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Using the Collective Intelligence for inventive problem solving: A contribution for Open Computer Aided Innovation

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A B S T R A C T

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Conceptual design
TRIZ

In the industrial context, an interest exists in the collective resolution of creative problems during the conceptual design phase. In this work we introduce an information-based software framework useful to collaborate for inventive problems solving. This framework proposes the implementation of techniques from the Collective Intelligence (CI) research field in combination with the systematic methods provided by the TRIZ theory. Both approaches are centered in the human aspect of the innovation process, and are complementary. While CI focuses on the intelligent behavior that emerges in collaborative work, the TRIZ theory is centered in the individual capacity to solve problems systematically. The framework's objective is to improve the individual creativity provided by the TRIZ method and tools, with the value created by the collective contributions. This work aims to contribute formulating the basis to extend the research field of Computer Aided Innovation, to the next evolutionary step called "Open CAI 2.0".

1. Introduction and scientific context

Nowadays, the act of innovation is a social activity, which requires the management of knowledge, and the techniques and methodologies to drive it. As Yannou, Bigand, Gidel, Merlo, and Vaudelin (2008) remark: innovation is not the product of one isolated intelligence, instead, it is the result of a multidisciplinary workgroup led by a process or a methodology. In the last years, 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 the ideas and technologies; specifically it requires a high degree of interaction between participants—internal and external—who develop strong and weak relationships (Michelfelder & 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 & Speidel, 2014). Chesbrough (2003) coined the term to present under the same denomination a group of existing management practices; Chesbrough defined open innovation as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of

innovation, respectively”. Therefore, the adoption of open innovation concerns two complementary modalities: outside-in and inside-out processes (Gassmann & Enkel, 2004).

Outside-in or inbound is the integration of knowledge, ideas, concepts or technologies externally generated. Namely, it denotes the integration of outside sources of innovation within one or more phases of the internal R&D process (Herzog & Leker, 2011). Inside-out or outbound, is the transfer of internal ideas or technology toward the market through external channels in order to generate additional value; concerned technologies are those not exploited commercially because they do not correspond to the enterprise business model (Chesbrough, Vanhaverbeke, & West, 2006). The inbound activities related to conceptual design of new product/process are perhaps one of the main difficulties the manufacturing industry faces, because of the highly demand for creative solutions. In this scenario, active researches are oriented to provide the means in the form of methods and computational tools for generating innovative ideas (Hüsig & Kohn, 2009), providing structured approaches to problem solving (Ilevbare, Probert, & Phaal, 2013), and harnessing the benefits of the collective effort of individual intelligences (Garcia-Martinez & Walton, 2014). Hence, the main objective of our proposal is 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. 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

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¹ Lopez Flores is a family name that may be ambiguous; it is according to Spanish naming customs: composite with two family names.

Acronyms

CAD	Computer Aided Design
CAI	Computer Aided Innovation
CBR	Case-Base Reasoning
CI	Collective Intelligence
ICTs	Information and Communication Technologies
LOD	Linked Open Data
NPD	New Product Development
OWL	Ontology Web Language
R&D	Research & Development
RBR	Rule-Based Reasoning
RDF	Resource Description Framework
RHA	Rapid Heat Ablation
RSS	Really Simple Syndication
SOA	Service Oriented Architecture
TRIZ	Theory of Inventive Problem Solving
XML	eXtensible Markup Language

Communication Technologies (ICTs) as tools to effectively support the collective work during the inbound process of open innovation.

The use of purposive inflows of knowledge in the phase of conceptual design makes necessary the incorporation of new technologies to collaborate across geographical distances (Huizingh, 2011). It is acknowledged (Enkel, Gassmann, & Chesbrough, 2009), that the 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 & Lan, 2007). But the adoption of a collaborative technology does not necessary contribute to the implementation of open innovation in the companies. On the other hand, collaborative technologies facilitate the aggregation of multiple intelligences for the search of new ideas and innovative solutions within a community. Thus, the collective search of innovative solutions is the result of the aggregation of multiple intelligences. However, an organization is required to aggregate the Collective Intelligence (CI) to complete, improve and implement an idea that seems innovative (Christofol, Richir, & Samier, 2004). According to Zara (2008), the challenge of CI and knowledge management is how to improve the collective efforts in order to be better than individual efforts. Zara defines CI as “the capacity to join intelligence and knowledge to achieve a common objective”. CI takes a new dimension with the incorporation of the information-based systems. For example, the center for CI at the MIT develops systems to connect people and computers so that collectively they act more intelligent (Leimeister, 2010).

As an application of the CI, crowdsourcing services are useful in the implementation of open innovation (Enkel et al., 2009). 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”. 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).

On the other hand, in the industrial context is required to have approaches and supporting tools to help product design, particularly in preliminary phases, where is highly desirable to produce original and inventive solutions. The concept of collective problem solving is seen as a process that occurs among a group of people, in which a shared solution is constructed, defining the conceptual characteristics of a new product. Collaborative innovation reflects the growing

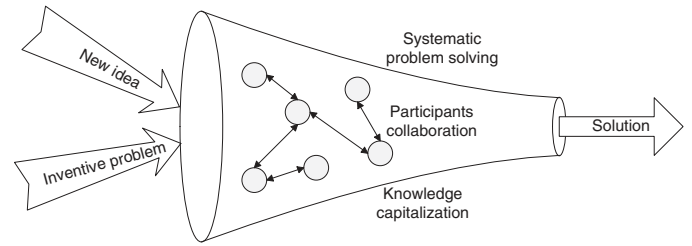


Fig. 1. Directing inventive problem solving under Open CAI 2.0.

interest among industries in developing methodologies and supporting tools. Currently, the innovation process in existing platforms that gather the CI 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 systematic approach to developing creativity for innovation and inventive problem solving (Iliev et al., 2013). However, software solutions inspired in TRIZ such as Computer Aided Innovation (CAI) tools, are limited to the practice of the closed model of innovation (Hüsig & 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.

Unlike existing implementation of crowdsourcing services for open innovation (i.e., InnoCentive, NineSigma or Hypios), in our contribution, we look at providing the participants with 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 implementation of the theoretical elements defined in the Open CAI 2.0 concept (discussed in Section 3.1). A general use case to illustrate the approach of this work is presented in Fig. 1. As observed in the figure, the process starts either with a new idea for general situations (e.g., a new development), or an inventive problem for a specific problematic situation (e.g., root cause known). In both cases, the systematic problem solving process provides the elements to reformulate the problem using well-defined models. A solution is built within a group of participants who collaborate; the generated knowledge through the process is managed for capitalization.

