". in *10ème congrès International de Génie Industriel (CIGI)*.
4. Lopez Flores, R., Negny, S., Belaud, J.P., Le Lann, J.M., 2013. "Plateforme collaborative pour l'innovation en conception préliminaire des procédés". in *SFGP2013 - XIVe congrès de la Société Française de Génie des Procédés.*

Workshop

1. "Assises de la Recherche autour de la TRIZ" 24-25 Juin, 2015 in Paris.

Appendix II Academic CAI related works

Mal'in (TREFLE-ENSAM, 2003) is software that proposes a structured methodology for the innovation of products. Figure A.1 introduces the elements of the methodology, as observed the activities are particularly relevant for the preliminary design phase of products. It is a sequential process that combines TRIZ classical tools (e.g. contradiction, separation principles) with other methods for problem resolution (e.g. analysis of needs, brainstorming). The version for ecological innovation (Samet et al., 2010), is an evolution mainly based on the set up of pre-analysis phase of product to define opportunities incorporating new environmental constrains.

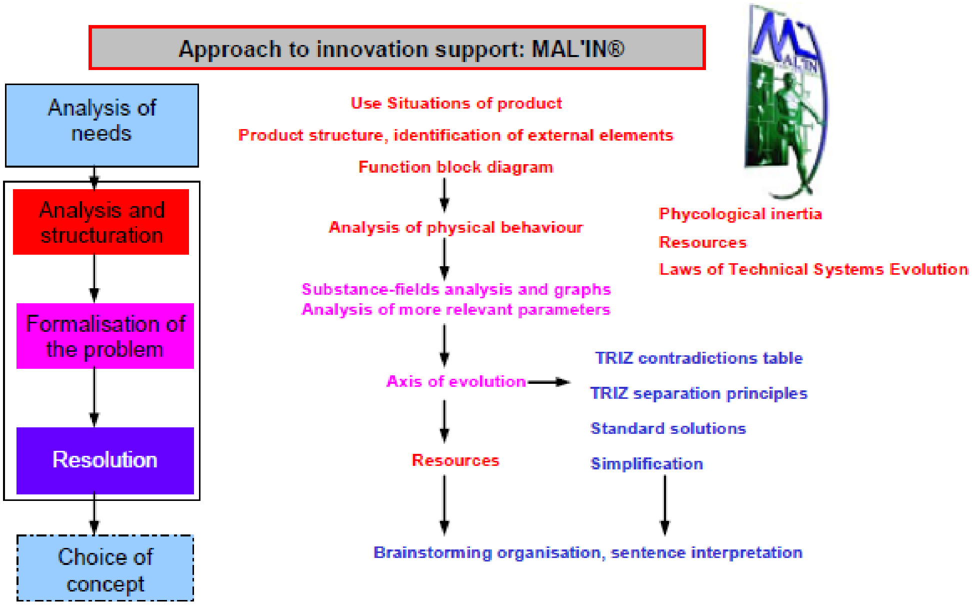

Figure A.1 Mal'in approach (Samet et al., 2010)

(Cavallucci and Leon, 2004) try to establish the theoretical basis to build a CAI tool by interacting with a traditional Computer-aided design (CAD) architecture. This research is based on the theoretical approach to inventiveness-seeking as developed by Genrich Altshuller. The authors outline the following points for designing computing products derived from the approaches advocated by TRIZ:

- Definition of a final ideal objective
- Relevant list of resources
- Designing up a contradiction network
- Exploiting the contradiction network to initiate the design path
- The factor of pin-pointing concordance between the directions taken and the laws
- Access to databases and their graphic form.

