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Information technology for supporting the development and maintenance of open innovation capabilities

Emmanuel Adamides, Nikos Karacapilidis *

Industrial Management and Information Systems Lab, MEAD, University of Patras, Greece

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ABSTRACT

We discuss ICT for Open Innovation (OI) from a capabilities perspective. We distinguish two types of capabilities for OI: *strategic*, which need to be developed so that the organization can take advantage of an OI strategy proactively, and *operational* for the efficient implementation of OI processes. ICT at the strategic level supports dynamic capabilities and related cognitive processes of managerial staff for developing and using the appropriate level of absorptive capacity and active transparency, whereas ICT as part of operational capabilities aims at enhancing the day-to-day performance of OI activities. Through analysis of capabilities, we associate specific ICT with the functionalities required in the entire OI process. Paying particular attention to the issues of collaboration and sophisticated data analysis, we also comment on the seamless integration of these technologies and their embedment in OI-related organizational processes.

Introduction

Undoubtedly, Open Innovation (OI) has become an established paradigm in innovation strategy. According to its main proponent, it is "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the market for external use of innovation, respectively" (Chesbrough, 2006). The adoption of OI by an organization implies that its innovation management process (Tidd & Bessant, 2014) becomes porous, and ideas, concepts, designs, products, services, etc., flow in and out of its boundaries. At the same time, internal and external organization actors, such as managers, users/customers, employees, suppliers, competitors, researchers and regulators are interconnected in many different ways. In fact, it is the different human and non-human knowledge sources that are interconnected, while informational and knowledge items of different forms flow between them and are transformed in many different ways. Clearly, in large complex organizations, this is accomplished in a complex web of social processes (Anderson & Hardwick, 2017), in which participate agents of different views, interests, cultures and power status (Mota Pedrosa, Välling, & Boyd, 2013), usually situated geographically and contextually at a distance.

It has been argued that organizations aiming at an OI strategy must be able to manage these relationships, processes and agencies effectively, in order to gain from their diversity (Sarker, Sarker, Sahaym, & Bjørn-Andersen, 2012). In other words, they need to develop a set of capabilities for making their interface to the external environment more transparent, as well as to be able to absorb and assimilate knowledge from different sources in an efficient and effective manner, in addition to disseminating knowledge-containing artefacts of value to their external environment (Hosseini, Kees, Manderscheid, Röglinger, & Rosemann, 2017). These capabilities are based on, as well as contribute to the development of, an organisation's *absorptive* (*and desorptive*) *capacity* that leverages its knowledge management operational processes, so that knowledge from the right source(s) arrives at the right time, in the most effective manner.

This suggests that, in order to embrace OI, an organization should develop capabilities at two levels: (i) at the *strategic level* (dynamic capabilities), by preparing its members so that they are able to absorb, utilize and transform *the right* external and internal knowledge into value to be disseminated to the economy through the development of the appropriate operational capabilities and (ii) at the *operational level*, for connecting knowledge sources, as well as for supporting the transfer and transformation of the required knowledge *right*. Given the complexity of these tasks (Sanchez, Heene, & Thomas, 1996), in the context of pluralistic and distributed modern organizations, information and communication technologies (ICT) have a very important role to play in the development, maintenance and appropriation of these capabilities (Majchrzak & Malhotra, 2013).

The use of ICT in OI implementations has been studied from different perspectives (e.g. Bengtsson & Ryzhkova, 2013; Bugshan,

* Corresponding author.
E-mail addresses: karacap@upatras.gr (N. Karacapilidis).