To meet the general use case requirements, the paper is organized as follows. Section 2 introduces the concept of CI, its use in the innovation process and its implementation mechanisms. The case of crowdsourcing services is particularly discussed. The limitations while driving creativity in the process of problem resolution are discussed. Finally, the creative design and the TRIZ approach are defined. Section 3 presents different aspects related to the framework core components, its functionality and interaction. Thus, the core elements are presented covering (a) the innovation process based on a problem resolution approach and its implementation via the TRIZ-CBR model; (b) the collaboration support; (c) the architecture of participation and the mechanisms for gathering the CI, and; (d) the main sections of the graphical user interface. The evaluation to demonstrate the feasibility is presented in Section 4 with an example of a rapid prototyping tool. Finally, Section 5 discusses the conclusions and perspectives about future work.

2. Collective Intelligence as an innovation driver

In a world increasingly interconnected via Web technologies, new challenges and opportunities are emerging to manage the innovation process in industries. The business model proposed in existing crowdsourcing services is an effort to democratizing the innovation

Table 1
Related works on CI for innovation activities.

Authors	System objective	CI strategy	Knowledge approach	Implemented	Technologies
Allio (2004)	To broadcast an open call to individuals outside the company to become involved in the solution of a challenge	Crowdsourcing	Content management	Yes (InnoCentive)	Internet/Web
Adamides and Karacapilidis (2006)	To integrate different actor's perspective and tools across the different activities in the process of problem resolution, by addressing the knowledge and social dynamics	Collective problem resolution, idea evaluation, users review	Net of hypothetical cause-effect relationships	Yes	Internet/Web
Pappas, Karatsou, Mavrikios, & Chrysosolouris (2006)	To provide an efficient robust collaboration tool for the real-time validation of a manufacturing product or process, from the early stages of the conceptual design until the latest stages of the production chain	Synchronous collaboration	Document management	Yes	Java Bean Architecture, XML, JavaServer, Oracle 9i, Virtual Reality
Liapis (2008)	To assist professional product designers in remote collaboration during the early stages of the design process	Synchronous collaboration, recommender system	RSS feeds	Yes	C++, Internet/Web
Sorli and Stokic (2009)	To provide an Extended Enterprise context for collaborative product/process design in the innovation process	Recommender system, user profile	CBR and RBR	Yes	SOA approach, Internet/Web
Stankovic, Roth, and Speidel (2010)	To organize problem solvers in a social network, encouraging solving problems together, with profiles, which they can use like enhanced business cards	Crowdsourcing, user profile, recommender system	Information retrieval system, Ontologies	Yes (Hypios)	Internet/Web, OWL, RDF
Salas López, López Flores, Hernández Marín, Cortes Robles, & Alor Hernandez (2011)	To create the conditions for enabling TRIZ-based open innovation services through collaborative web services and software architecture	User profile	CBR	No	SOA approach, Internet/Web
Ramos, de Souza, Mourão, Adams, and Silva (2012)	To identify the crowdsourcing innovation brokerage facilities needed by SMEs, and to present an architecture that encourages knowledge sharing, development of community, support in mixing and matching capabilities, and management of stakeholders' risks	Crowdsourcing, user profile	Knowledge repository, Ontology	No	Internet/Web

activities (Hippel, 2005). Their business models try to make accessible the innovation process to the crowd, aided by the improvements ICTs. It is possible to study the use of ICTs to lead individual participations in the innovation process using the CI approach. For Glenn (2013) CI emerges from the synergy of three elements: (1) data/information/knowledge; (2) software/hardware; and (3) stakeholders and experts whom produce just-in-time knowledge from their contributions and feedback. Table 1 presents a summary of related works on CI. Appendix A details the review process to select the listed works in the table.

2.1. Collective Intelligence in the innovation process

The study of the intelligence emerging in groups of individuals doing things collectively is not new, but in recent years it has received special attention with the raise of Web 2.0 applications (Leimeister, 2010). The Web 2.0 or Social Web helps to unlock the potential of the CI due to its architecture centered in the user participation, while simultaneously enhances connectivity (Adebanjo & Michaelides, 2010). As a platform for collaboration, the Web 2.0 is useful for implementation different collaboration patterns (Campos, Pina, & Neves-Silva, 2006), for example:

- Temporal: Synchronous, asynchronous and multi-synchronous.
- Spatial: Locally and distributed.
- Rules: Work rules, norms and constrains.

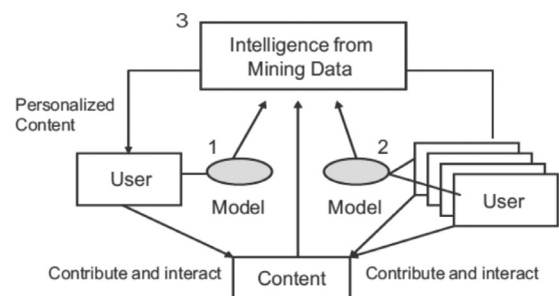


Fig. 2. Architecture for a Collective Intelligence system (Alag, 2008).

The use of the Web 2.0 technology for collaboration in innovation activities does not necessarily implicate an implementation of CI. However, the correct use of practices related to Web 2.0 applications (e.g., recommendation system, user review, user profile, tagging) increases the opportunity to harness the CI in a collaborative application (Alag, 2008; Musser & O'Reilly, 2007). As observed, the model in Fig. 2 represents the user's interactions to gather CI from a Web application. The application should aggregate the content in models, and the aggregation allows learning 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, implicit, and derived.

The cornerstone of applications that appeared after the dot-com era was the capacity to exploit the users' contributions. Nowadays, the ecosystem of participation in the Web 2.0 enables the emergence of surprising new forms of CI (Malone, Laubacher, & Dellarocas, 2009). However, according to Gruber (2008) it is premature to apply the term CI to the class of web sites that are part of the Social Web. For Gruber, the way to unlock the CI in the Social Web is through the use of Sematic Web, in order to represent knowledge and to use reasoning techniques. An integration of Semantic Web concepts and the Web 2.0 is found on Esteban-Gil, Garcia-Sanchez, Valencia-Garcia, and Fernandez-Breis (2012), where the authors propose to automatically create semantically-empowered relationships between the users based on their social interaction.

According to Pérez-Gallardo, Alor-Hernández, Cortes-Robles, and Rodríguez-González (2013), there is an interest about the use of CI in different domains. Leimeister (2010) argues that for the companies exist a new potential and areas for improving creativity, and innovation capabilities by leveraging their inherent CI. 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, the open innovation paradigm is the leading strategy adopted by companies to improve its innovation capacity (Mortara & Minshall, 2011).