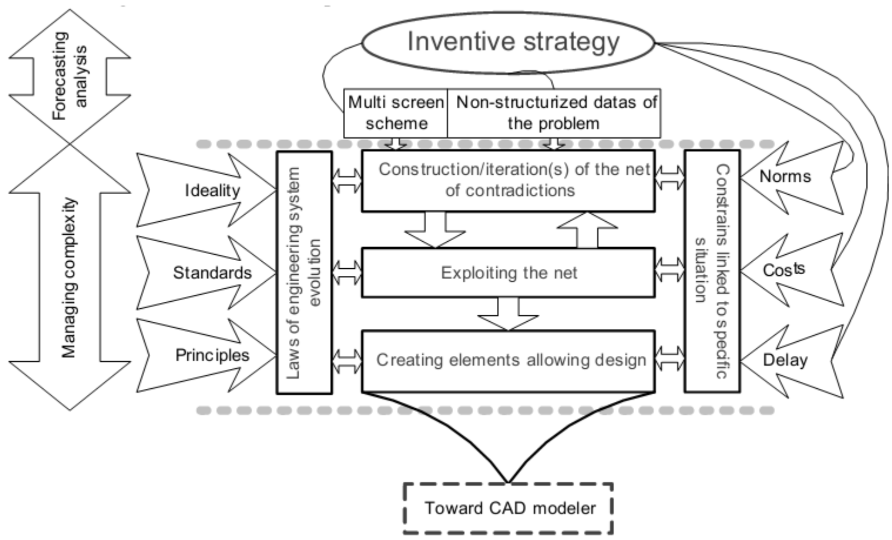

Figure A.2 CAI model architecture proposal (Cavallucci and Leon, 2004)

For Cavallucci and Leon, all this factors must form a coherent whole, helping the designer to formalize his technical problem and come up with an inventive solution (conceptual) on a basis which idealizes the technical solution to be built.

The proposal of architecture model (see Figure A.2) reflects the integration of the different components for the CAI tool proposed.

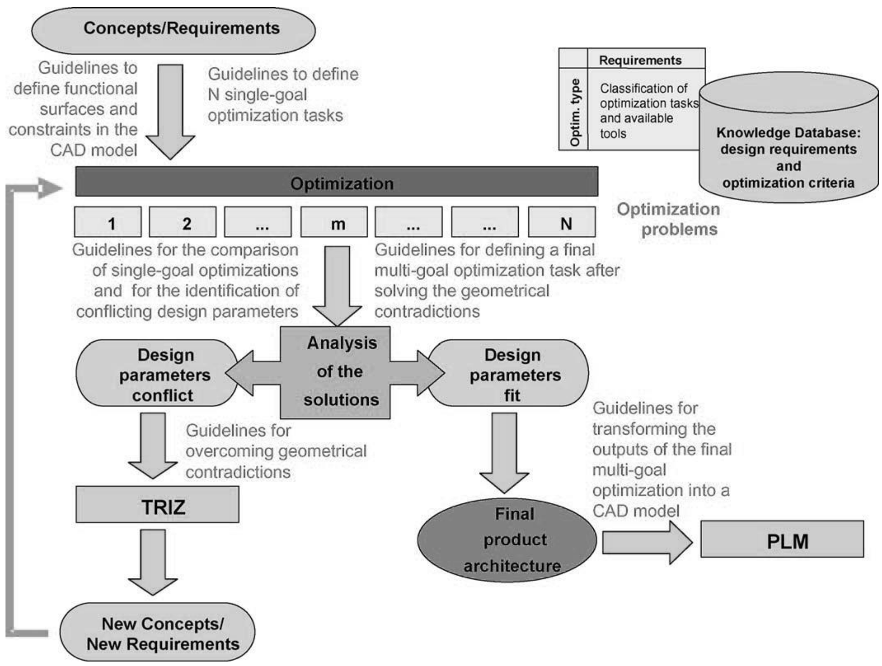

Figure A.3 PROSIT design flow (Cugini et al., 2009)

In (Cugini et al., 2009) the authors presents a design tool to improve product development cycle integrating CAIs tools with optimization and Product Lifecycle Management (PLM) systems. They argue that integration is possible by using optimization systems as a bridging element between CAI and PLM systems.