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2015; Corvello, Gitto, Carlsson, & Migliarese, 2013; Cui, Ye, Teo, & Li, 2015; Dodgson, Gann, & Salter, 2006; Hrastinski, Kviselius, Ozan, & Edenius, 2010), and a number of OI platforms are now available (Bieler, 2016). Nevertheless, so far, research has not considered the importance and structure of ICT infrastructure for OI operational capabilities in a *holistic* manner: the majority of these efforts asymmetrically concern predominately the front-end of the innovation process, i.e. concentrate on the interaction/interfacing of the organisation with external parties, and pay little attention to knowledge integration and (re)generation (Malhotra & Majchrzak, 2016). They consider individual front-end OI processes, mainly from a *functional simplification* perspective, i.e. how to *reduce the complexity* of real processes by imposing structure (ordered procedural sequences), to *seal off processes* from their messy and ambiguous environment, and to make them "*transferable*" by detaching them from their social context (Kallinikos, 2011). This fragmented and stylised focus to individual OI processes and stakeholders (Corvello et al., 2013) is desirable only when the objective is to develop static strategies of (knowledge) depth/intensity, as far as external knowledge management is concerned (Cui et al., 2015), through integration of an organisation's information systems with specific external knowledge sources (Barua, Konana, Whinston, & Yin, 2004; Rai & Tang, 2010). Limited research has addressed the role of ICT in the development and maintenance of the dynamic capabilities required for the deployment of more dynamic OI strategies (Cui et al., 2015).

A holistic consideration of ICT for open innovation can be facilitated by adopting a capability-based perspective. ICT artefacts of various forms are assets engaged in capability-defining knowledge and social processes/routines at different levels and modes. For instance, there are a number of ICT tools that can be used on the side of actual OI operational processes to develop and exploit organizational absorptive (and desorptive) capacity in a cooperative manner for enhancing OI-related dynamic capabilities (in the rest of the paper, without loss of generality, we use the term absorptive capacity to include the intangible asset of desorptive capacity). These, together with a bouquet of ICT technologies for supporting operational level capabilities, can provide the basis of a technology infrastructure for OI. Towards this end, in this paper, by adopting an *inbound OI perspective* (Gassmann & Enkel, 2004), and by juxtaposing OI capabilities' requirements with basic information system functionalities and associated technology and systems characteristics, we discuss, for the entire OI process, the association of knowledge management capabilities to ICTs as they are moderated by specific OI models/strategies. The aim is to facilitated management decisions on the employment of technology for Open Innovation strategies. The research and discussion are based on secondary sources, as well as on the findings and the experience from the development and use of related collaborative and knowledge-management information systems in the framework of a set of private and public, national and multi-national projects. The paper also discusses technologies for the seamless integration of the abovementioned ICTs and their embedment in the organizational processes, paying particular attention to the issues of collaboration and sophisticated data analysis.

Open Innovation, organisational capabilities and ICT requirements

Strategic capabilities for OI

In the resource-based view (RBV) of strategy, competitive advantage is a function of the availability of certain resources and capabilities (Grant, 1997). Capabilities are constituted by assets/resources, such as ICT artefacts, and routines/processes for deploying these assets (Amit & Schoemaker, 1993). In a generic capabilities perspective, strategic level capabilities for OI are linked to the notion of dynamic capabilities (Teece, Peteraf, & Leih, 2016), i.e. to the ability to select or change operational/ordinary capabilities and switch strategies between breadth (diversity) and depth (intensity) in the effective use of knowledge sources (Laursen & Salter, 2006). More specifically, they are linked to an organization's ability to innovate through the appropriation of the right knowledge by *sensing* the environment, *seizing* opportunities and *transforming* its innovation process(es) and value offerings. Sensing is associated with exploration, whereas seizing with both exploitation of the internalized environmental signals, ideas, concepts, technologies, etc., as well as with the exploration of the external environment for gaining economic value from the innovative products and/or services developed through transforming activities. In the inbound open innovation approach, all these activities will have a certain degree of openness too (Tavakoli, Schlagwein, & Schoder, 2017), while their effectiveness will depend on the level of absorptive capacity (ACAP) of the organization (Cohen & Levinthal, 1990), as well as on its level of "*active transparency*", which may be defined as a form of "generative sensing" (Cui et al., 2015; Dong, Garbuio, & Lovallo, 2016).