Regarding to the services of crowdsourcing for implementing open innovation, they emerge as an option to access a global market of ideas. In literature the terms CI, crowdsourcing and brokering services are often used as synonyms (Feller, Finnegan, Hayes, & O'Reilly, 2012; Lytras, Damiani, & Pablos, 2008; Majchrzak & Malhotra, 2013). However, there are some minimal differences tried to be exposed here. CI is presented by Alag (2008), as a research field that groups scientists from different fields (sociology, mass behavior, and computer science); this research field looks at creating software solutions that benefits from the "network effect": they get better the more people use them (Musser & O'Reilly, 2007). Crowdsourcing is a form of service that makes use of the CI for completing a task (Yankelevich & Volkov, 2013), in this sense crowdsourcing is a mechanism to implement CI (Rouse, 2010). Finally, the broker is the technological element that makes the link between an innovation-seeker and the community that provides solutions (Nunez & Perez, 2007). Fig. 3 presents the relation between the three concepts and their place in the open innovation practice.

Considerations like the complexity in products, new paradigms in innovation management, the need for external knowledge, and the time-to-market reduction have influence in the commercial success of crowdsourcing intermediaries. It is the case of platforms like Innocentive, NineSigma and YourEncore. In Feller et al. (2012) there is an analysis about the operation of these platforms, as study parameters the authors identify three processes: knowledge mobility, innovation appropriability and dynamic stability.

Nevertheless, the operation (see Fig. 4) 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 & Malhotra, 2013).

Despite the limitation in the operation model of crowdsourcing services, different companies are using CI to solve problems (Georgi & Jung, 2012). According to Georgi and Jung (2012), the lack of systematization makes the use of CI an unpredicted process. Build on the idea, that it is possible to overcome the randomness in the problem resolution process while using the CI; this work proposes a framework to develop creativity following a systematic approach. The details are described in Section 2.2.

2.2. Creative design

The frond end of the innovation process, either in an open or close model, as it is presented in Fig. 5 comprises the most creative

activities of such process (e.g., idea generation and/or product design). The New Product Development (NPD) process from Pahl and Beitz is often presented as a closed model for innovation management (Sorli & Stokic, 2009).

The approach for the front end of innovation may differ according to the industrial practices. But in general it involves the following phases: conceptual design, detailed design and final design. The conceptual design phase (also known as preliminary design) groups the search activities of new concepts (i.e. innovative solutions), and the architectural design of the new products. According to Wang and Lee (2012), conceptual design is perhaps the most important task in product design. Nevertheless, the continual increase in complexity and high uncertainty in designing complex products forces designers to use techniques for improving their creativity. In addition, creativity has a pivotal role in the innovation process, because it helps to transform knowledge into a novel and useful solution (McAdam, 2004). Commonly, the creative phase of idea generation is chaotic, unstructured, and unsystematic. For Carayannis and Coleman (2005), the challenge is how to integrate the creativity into the innovation process and in particular in complex system design (i.e., a new product, process or service).

In Shai, Reich, and Rubin (2009), the authors point out the importance of using strategies for improving creativity in conceptual design. According to Belleval, Deniaud, and Lerch (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. Usually to solve inventive problems or generate ideas in conceptual design, engineers use traditional methods such as: concept-knowledge theory, brainstorming, and trial-error. Nevertheless, these methods have certain drawbacks: randomness, the lack of systematization and the relay on individual talent (Cortes Robles, Negny, & Le Lann, 2009). From a systematic perspective, innovation can be addressed through a controllable and creative thinking method.

To remove existing barriers in traditional methods, the Theory of Inventive Problem Solving (TRIZ) gathers a set of methods and concepts to systematize innovation. Compared to other methods, the advantage of TRIZ is that it is a heuristic based on scientific knowledge and the study of millions of patents (Savransky, 2000). The way that TRIZ drives creativity in the innovation process is via a problem resolution process. It agrees with the vision of Adamides and Karacapilidis (2006) and Hippel (2005) about the innovation process, and new product and service development, whom argue they are a continuous problem-solving process.

The main concepts in the TRIZ theory from existing literature (Altshuller & Clarke, 2005; Rantanen & Domb, 2002) are:

- **Contradictions:** Frequently, when solving problems that have contradictory requirements. Contradictions are revealed in situations like these: (1) a technical contradiction, when trying to improve a characteristic in the system, another useful characteristic gets damaged or deteriorates negatively; (2) physical contradiction, when a system needs operate at two opposite/exclusive states (A+) and (A-) for achieving performance. This kind of problems could be solved with the TRIZ tools contradiction matrix, or separation principles.
- **The substances-field (Su-Fi) analysis:** It is a modelling approach, useful to represent processes and describe physical phenomena in a system. This formalism assists and helps designers to clearly identify what transformations or changes (solutions) are necessary to improve technical systems. The model can be represented graphically with circles representing the field and the substances and some symbols that represent the relationships among the substances and the field(s). A set of strategies for problem solving called the 76 standard solutions could be applied.