The results are resumed in the architecture (see Figure A.3) of PROSIT project. The novelty of this work is the adoption of optimization tools not only to generate optimized solutions, but also as a design analysis tool. The authors argue that the model provides advantages in terms of design costs reduction, errors reduction, product quality improvement, process execution time and more effective internal and external knowledge use. However, the tool is more oriented to improve existing technical systems, than to create innovative solutions.

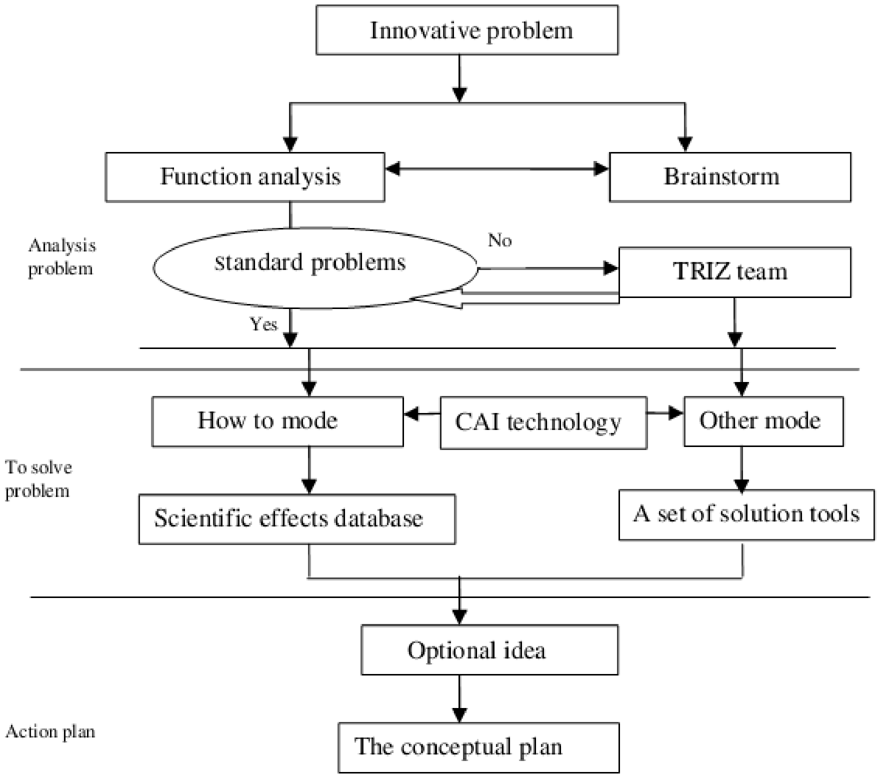

Figure A.4 Problem-solving process based on CAI technology (Chen et al., 2009)

The work of (Chen et al., 2009) argues that it is feasible and necessary to involve non-technical participants in the innovation process. For implementing it, the authors proposed the use of science effects database within CAI technology. Their innovation process, based on CAI technology using TRIZ is focused especially on non-technical employees. This proposal is supported by the idea that without scientific search method, it is almost impossible to find any required suggestion from different source of information as patents, scientific principles, know-how records, successful cases, failure cases, etc. The authors state that one principal function of CAI technology based TRIZ theory is precisely the searching capability from mass information. Non-technical department participants can search similar solutions by “how to” functional mode of the CAI technology. That is why CAI technology could be a powerful tool in the innovation process.

The process represented in Figure A.4, is divided into three stages:

a) Phase of analysis and problem identification
b) Generation of many problem-solving ideas
c) Ideas selection and action plan.