Active transparency allows an organisation to control proactively and effectively its interface with the external environment, as far as knowledge inflows and outflows are concerned. Both the active transparency and ACAP of an organisation depend on the corresponding qualities of its individual members. Active transparency refers to an active organisational interface that has the ability to develop hypotheses on the possible use and effects of incoming and outgoing knowledge items, and to test them for their validity (Dong et al., 2016). ACAP determines an organization's capability to recognize the value of new external information, assimilate it, and apply it to commercial ends (Cohen & Levinthal, 1990). Recent research directly associates absorptive capacity to the dynamic capabilities framework and stresses its importance as a degrees-of-freedom provider towards innovation and change (Teece et al., 2016; Zahra & George, 2002). Absorptive capacity is a function of the richness/diversity of the pre-existing knowledge structure, personalized (tacit) and impersonalized (codified). Hence, although some authors consider ACAP as dynamic capability (e.g. Lichtenthaler & Lichtenthaler, 2009), in our view it more appropriate for OI, and closer to the actual definition of capabilities, to consider it as an intangible accumulating and depleting strategic asset employed/used in organisational processes/routines.

Understanding dynamic capabilities requires understanding their microfoundations (Dong et al., 2016; Helfat & Martin, 2015). At that level, the importance of the diversity of prior knowledge in learning (Cohen & Levinthal, 1990) can be better understood by considering two key attributes of mental models that are directly related to absorptive capacity: *complexity* and *centrality* (Nadkarni & Narayanan, 2005). Complexity is the result of the degree of differentiation (the range/diversity of internal and external organizational concepts included in the mental model) and integration (degree of connectedness among concepts) of the model. Complex change- and innovation-related mental models allow firms to notice and respond to a larger number of different stimuli, thus increasing their innovation capacity. They allow managers to scan the environment and respond to incoming stimuli more effectively by associating environmental events with elements of the existing organizational knowledge base. Centrality, on the other hand, refers to the focus and hierarchy of mental models. A centralized model is focused around a limited number of core concepts. As a result, it is complex mental models that are responsible for increased absorptive capacity and active transparency, making the organization more responsive to external signals, and better positioned as far as exploitation of the benefits of OI are concerned (Doz, 2013).

Knowledge creation is largely associated with interaction and socialisation (Nonaka & Takeuchi, 1995). So, a knowledge management strategy for OI that aims at the efficient and effective creation of knowledge from different intra- and inter-organizational sources, as well as at augmenting learning capacity, should be primarily targeted on the use of ICT for the development of social capital, rather than on the installation of technology systems for the storage, transformation and distribution of codified knowledge (Lichtenthaler & Lichtenthaler, 2009). Towards this objective, three main areas of intervention are of particular importance: (i) intervening on the way mental model characteristics influence the accumulation of learning capacity, (ii) improving managerial participation in the development of innovation strategies and in the deployment of required operational processes, and (iii) improving the processes, methods and tools for assessing the future environment. In other words, the objective of open innovation and flexible learning as strategic capability suggests a *personalization* rather than a *codification* knowledge management *meta*-strategy (Scheepers, Venkitachalam, & Gibbs, 2004), paying particular attention to identifying *learning* gaps, rather than *knowledge* ones. Information and communication technology has an important role to play in this strategic choice. There is a wide range of technologies that can be used for augmenting learning processes and building ACAP and active transparency. In "Technologies for strategic OI capabilities" section, we discuss these technologies in the context of their use for developing and supporting dynamic capabilities for OI.

Operational capabilities for OI

In addition to the strategic (dynamic) OI capabilities that are associated with the development of an infrastructure for augmenting organisational learning, the development of operational level capabilities is necessary so that OI processes are supported appropriately in terms of efficiency and effectiveness (Chen, Wang, Nevo, Benitez-Amado, & Kou, 2015). The structure of OI processes depends on the model of OI adopted. In general, there are four operations models associated with the inbound OI approach (Möslein, 2013). In *innovation markets*, organizations and individuals act as *seekers* of innovation solutions and *solvers* of innovation problems. This model is usually implemented through intermediaries that facilitate the matching of problems to solutions. In the model of firm-sponsored *innovation communities* agents of different size and complexity develop ideas, discuss concepts and promote innovation. Crowdsourcing is a particular strategy in the framework of this model. In *innovation contests*, a firm gets ideas for products, services, solution, or even business models from different sources (customers, suppliers, etc.) which are also involved, in association with panels of experts, in their evaluation and selection. When *innovation toolkits* are used, users develop solutions in prescribed steps, sometimes using standard components and modules in a predefined solution space, and interacting with the company to get feedback. The former two approaches are based on a dyadic (1:1), whereas the latter two in a network collaboration model (1:n/n:n). Innovation markets and the related *social product development forums*, as well as the *ideas contests*, provide solution spaces with a high number of degrees of freedom, whereas innovation and co-design toolkits and innovation communities, through predefined procedures, restrict the solution space and processes (Piller & Ihl, 2013).