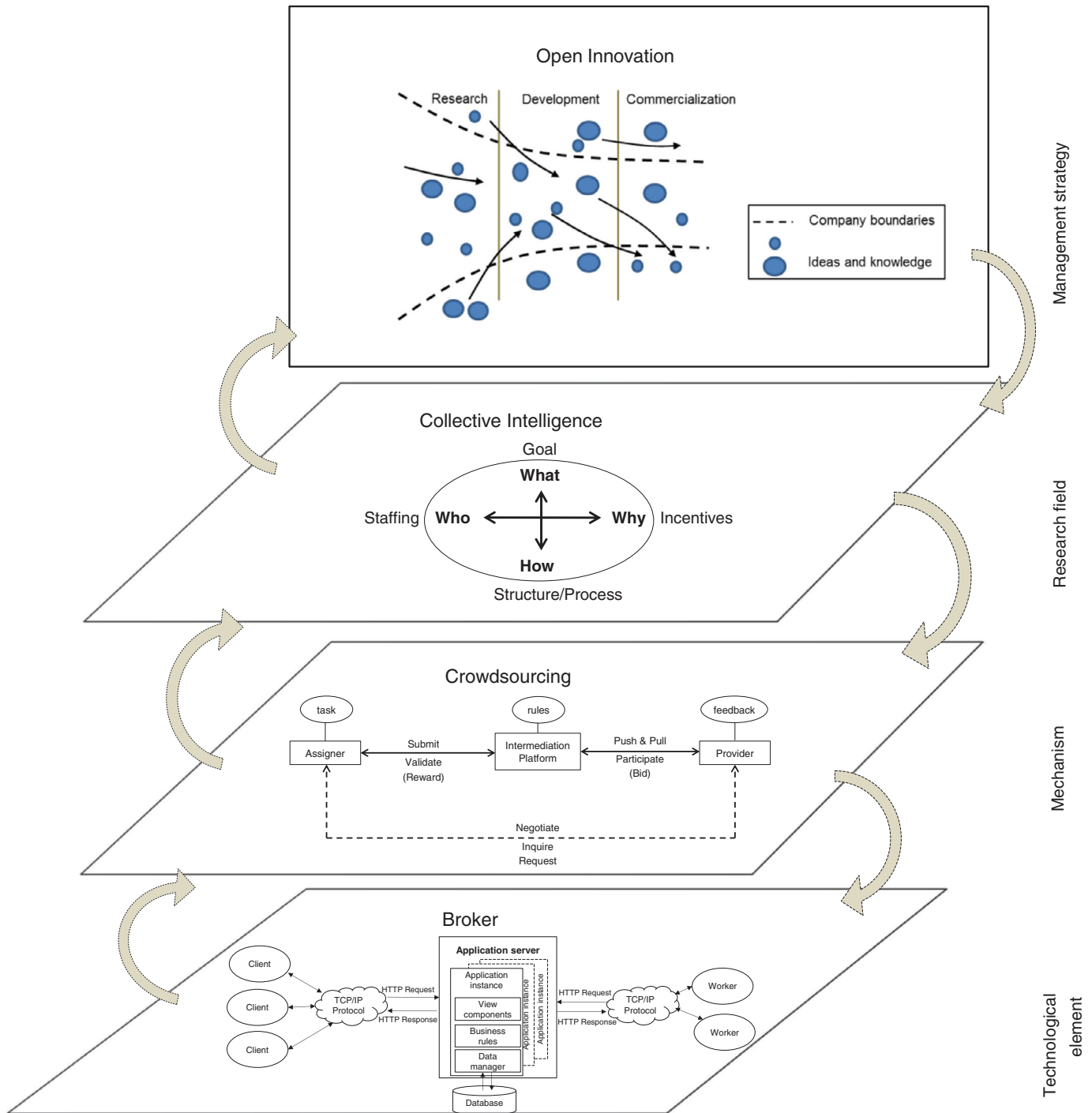


Fig. 3. Collective Intelligence implementation for open innovation.

- **Resources:** According to TRIZ, every system in evolution has available reserves that could be mobilized to improve its performance or for solving its intrinsic problems. A resource can be anything in or around the system that is not being used to its maximum potential, such as unoccupied space, information, substance properties and wastes among other elements.
- **Ideal final result:** It is a tool that has its foundation over a TRIZ capital concept: Ideality. Ideality is an evolution pattern that states that every system evolves to one direction: an increasing degree of proficiency.

Despite the multiple advantages the practitioners of TRIZ promote, the theory needs to overcome limitations and drawbacks.

Challenges associated with the practice of TRIZ are: it is difficult to learn, it needs to improve the ability to solve non-technical problems, it does not include the needs of customers in the product development processes, or there is a loss of knowledge while solving problems. Consequently, models that extend the application like TRIZ-OTSM are proposed (Cavallucci & Khomenko, 2007). Or new methods emerge integrating TRIZ with other methodologies (Yamashina, Ito, & Kawada, 2002). In other work (Cortes, 2006), the limitation of knowledge capitalization is explored proposing a model named TRIZ-CBR. A deeper review (Ilevbare et al., 2013) regarding the benefits and challenges about the acquisition and application of TRIZ, suggest to enhance communication and cooperation; this is done through: (1) better cooperation between TRIZ beginners and

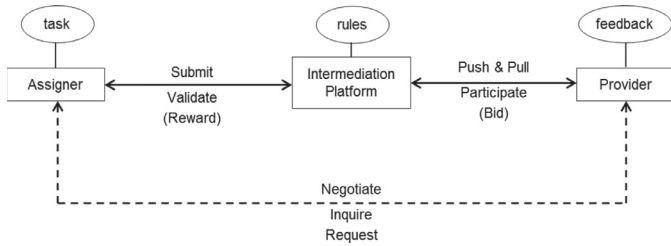


Fig. 4. Crowdsourcing operation model (Zhao & Zhu, 2012).

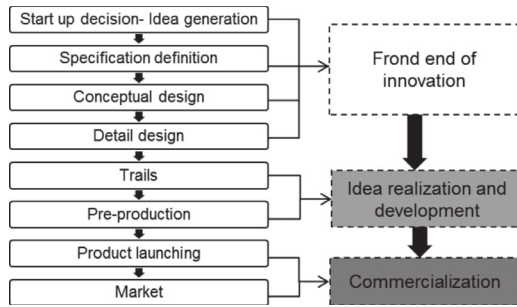


Fig. 5. Creativity in NPD process and open innovation phases.

experienced users, (2) increasing communication about the application cases and (3) more global co-operation and exchange of information. This challenge uncovers an opportunity to make the TRIZ theory available to more people (practitioners and no practitioners).

In this work, we support the hypothesis that with the use of principles found in CI systems, it is possible to develop applications in order to reduce the gap of the different practitioners in the TRIZ theory community, and even more, to make the tools available to a wider public. In addition, the use of TRIZ via a CI system could impact positively the quality of the solutions, due to the network effect (Nieto & Santamaria, 2007). It is important to highlight, that at the present there is not a report about a platform or service taking advantage of the benefits of using the TRIZ tools via a CI system. On the other hand, existing platforms for crowdsourcing innovation activities lack tools to enhance creativity. The next section introduces the elements of the framework to overcome these limitations; the development follows an Open CAI 2.0 approach.

3. Conceptual framework for inventive problem solving

3.1. Open CAI 2.0

According to Leon (2009), CAI is the research field leading the efforts throughout the last decades, to develop computer solutions in order to support the different activities in the innovation process. Based on Leon's work, it is possible to describe CAI as a discipline in Computer Aided technologies, influenced by innovation theories to develop systems using ICTs, with the objective of assisting enterprises through any stage or the entire innovation process. For Kohn and Hüsig (2006) the potential benefits of this kind of software are categorized as: enhancing efficiency, enhancing effectiveness, enhancing

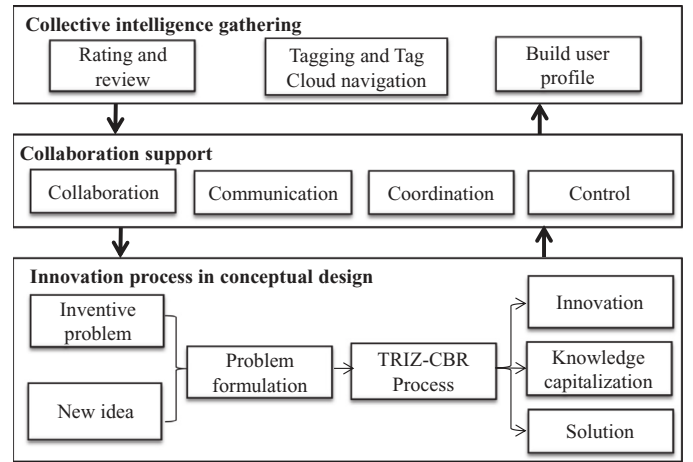


Fig. 7. Core components.

competence and enhancing creativity. Recently, two major changes are driving the evolution in CAI tools. The first one is the technological aspect based on the advantages that the Web 2.0 offers as a platform. The second one is the management strategy of the open innovation. In this scenario, Hüsig and Kohn (2011) propose the Open CAI 2.0 concept as the next evolutionary step on CAI development. The authors define it 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".