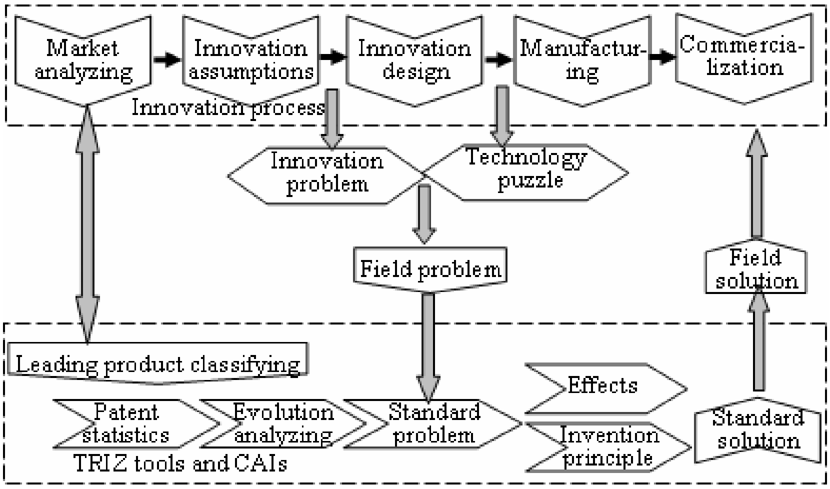

Figure A.5 Innovation process based on the TRIZ and CAIs (Li et al., 2009)

For (Li et al., 2009), to develop CAI applications it is necessary to solve some problems, such as the way to choose technology innovation, establishment of technology innovation organization network (TION), and achievement of innovative process based on TRIZ and CAIs. CAIs are efficient tools during the innovation process of enterprises, because they can include knowledge of different fields. Li et al. (2009) centered their work on technology innovation process of manufacturing enterprises. In the innovation process described in Figure A.5, the authors stand that there is a combination of existing innovative processes in enterprise with TRIZ and CAIs to support the enterprise products innovation. The innovation process gathers steps like: changing the problem need to be solved into TRIZ standard problem, using TRIZ tools (i.e. the invention principle and effect) to obtain the standard solution of the problem, and finally to change it into the domain solution, to form the innovation result.

A computer aided innovation system based on knowledge discovery is presented in (Zhang, 2011). The proposed system tries to simulate the thinking process of human in the innovation to reduce time. The proposed CAI, named Computer Aided Innovation Intellect System based on the Knowledge Discovery (CAIISKD). It is mainly based on knowledge discovery. It is framed with an intelligent system. And, in the core it includes TRIZ and other advanced design method and innovation skill. The CAIISKD objective is to make easy get the insight and inspiration as soon as possible, by shortening the phase of knowledge storage