Regarding the capabilities required to support open innovation, after reviewing related literature and distilling its aggregate formulations (e.g. in Hosseini et al., 2017 and Lichtenthaler & Lichtenthaler, 2009), we can conclude that, in addition to *collaboration* (COLB), the most important capabilities for the implementation of OI are: *knowledge exploration* (KXPL), *knowledge exploitation* (KXPT), *knowledge retention* (KRTN), *decision making* (DMKG), *partner relationship management* (PREM), *social integration* (SINT), and *intellectual property management* (IPMA). Clearly, the importance of these capabilities varies across the spectrum of the above models of OI, especially as far as the upstream stages of the innovation process are concerned. A coarse-grain innovation process consists of the sequence of activities: idea generation, selection and conceptualization of product/service/process, technical development, product/service launch, and (possibly) improvement of the concept (Tidd & Bessant, 2014).

Knowledge exploration (KXPL) is a capability needed in all models of OI for the idea generation phase to support the sourcing, internally and externally, of as many as possible and diverse ideas for products, concepts, etc. KXPL may concern the experience available in the organisation, experimentation carried out with concepts and ideas in the organisation, or the acquisition of external knowledge (Tidd & Bessant, 2014). It is directly linked to absorptive capacity, and if there is not available at a sufficient level, intermediaries can act as compensators. In addition, in the innovation community model, in the same phase, social integration (SINT) capability (capability to facilitate interaction and coordinate individuals building relations with external entities, such as universities and research institutes, or projects and project managers in other organisations) is required to strengthen relationships in the community and to develop social capital (trust and quality communications) and common understanding. Moreover, in the innovation toolkits model that offers a more restrictive and structured interaction process, closer relationships with external agencies require higher partner relationship management (PREM) capability (capability to identify, assess and select the right partners, as well as to motivate them so that they contribute to innovation).

In the same model, PREM is necessary for the selection and conceptualization phase, as external partners are actively engaged. In all OI models, this phase requires a certain level of knowledge exploitation capability (KXPT) to combine external knowledge with existing internal one, motivate internal sources to contribute, make tacit knowledge explicit and commercialize it through products and services. It also requires decision making capability (DMKG) for constructing and managing a portfolio of projects (principally investment and resource allocation decisions) for the selected ideas/concepts and for making decisions on issues related to Intellectual Property Rights. DMKG and KXPT capabilities are necessary for the technical development stage too. In addition, organizations have to have effective mechanisms for maintaining their knowledge (knowledge retention capability (KRTN)) that is produced during the technical development of the concept/product to be used in consecutive projects to shorten the developing time and the time to market (market launch phase). Knowledge retention is also achieved, indirectly, by retaining relationships with important partners-holders of knowledge. To have an effective market launch phase with timely product/service introductions, use of previous knowledge is necessary (KXPT), as well as effective partner management (PREM). Before, or at the same time, activities for the management of intellectual property must be undertaken by deciding what to disclose and what not (need for intellectual property management capability, IPMA). IPMA capability is required in most innovation process stages to assess IP held in the organisation, to identify IP needed and possibly held by partners, to value IP exposed to other parties (important in innovation communities model) and to search for IP for sourcing.

Operational capabilities are reified in organizational processes that use specific assets. For instance, the knowledge exploration capability is typically reified in a "knowledge seeking and finding" organisational processes. In fact, all the aforementioned capabilities are associated with processes that are dominated by activities of collaborative *interaction* (between information sources) and *transformation/processing* (of data/information items). In the