The solution discussed in this paper is a proposal following the principles of an Open CAI 2.0 tool. The main focus of our work lies in the adoption of a systematic innovation process, which integrates the capitalization of previous experiences in a collaborative environment. Gathering CI is considered in this framework, as the key element to overcome the obstacles created by the individual cognitive limits, typical of a creative activity, as it is the preliminary design.

3.2. Core components

The basic functionality of the framework could be expressed in Fig. 6. One stakeholder has an idea or a problem. He creates a project and shares it with the community members (registered users). Through an asynchronous collaboration they deploy the process presented in the TRIZ-CBR model. As a result, the users have a collective solution.

The components which make possible this functionality are presented in Fig. 7. Our framework's core is organized as follow: (1) the innovation process, which centers in assisting the participants in the process of problem resolution. It is acknowledged that problem formulation (and then its solution) ends with defining the product specifications (Shai et al., 2009). The TRIZ-CBR model offers an alternative to traditional tools and models used for this activity. In a first instance, the framework uses this model to guide the process of problem resolution; (2) the organization of activities to support the actors' collaboration, and (3) the techniques to gather CI in order to improve the innovation process.



Fig. 6. General framework use case.

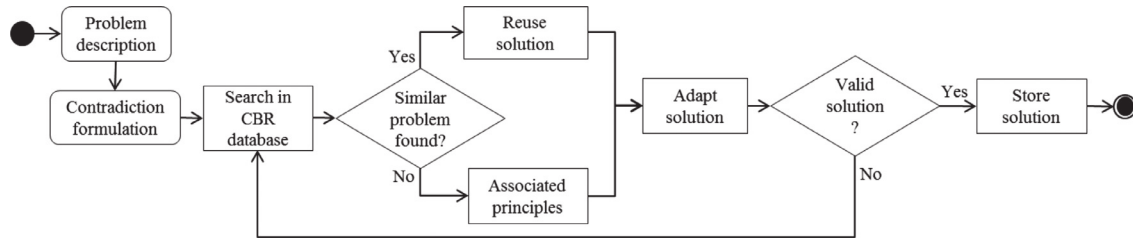


Fig. 8. Model TRIZ-CBR. Adapted from Cortes (2006).

The role of technology follows others works consideration to treat technology as enabler for virtual collaboration (Tickle, Adebajo, & Michaelides, 2011). Below are presented the details about the integration of the core components, to develop a collaborative application in order to implement CI techniques for the front-end of innovation.

3.3. Resolution process and the TRIZ-CBR model

The TRIZ-CBR model integrates the TRIZ, and the Case-Based Reasoning (CBR) in order to conceive a problem resolution process, capable to guide creativity for generating innovative solutions. The model allows at the same time the storing, indexing and reusing knowledge with the aim to accelerate the innovation process (Fig. 8).

The solving process in Fig. 8 is composed as follows: the preliminary step is to collect data and to describe the handling problem. 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 valid 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 valid solution. Finally, the new solution is incorporated in the memory in order to be re-utilized in the future. The resolution proposed in model TRIZ-CBR has demonstrated its efficiency as it is reported by Cortes Robles et al. (2008, 2009) and Negny, Belaud, Cortes Robles, Roldan Reyes, and Ferrer (2012). By using the TRIZ-CBR model we look to drive the innovation process (creativity) within a social environment of collaboration. The details about this environment are discussed in Section 3.4.

3.4. Collaboration process

Situations of collaboration in the industry seek to facilitate the participation of different actors in the activities related to reach a common objective (e.g. solving a problem, designing a new product). Fig. 9 models the activities common to all collaboration processes and independent of a specific situation (Campos et al., 2006; Sorli & Stokic, 2009)

The activities presented in the model from Campos et al., comprehend:

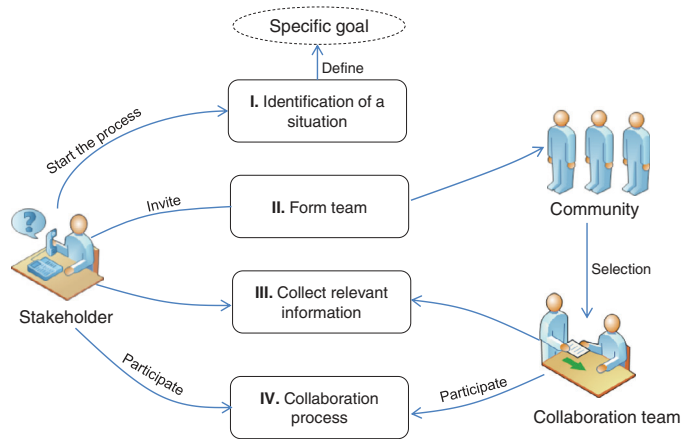


Fig. 9. Generic collaboration model. Adapted from Campos et al. (2006).

- (I) Identification of 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) Form team. The starting actor invites the members of a community to form the collaboration team. For a better result, a recommendation services can find an optimal team composition. The actors involved have the role of collaborators.
- (III) Collect relevant information. The participants provide the necessary information for the situation, by gathering knowledge from different sources, processing and analyzing it.
- (IV) Collaboration process. According to the nature of the situation different tools and collaboration patterns will be necessary. It is required to make register of all contributions in order to trace the collaboration process.

In this work, we adapt the collaboration activities to the TRIZ-CBR process in order to propose a collaborative resolution process based on a systematic approach. The operation of the collaborative resolution process is introduced in Fig. 10. The rationale of the collaborative resolution process consists of orienting the interactions of the involved participants in such process with a common language to communicate the problem formulation (Ilevbare et al., 2013), specifically the logic approach of TRIZ methodology (Fig. 11).

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

- (1) Following the generic collaboration model specification, the first activity—identification of a situation—corresponds to the description of the problematic situation.
- (2) The stakeholder invites other participants, it is highly recommended to have at least the participation of one TRIZ practitioner.
- (3) Collect relevant information helps to provide details to make clear the problematic situation.
- (4) The collaboration process uses an asynchronous pattern to coordinate the participations in order to ensure information