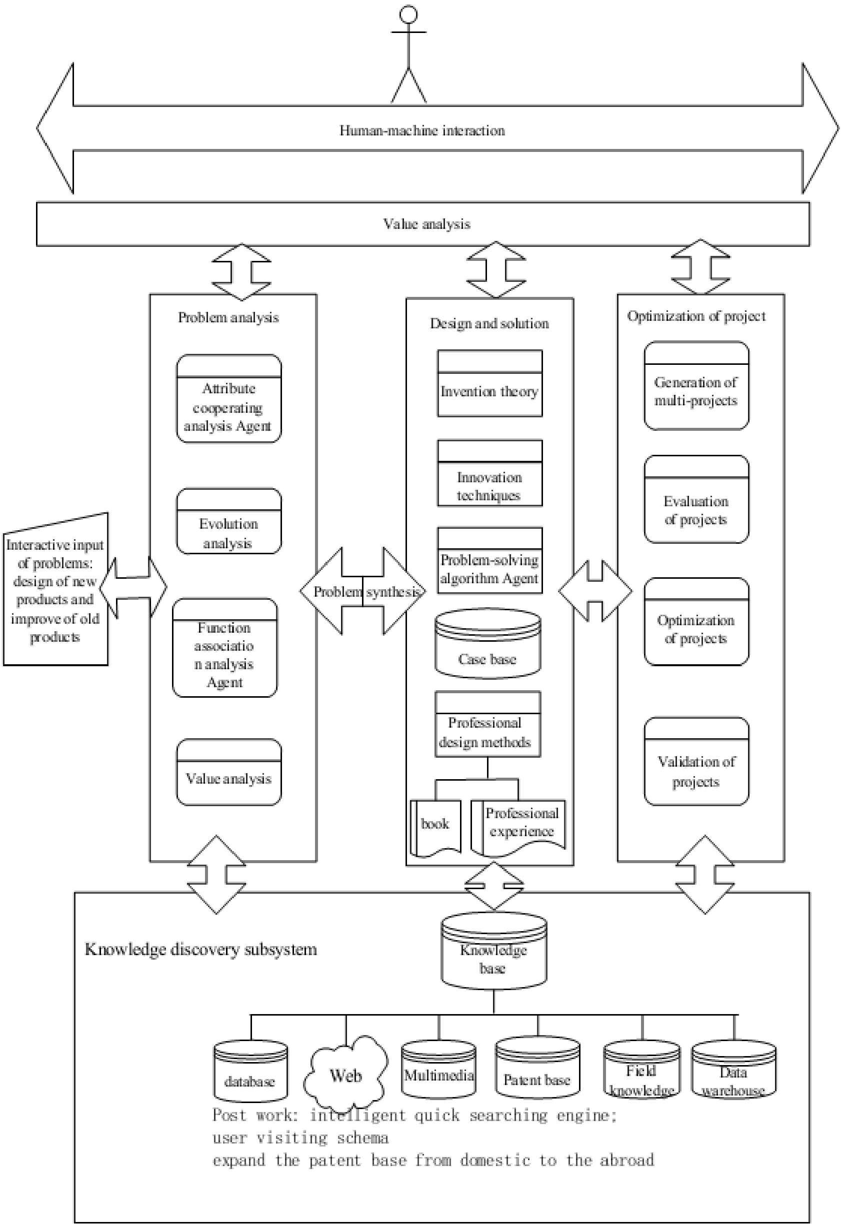

Figure A.6 Knowledge discovery system (Zhang, 2011)

and knowledge gestation during the innovation thinking process. According to the authors, the model shown in Figure A.6 corresponds to stages human follow to generate inventions and innovations: input problem, problem analysis, design solution, project evaluation and optimization.

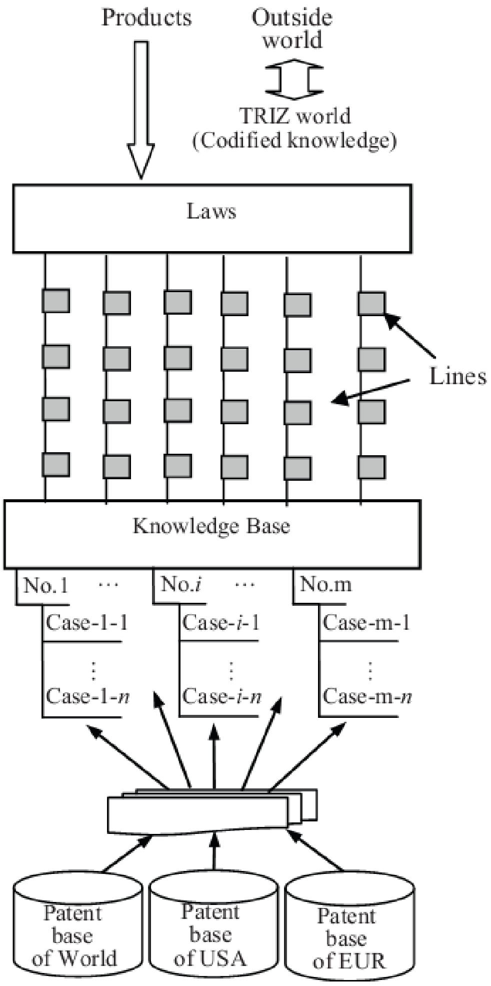

Figure A.7 Framework for technological evolution system in CAIs (Tan, 2011)

(Tan, 2011) considers that ill-structured problems are the root causes of technical obstacles in innovation pipeline, and problem solvers or designers might apply CAIs and TRIZ to solve them. The process described in Figure A.7, represents how problem solver uses CAIs, to find a suitable technological evolution law and some technological evolution lines. In such process, each line drives to a few abstracted cases from worldwide patent bases in which the knowledge of different fields is included. Thus, technology forecasting using the knowledge from different fields can be carried out and some high quality ideas for future innovations can be generated.