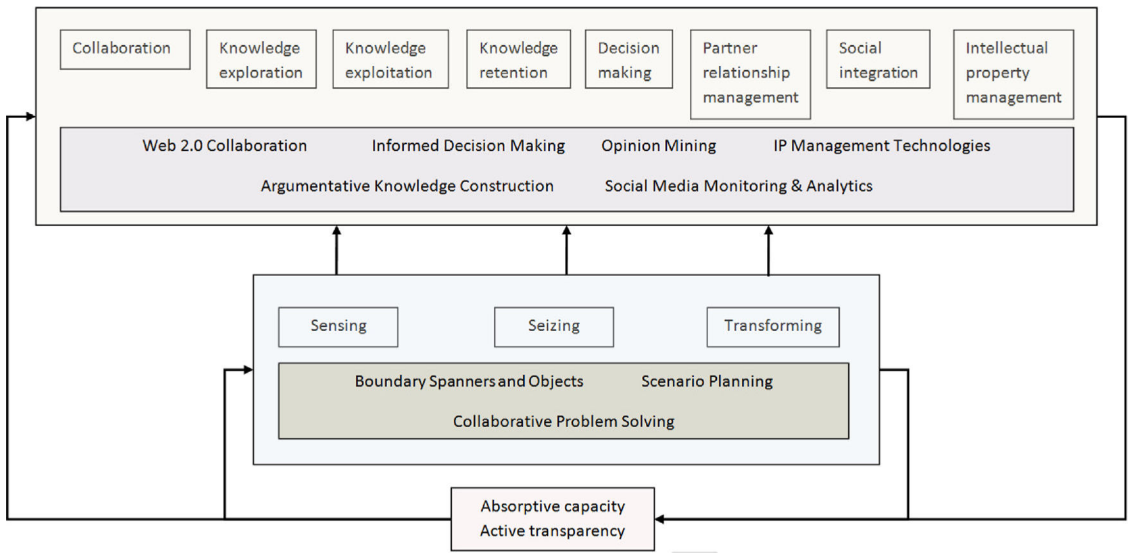

Fig. 1. The proposed capability-based framework for Open Innovation and its association with ICT.

complex and pluralistic context of modern organizations, efficient deployment of these activities requires the support of ICT (Cui et al., 2015). In terms of basic information systems functionalities and operations these requirements correspond to *encoding* the user(s) will and emotions, the automatic or human-assisted *aggregation* of the encoded data, the *computability* of the data/information for constructing meaning (Alaimo & Kallinikos, 2017), as well as *exchange* and *transformation*, and *storage* and *retrieval* of data in various formats. More complex operations/functionalities, such as experimentation, dialoguing, process representation, etc. are based on these basic operations. Technologies for implementing these functionalities are discussed in "Technologies for operational OI capabilities" section. Some of these technologies can be assets to both strategic and operational level capabilities. Our discussion has a critical perspective towards isolated/fragmented adoption, arguing for their integration in the framework of a flexible ICT infrastructure. Fig. 1 depicts the entire capability-based framework for Open Innovation discussed above and its association with ICT. The specific ICT depicted in the figure for both level capabilities are discussed in Sections "Technologies for strategic OI capabilities" and "Technologies for operational OI capabilities".

Technologies for strategic OI capabilities

On the basis of the three abovementioned (see "Strategic capabilities for OI" section) areas of intervention for building strategic dynamic OI capabilities for scanning, seizing and transforming knowledge, three knowledge-management-related practices (boundary spanning, collaborative problem solving and participative scenario planning) with their associated processes (routines) and ICT toolsets (assets) are presented below. Table 1 presents them in a compact form.

Boundary spanners and boundary objects

In modern organizations with modular and distributed characteristics, there is an inherent tendency to localize and embed knowledge and learning practices within the boundaries of individual modules. Interfacing with other modules is by means of pre-defined, standardized interfaces. Clearly, this logic increases mental model centrality and fragments knowledge and knowing, and their creative interplay in strategic processes (Amin & Cohendet, 2004). However, OI requires the creation of "hotspots" of creativity and innovation where people "working across function, national and organizational boundaries" are energetically involved (Gratton, 2013). The requirement for crossing boundaries is not just to facilitate communication, but principally to resolve the negative consequences of the attitudes of the individuals from each organization and module against altering their own knowledge, as well as to leverage their capabilities of influencing or transforming the knowledge used by others. Knowledge boundaries limit not only organisational processes for responding to environmental signals when changes at the interior, exterior and architectural level of processes and products need to take place, but also the planning for the future when knowledge generated is being exploited. Two interrelated concepts have been developed for overcoming the problems of knowledge boundaries and facilitating distributed coordination: *boundary spanners* and *boundary objects*.