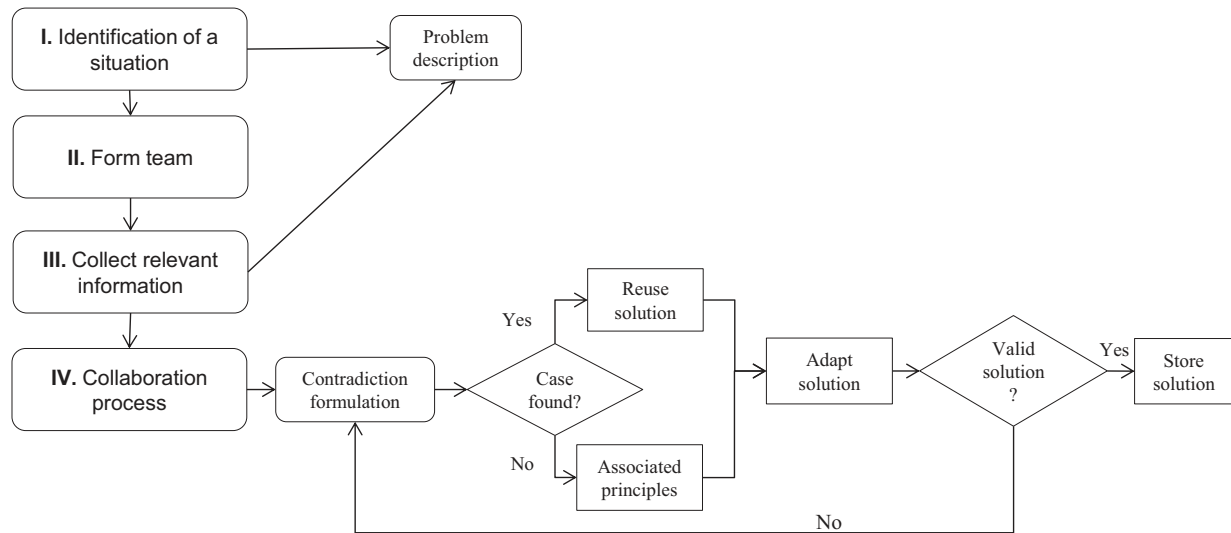


Fig. 10. Collaborative resolution process.

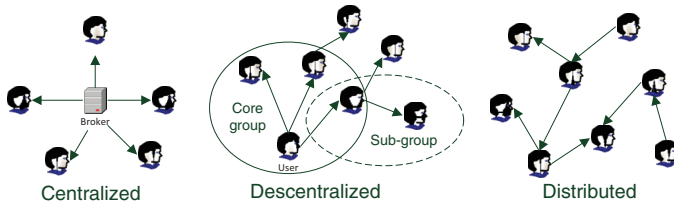


Fig. 11. Collaboration organisation (Nguyen et al., 2012).

integrity. In this phase, it is the TRIZ-CBR model which drives the collaboration activities.

Regarding the technology to implement the collaboration functionality, this work follows the Open CAI 2.0 proposition about the use of Web 2.0 technologies, because they provide the network services to join, create social links, search for specific user, and share content in a virtual community (Wilson, Boe, Sala, Puttaswamy, & Zhao, 2009). In addition, for Caseau (2011) social network services are an emerging way of organizing collaboration in the industry, leading to what is known as the Enterprise 2.0. Other advantage for using social networks is the phenomenon known as “the network effect” (Esteban-Gil et al., 2012): the more users participate in a network, the more are the benefits they get from it. For coordinating collaboration among users in a social network, Nguyen, Duong, and Kang (2012) present three architectures: centralized, distributed and decentralized.

- Centralized. There is a central unit that controls participations and information flow. The platforms Innocentive and NineSigma could be classified in this category.
- Decentralized. This organization divides the task and assigns them to smaller groups.
- Distributed. This model has no center. All the participants are linked in the bases of equality, independence and cooperation. The social networks (i.e. Facebook, Twitter) are well known examples.

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

3.5. Collecting intelligence from user-generated content

The expansion of Web 2.0 technologies leads to new services in the form of social platforms. The justification to base this solution on the use of Web technologies is their recent incorporation in the industry, and a number of facilities they provide such as sharing information, communication tools and the collaboration among users, often distributed geographically and in time. In this development, we consider the recommendations from Alag (2008) to integrate CI in a Web application as presented in Fig. 12. These elements are:

- Facilitate user participation and user collaboration.
- Gather important knowledge in easy-to-share models.
- Use those models to provide the user with useful content

In order to implement the CI mechanisms the following main features are included:

- Being based on the Social Web to deploy a space for user participation, and promoting weak links among participants. This social platform allows the users the freedom to create, share and collaborate in the generation of content associated to technical problems and their solutions.
- Exploring the use of Semantic Web technologies as a powerful mechanism for (CI) knowledge representation (Cimiano, 2006).
- Enabling community participants to interact with information of interest according to a profile (problem profile and user profile).
- The incorporation of a knowledge database to support the systematic resolution process.

While creating the project, the owner is able to add free-tags as a part of the CI strategy. This strategy has for objective to create a classification system of type folksonomy about the project (Weller, 2007). Then, the system is capable to provide certain recommendations applying CI. In first instance the system deploys a mechanism to provide a list with possible collaborators in relation with the problem folksonomy. Once the project has collaborators, they could enrich the project folksonomy with newer tags. Next, the platform learns more about the user through a profile creation. Inspired in Stankovic (2012) two kinds of profiles are created: conceptual profile and social profile. Conceptual profile is created with explicit information the users provide as part of their accounts, but also, by collecting implicit information from the users' interaction—this includes information such as the projects the user has created, and the participations in other projects. The social profile comes from the interaction the user establishes with other users through the collaborations.

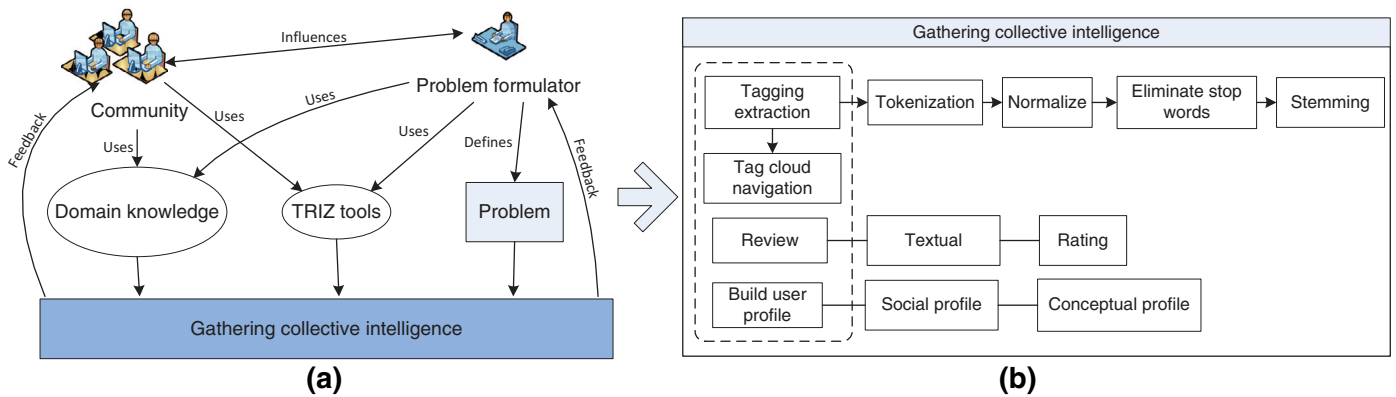


Fig. 12. Architecture of participation for gathering Collective Intelligence.