(Li et al., 2012) present a framework based on concepts from an engineering design theory. This framework incorporates data mining on patents, natural language processing, and creation of machine learning models for classification of the patents into several categories of inventiveness. In this work, patents are considered as providers of wealth of information about design concepts. The search for solution ideas in conceptual design is illustrated in Figure A.8; the process is divided in three phases:

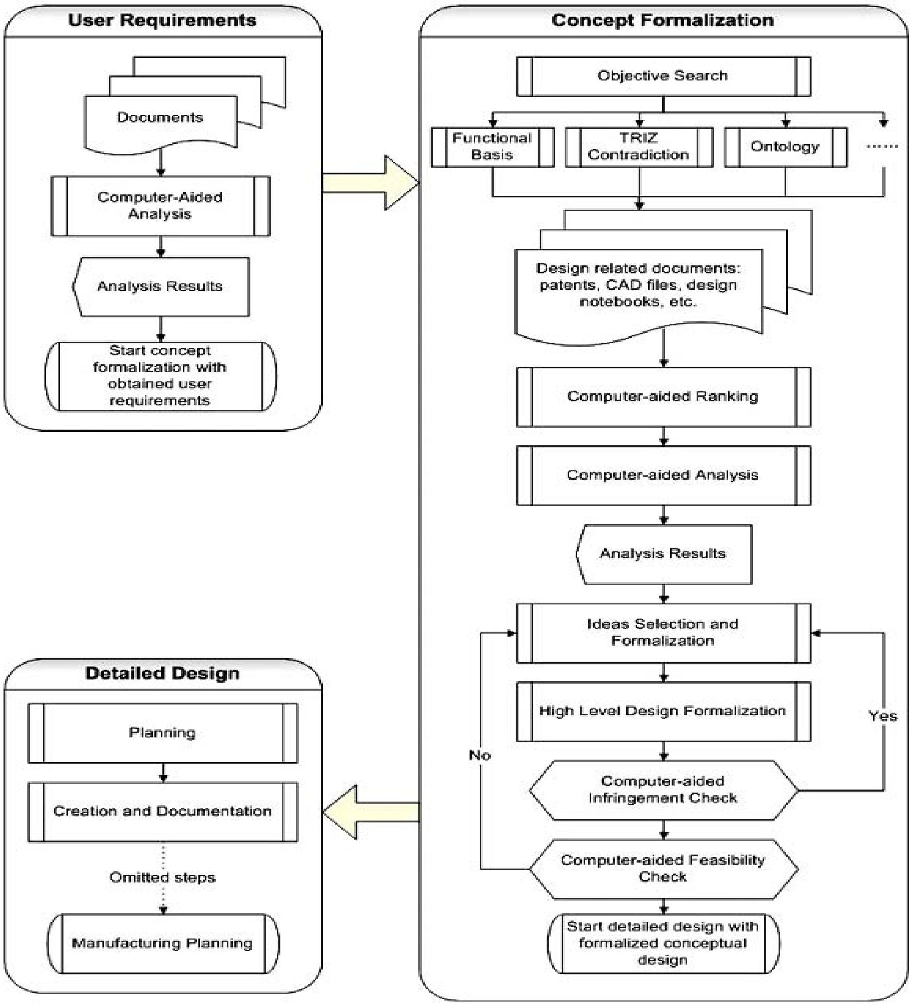

Figure A.8 Ideas search in conceptual design (Li et al., 2012)

- User requirements. It is focused in the analysis of the design from user perspective.
- Concept formalization. In this phase the designer searches for design ideas in a patent database. To make the search he may use different techniques like functional-based search or TRIZ.
- Detail design.