Boundary spanners are organization members assigned the specific role of facilitating the collaboration of individuals in different organizations or different organization modules. They coordinate activities across and on the edge of boundaries they cross or overlap. Boundary spanners can be complemented by ICT boundary objects, which are artefacts used to create shared context among different parties in cross-module activities. Carlile (2002) formed a classification of boundary objects into repositories, standardized forms and methods, and objects, models and maps. This last category is the only one that directly supports the transformation of knowledge, in addition to representation and learning, and therefore is suitable for overcoming knowledge boundaries.

Boundary objects such as process maps, strategy maps, process and system dynamics simulation models, collaboratively manipulated/drawn 2D and 3D objects, as well as computer-based learning environments, can trigger and support learning-by-adaptation, eliminating, probably with the help of a boundary spanner, knowledge boundaries. From a different perspective, they constitute "transitional objects" (Morecroft, 2004) for aligning in the short term, and expanding, in the long term, mental models of individuals in different functions and organisations, thus increasing the effectiveness of collaboration. Graphical modelling and simulation environments in which models are built include discrete-event simulations systems such as *Arena*, *Extend*, *ProModel*, etc., system dynamics modelling systems, such as *Vensin*, *Powersim* and *ithink*, as well as agent-based simulation environments (*AnyLogic*, etc.). All can be integrated, technically and operationally, in wider enterprise-level information systems, such as ERP.

Table 1
Methods for the development of OI strategic capabilities and their supporting ICT.

Required strategic level capabilities development activities (processes)	Methods and supporting ICT (assets)
Activities: Intervene on the way mental model characteristics influence the accumulation of learning capacity Requirements: Development of the conditions for boundary spanning through boundary objects	• Graphical modelling and simulation environments (discrete-event: Arena, Extend, ProModel, etc., system dynamics: Vensin, Powersim, ithink, etc., as agent-based: AnyLogic, etc. • Integrated, technically and operationally, in wider enterprise-level information systems, such as SAP
Activities: Improve managerial participation in the development of innovation strategies and in the deployment of required operational processes Requirements: Support collaboration for issue resolution and strategic thinking	• Participative systems methodologies (problem-structuring methodologies, such as SSM, SODA, etc.) • Simulation-based participative modelling, methodologies • Information systems supporting collaboration and argumentation
Activities: Improve processes, methods and tools for assessing the future environment Requirements: Establish practices for participative scenario planning	• Methods of intuitive logics (qualitative) • Methods that belong to the area of Probabilistic Modified Trends (PMT) (IFS (Interactive Futures Simulations), INTERAX (Interactive Cross Impact Simulation), SMIC (Cross Impact Systems and Matrices) with their corresponding support software tools • Method of "La Prospective" (Micmac, ProbExpert, Scenaring Tools, etc.)

Methods and systems for collaborative problem solving

When used at cross-functional and cross-organizational level, collaboration supporting methods and systems can be considered as a particular class of boundary objects that promote diverse participation and facilitate the activation of the micro-instantiation of the *organizational knowledge cycle* over particular cross-organisational/functional issues and problems (Adamides & Karacapilidis, 2006). As indicated in "Web 2.0 collaboration" and "Argumentative knowledge construction", computer-based collaboration and argumentation systems can actively support OI operational processes. Similar methods and artefacts can also be used at the strategic level to structure *problem-solving/issue-resolving processes* and the related dialoguing. By the collaborative development and manipulation of structured models, as well as by the embedment of dialectic logic in the form of argumentation schemes in the collaboration processes (dialectic logic facilitates synthesis of perceptions), they can increase the organization's problem-solving and planning capability. Information and communication technologies are used to support the knowledge flows among the relevant actors and artefacts, in a way that enhances the creation of new knowledge (the process of *knowing*). These are the main tasks of a class of Computer-based Knowledge Management Systems (CKMS), which are systems that provide a corporate memory, i.e. an explicit, disembodied persistent representation of the knowledge and information in an organisation (a sort of knowledge base) and mechanisms that improve the sharing and dissemination of knowledge by facilitating interaction and collaboration. Moreover, the provision of an associated ICT infrastructure that supports virtuality (dispersed groups, asynchronous collaboration) attracts wider membership and hence increases the diversity and richness of knowledge, promotes active participation, and further increases the productivity of strategic issue resolution (Adamides & Karacapilidis, 2006; Adamides & Pomonis, 2008).