The requirements for supporting the task to gather CI are divided into two types according to Alag (2008):

- Explicit intelligence. The user provides this kind of intelligence in the application in a declarative way. The user provides this intelligence in the form of reviews, tags or by using a particular tool from the TRIZ toolkit (i.e. defining a contradiction).
- Derived intelligence. The framework using automated algorithms infers this intelligence. In order to deal with derived intelligence the platform implements mechanisms for dealing and indexing unstructured content, and then performing intelligent search in order to recommend relevant content to the users. The Linked Open Data is a rich source of information the users can access to enrich a solution.

3.6. Human-machine interaction

The emergence social networks services has changed the way people interact through virtual spaces. 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 development of systems for collaboration teams should allow information exchange through a friendly and easy to use 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. The first view of the system is proposed as it is in Fig. 13, where several sections including the elements and tools to promote collaboration and communication construct the initial interface. The hierarchy of all the elements was determined to provide the structure needed by the users to understand the system functionality in an organized environment. This system design allows the user to access all content in the first page of the system and also presents all the components arranged by its nature. The sections are:

- My projects: Space with the option to create, edit or modify the projects that include the problems that need to be solved.
- Collaborations: Space where the user accesses the projects where he/she was invited to collaborate.
- Latest updates: Space including updates on collaborations or in projects created by the user.
- Information exchange components: These components 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. The components that compose this section are the statistics and the chat.
- Workspace: Space where the user accesses to all the information related with a project and the resolution process. It includes a

marker of progress and color indicators of the current section the user is working in.

- Components to reduce communication errors: These components that allow users to make contributions in all the phases of the resolution process. The components interacting in this section are the tags and comments.

Fig. 13 corresponds to a real software implementation based on the proposed framework. This is a first version of the prototype, which is designed for an incremental development.

4. Discovering the use of the framework

4.1. The case of rapid prototyping in manufacturing

In order to validate the reasonableness of the proposed Open CAI 2.0 tool, we briefly describe how this approach can be used in a specific technical problem. Rapid prototyping is a technology for generating physical objects from graphical computer models (Jacobs, 1992). According to Jacobs the technology is used for engineering prototype and manufacturing applications. In product development, prototyping is an essential part because it allows to assessing the form, fit and functionality of a design before production (Pham & Gault, 1998). Technologies for rapid prototyping include adding materials and removing materials methods. Plastic foam cutting is a removing material technology capable of producing large plastic foam objects directly from a CAD model (Brooks & Aitchison, 2010). According to Brooks and Aitchison, the incorporation of polystyrene in rapid prototyping has different uses such as: conceptual design of commercial products, automotive design, aerodynamic and hydrodynamic testing, among others. Rapid Heat Ablation (RHA) is presented (Kim, Lee, & Yang, 2007) as a method to improve the cutting mechanism, and to solve the problems of excessive cutting time and leftover material by developing a new material removal method. The objective is to reduce the heat-affected zone, thus with the support of TRIZ for guiding the conceptual design Kim et al. formulated the problem as a physical contradiction. The solution proposed by Kim et al. is applying the principle of separation in space (see Fig. 14). The result is a tool that has tangential grooves on the side of the tool separated into two regions for minimization of the heat-affected zone.

The case we treat involves a new conceptual design for the tool proposed by Kim et al. The application of the Open CAI 2.0 proposed in this work is to reformulating the problematic and developing a different solution in the design of the RHA tool.

4.2. The use-case scenario

Members located in three different countries conducted the first experimentations within the framework: France, Mexico and

The screenshot shows the itSolveR web application interface. At the top, there's a navigation bar with links: HOME, OPEN INNOVATION, PROFILE, ABOUT TRIZ, and YOUR OPINION. Below this is a 'COLLABORATION' section with buttons for 'Accept', 'Reject', and 'Collaborate'. The main content area is divided into tabs: 'General', 'Resolution process', and 'Assistant'. The 'General' tab is active, showing 'Project information', 'Problem Description', 'Images and media', and 'Comments'. The project name is 'A rapid heat ablation process'. The project description states: 'This project treats about rapid prototyping and manufacturing (RPM) technologies. One of fundamental disadvantage in RPM is the unsatisfactory cutting mechanisms, such as excessive cutting time and leftover material caused by cutting mechanisms. The rapid heat ablation (RHA) process is developed as a new rapid manufacturing process using the heated tool, it incorporates a new material removal method. Nevertheless, the RHA has some drawbacks which are addressed in this project.' The estimated release date is 'Mar 24, 2015'. The collaborators listed are 'jbarragan', 'alfores', and 'snegny'. The tags are 'ablation', 'prototyping', and 'manufacturing'. On the left, there's an 'UPDATES' section showing the latest updates: 'description: Project edited 2015-05-28 10:07:46.0' and 'User: rene lopez Project: Conceptual design for a fluidized bed gasifier Description: Project edited 2015-05-28 10:03:22.0'. At the bottom right, there are 'Save' and 'Cancel' buttons.

Fig. 13. Overview of graphical user interface.

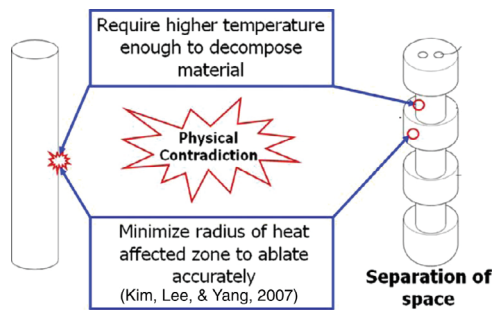


Fig. 14. Separation in space principle.

Table 2
Participants profile.

Function	TRIZ practitioner	Number
Associate professor	Yes	2
Mechanical engineer	Yes	1
Computer science engineer	No	1

Lithuania. They were selected taking into account to have participants located in different geographical locations, and with different cultures. No specific role was imposed to each participant, and their participation was at different levels of engagement. The profiles of each participant are presented in Table 2. Because of the initial operation of the framework, the profiles are still under creation. Profiles are completed as the users interact within the framework.

During the collaboration process for solving the problem in design of the RHA tool, the framework operates according to the functionality exposed in Section 3. The process starts with the creation of the project in the platform. Once the project is created, the project creator (i.e. stakeholder) describes the problematic situation. The framework

includes forms and dialogs to guide the participants in order to properly describe the problem by using free-text formularies. Participants have access to the three main options to modify the project (General aspects, Resolution process and Assistant). The information and details aims to communicate the essence of the problem. The incorporation of free-text dialogs in the framework deals with the means of humans communicates on the Web. The use of natural language, and particularly text based communication is widely widespread in most of the available Web applications (Cimiano, 2006).