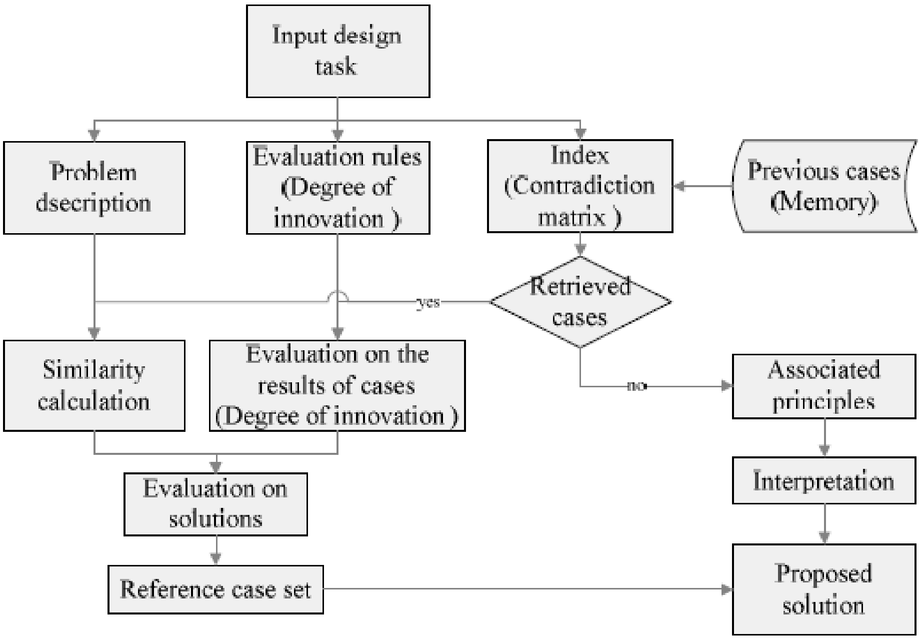

Figure A.9 Model CBDT and TRIZ (Hu et al., 2013)

In (Hu et al., 2013), the authors develop a CAI tool for finding inventive principle which supports decision-making during the design process. The tool combines two approaches, Case-based Decision Theory (CBDT) [19] with the TRIZ , the tool helps designers rapidly find the effective inventive principles which possess the highest utility value evaluated by (CBDT), methods. CBDT with the TRIZ tools to produce a CBDT-TRIZ model for design. The model is illustrated in Figure A.9 and it includes the operation for case representation, index, evaluation and similarity calculation. According to the authors (Hu et al., 2013), the model allows designers to accelerate the conceptual design process by using past experiences for decision-making and problem resolution.

[19] The ability to rapidly store and reuse knowledge, it views cases as instances of decision making. The decision process depends on the similarity between the target problem and memory problems.

Appendix III Resources list

Resource category	Resources sub-category	Resources
Material	• Human • Gas • Liquid • Plasma	
	• Solid	• Object • Composite • Particulate
	• Mixture	• Liquid-liquid • Gas-gas • Solid-solid • Solid-liquid • Solid-gas • Liquid-gas • Solid-liquid-gas • Colloidal
Energy	• Generic Complements	• Effort • Flow
	• Human	• Force • Velocity
	• Acoustic	• Pressure • Particle velocity
	• Biological	• Pressure • Volumetric flow
	• Chemical	• Affinity • Reaction rate
	• Electrical	• Electromotive force • Current
	• Electromagnetic	• Generic Complements • Optical • Solar
	• Hydraulic	• Pressure • Volumetric flow

	• Magnetic	• Magnetomotive force • Magnetic flux rate
	• Mechanical	• Generic Complements • Rotational energy • Translational energy
	• Pneumatic	• Pressure • Mass flow
	• Radioactive (Nuclear)	• Intensity • Decay rate
	• Thermal	• Temperature • Heat rate
Signal	• Status	• Auditory • Olfactory • Tactile • Taste • Visual
	• Control	• Analog • Discret

Appendix IV Agile Programming methodology

The prototype development followed the workflow illustrated in Figure A.10. Throughout the development process it was very important the participation of final users (i.e. members of TRIZ community).

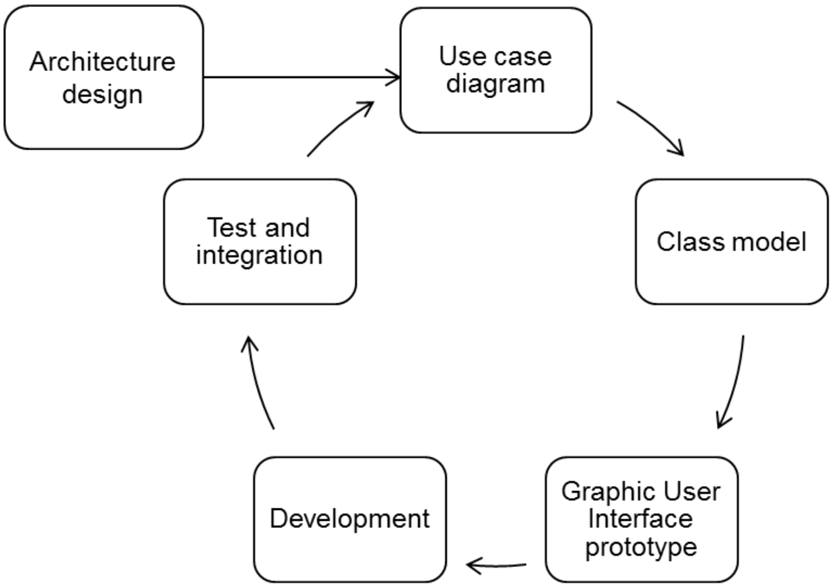

Figure A.10 Programming methodology flow

Appendix V Classes dictionary

Class name	Description
Profile	Gathers information about the user personal information, it tracks user activities, it also keeps the user rating and the tags associated.
UserAccount	It is the credential to access the system. It has associated the user profile.
Project	It encapsulates and keeps the information associated to a problematic situation, as well as the resolution process and the solution accepted.
Collaboration	It is a relationship between a project and profile. It is useful to limit the access to certain projects and to control user participations
Dashboard	It keeps track of the different notifications.
Notification	It is an action or event that happens when a user creates or modifies a project. The notifications are associated with all the participants in a project.
Review	It is an opinion about and item (i.e. project) expressed by the users. They are of two kinds textual and numeric (i.e. rating).
Textual	It is a textual opinion about and item.
Rating	It is an opinion expressed numerically, usually through starts (1 to 5).
Tag	It is meta-content associated to items.
MediaResources	It represents items as documentation support.
File	It is a sub-type of media resource for different kind of file documents (i.e. PDF, Word, Power Point), except images.
Image	It is a sub-type of media resource to save images documents.
ProblemDescription	It gathers information about the problem description; it is associated to the project.
ProblemBackground	It gathers information about the problem background; it is associated to the project.
ResolutionProcess	It is a class to aggregate the different classes associated with the process of problem resolution.
AnaliticalTool	It is a class to define information common to different analytical tools.
IdealSolution	It is an analytical tool inspired in TRIZ theory to define the

	ideal indeed solution.
NineWindow	It is an analytical tool to document the different phases of a technological system in time (past, present, future) and in scope (sub-system, system and super-system).
ProblemFormulation	A class to represent the different ways to formulate a problem.
Contradiction	A problem formulation class to formulate a problem as a contradiction.
Characteristic	It is the positive or negative characteristic associated with a contradiction.
Physical	A sub-type of contradiction when the two Characteristics are the same.
Separation	The solution associated to Physical contradictions is through Separation principles.
Technical	It is a sub-type of contradiction when the two characteristics are different.
InventivePrinciple	It is a list of principles inspired in TRIZ associated to a particular contradiction.
SolutionDocumentation	It is the information associated to a solution. A resolution process has one or more solution proposals but only one solution accepted.
CBRCase	It is a class to save the information of project as a case in the CBR database once the project has concluded and a solution (satisfactory or failure) has been accepted.
CBRDescription	It is the basic information of a project that composes the problem description in the CBR database.
CBRSolution	It is the information associated to the project that corresponds to the problem description, resolution process, proposed solutions and accepted solution.