The emergence of the CI starts when the project owner identifies the collaborators and shares with them the project resource. The collaborators had access to make contributions in the different options of the resolution process. Regarding the problem formulation, we include the option to define contradictions (technical and physical). The framework allows to make more than one formulation of the problem in order to reflect the different opinions. In our example, the participants formulated six different contradictions. In the list of contradictions, there is a column with a sequential generated name, the name of the author and the options to edit or remove a defined problem. In addition the list includes a voting system to explicitly promote the most appropriate problem formulation. One advantage of the voting system is the relative facility to resolve conflicts when there is more than one opinion about the problem.

Contrary to Kim et al. (2007) where the authors based their solution in the formulation of a physical contradiction, in this example we formulated the problem as a technical contradiction. The contradiction formulated to propose the solution is composed by the positive characteristic Temperature and the negative characteristic object-affected harmful effects. The TRIZ principles associated with the contradiction are:

- Tacking out/extraction
- Local quality/local capacity

- Dynamics
- Periodic action

The next step is to look for similar case in the CBR database. However, as the framework is beginning its operation, there are not enough cases to make the search. In fact, one drawback in the CBR systems is the initialization of the knowledge database, but as the TRIZ-CBR model claims, it is possible to propose a solution using the TRIZ principles when there is not a similar case. Thus, the envisaged solution in our example uses the dynamics principle. Up to now there is not a formal mechanism in the framework to take the decision to use either an existing solution when there is a similar case in the knowledge database or to use a particular solution principle. The consensus about which principle to use is done using an option to make comments in the project. In fact, the comments option is a communication tool between the participants that has been helpful through the entire resolution process. According with the TRIZ theory, the dynamics principle is about to change parameters in time. The conceptual solution proposed for the RHA tool is following the sub-principle: If an object is fixed, make it have free motion. The adaptation of this principle is described as: The tool in the axis is fixed. Thus, we propose to make it dynamic (as a drill). The solution requires a detailed design, but the objective of the conceptual solution is that the hot tool turns in its axis to increase its efficiency.

For the last phase of Implementation, the framework proposes the options to select the solution proposal that results from the community consensus. Also, it includes the options to document the best possible solution details. The process ends when the user confirms the solution, with this action the framework stores a new case in the database that will be available in future searches.

The Assistant option is conceived to help the participants in the resolution process. It is focus in two main functionalities: discover helpful content on Linked Open Data repositories and providing a list of possible collaborators. It is worth to mention that this is an option currently under development; nevertheless some preliminary results are available. For example there is an option to extract relevant concepts from the textual description of the problem situation by using Natural Language Processing (NLP). The pending development is to use these keywords, as part of the problem characterization to gather on LOD sources and enhance the resolution process with useful information. The other envisaged functionality is to use the problem characterization, to search into patents databases to provide a list of possible collaborators. A patent citation study through social network analysis is proposed in order to get a list of inventors and their relationships. This remains as part of future work and perspectives.

5. Discussion and perspectives

5.1. Discussion

Given the importance of the incorporation of collaboration patterns in industrial activities, this work analyses the implication of the concept Open CAI 2.0 to foster open innovation activities. Specifically, the paper examines the incorporation of a logical approach to drive the creative generation of solutions during the inbound process of the front-end of innovation. The preliminary results 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 & Malhotra, 2013).

- For Majchrzak and Malhotra (2013), existing crowdsourcing services lack of collaborative mechanism among participants to construct a common solution is limited.
- 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 CI.
- 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 framework is planned to be used in academic context in order to spread the interest in the methodology.

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, Lüthje, & Haag, 2011).
- The success of collaborative innovation is mainly determined by the selection of appropriated participants (Geum, Lee, Yoon, & Park, 2013).
- For Martínez-Torres (2013), the huge amount of information generated by users, makes difficult the identification of applicable ideas.
- Reliance on the emotional states and motivation of participants.
- Difficulties to attract skilled people (Stankovic, Rowe, & Laublet, 2012).

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 paper 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 CI expose the possibilities to improve participant's creativity in the phase of conceptual design. The CI provides a way to expose knowledge that is otherwise hidden in a collective environment, for example, bubbling up interesting content or dynamic content classification.

5.2. Perspectives

Although the contradiction matrix is an important tool, 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). In relation to the work in progress, we intend to develop missing functionality about CI. However, it is possible to present some of the characteristics expected. Firstly, incorporate tag clouds. This component helps the user to make a rapid search using the tags concepts generated manually by the users or the process for tags extraction. Secondly, provide review functionality: the reviews are useful to quantify the quality of the content generated by the users. In the platform the reviews are focused on problem solutions, and they could be of two types: textual and rating. Both kinds allow the users to provide an instant feedback about the solution's relevance. The rating option has an advantage over the textual review because the information provided is quantifiable and used directly. Thirdly, complete the Assistant tool with the options to discover information in LOD related to the problem based on its

Table A1
Reviewed journals.

Journal	Database	Coverage
Technovation	ScienceDirect	1990–2014
Computers in Industry	ScienceDirect	1990–2014
Journal of Engineering Design	Taylor & Francis	1990–2014
Computer-Aided Design	ScienceDirect	1990–2014
Expert Systems with Applications	ScienceDirect	1990–2014
International Journal of Computer Integrated Manufacturing	Taylor & Francis	1990–2014
Advances in Intelligent Systems and Computing.	Springer	1990–2014
Conferences Proceedings	ACM Digital Library	1990–2014
Lectures Notes in Computer Science	Springer	1990–2014

characterization. In addition, other functionality envisaged is discovering collaborators after a social network analysis in patent citation. And lastly, create a user profile: the importance to build a user profile is because it allows the framework to provide more relevant and personalized information. Our framework proposes to generate the profile base on the content user generates and the social interactions. The use of TRIZ tools and domain knowledge via tag extraction are the base to build a profile of concepts. The collaboration between the user and the community is the base to build the social profile. For example, Stankovic et al. (2012) propose to use the social profile to find possible collaborators for a particular project in a recommendation system. 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 no-technical fields.

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Appendix A. Literature review process

Searching for literature of related works about the use of CI in innovation activities was a challenging process. Among the difficulties found are: the use of related terms is not homogeneous (e.g., Collective Intelligence, the wisdom of the crowds), the different models for the innovation process, and the lack of a specialized journal. To ensure that the literature review covers relevant works, the literature review was driven by a concept-centric search.

The keywords used in the search include: 'collective intelligence', 'crowdsourcing, wisdom of the crowds', 'problem resolution', 'conceptual design', 'TRIZ', 'creativity', 'systematic innovation', 'innovation broker' and 'innovation'. The review was performed using journals from the following databases: ScienceDirect, Springer, Taylor & Francis, and ACM Digital Library. And the period covered was from 1990 to 2014. The criteria to select the articles were the relationship with the subject, impact factor, and the citations to the articles. The list of reviewed journals is included in Table A1.

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