The methods and systems developed over the last two decades for supporting collaboration in issue resolution include participative systems methodologies (problem-structuring methodologies, such as SSM, SODA, etc.), methodologies that rely on simulation modelling, methodologies that use collaborative information technology, and information systems supporting collaboration and argumentation (Adamides & Karacapilidis, 2006). These systems have a significant role to play as far as the democratization of innovation is concerned (von Hippel, 2006), which goes beyond mere gathering ideas/concepts from diverse sources. While some of the available networking and collaboration supporting software packages, such as Lotus Notes, contribute to functional specification and homogenisation in information distribution and to the conservation of power structures (Lilley, Lightfoot, & Amaral, 2004), thus limiting pluralism in actual innovation, more sophisticated tools, as those mentioned in "Web 2.0 collaboration" and "Argumentative knowledge construction", reaching wider participation and implementing more democratic rationales in argumentation and conflict resolution, embedded in specific organisational contexts appropriately, can act as enablers of the enlargement of the innovation discourse, and as arbitrators that facilitate the re-distribution of power.

Participative scenario planning

Scenario planning is the most frequently used tool of the "prosessualistic", or learning, school of strategic management (Schoemaker, 1995) that has penetrated the field of strategic innovation management (Tidd & Bessant, 2014) and the development of dynamic capabilities (Teece et al., 2016). The value of scenario planning does not stem from the outcomes it produces but rather from the *process* of scenario construction, which through the dynamic interaction between the organization and the environment, stimulates learning by considering possible and "impossible" future events and their consequences. Written scenarios, frequently complemented by computer simulations, are used to explore the concurrent impact of various uncertainties by modifying multiple variables at a time and by speculating on their outcomes. In this way, the process of scenario construction stimulates and facilitates the sharing and recombination of personal knowledge to build a holistic understanding of the internal and external environment of the organization. Scenario planning makes explicit the implicit assumptions of individuals about the future, stimulating creative and innovative thinking (Karacapilidis & Gordon, 1995; Meissner & Wulf, 2013).

Scenario planning constitutes one of the most popular and effective exercises for knowledge creation and learning in knowledge management initiatives such as communities of practice (CoP). Managers from different departments, as well as external actors, participate in a typical scenario construction process, which is usually comprised by a number of distinct stages (Schoemaker, 1995) using ICT that comprises databases with specialised optimisation and simulation methods. A large number of public and private organizations uses scenario planning in connection with advanced information systems (corporate data and knowledge bases, economic intelligence databases, GIS, technology databases, etc.) for mentally visiting the future in order to build the required flexibility in their tangible and intangible strategic resources.

Scenario methods and tools include methods of intuitive logics, which do not apply quantitative assessment and require limited IS support, methods that belong to the area of *Probabilistic Modified Trends* (PMT) and include methods, such as, *IFS* (Interactive Futures Simulations), *INTERAX* (Interactive Cross Impact Simulation), *SMIC* (Cross Impact Systems and Matrices) with their corresponding support software tools, and the French method of "La Prospective", supported by a number of software systems (*Micmac*, *ProbExpert*, *Scenaring Tools*, etc.) (Amer, Daim, & Jetter, 2013).

Technologies for operational OI capabilities

As it has already been mentioned, collaboration is the dominant characteristic of OI processes. From the technology point of view, compared to traditional groupware applications for brainstorming, argumentation and group decision support, the diverse types of ICT-based open innovation systems differ in terms of the number of users (scale) and goal of the system, in that open innovation systems assume, by design, a larger number of users and a narrower goal (Klein & Convertino, 2015). This goal is largely supported by Web 2.0 technologies (O'Reilly, 2008), which led to new knowledge sharing paradigms due to their inherent user-friendliness, intuitive character and flexibility. At the same time, as discussed in the previous sections, it has been broadly admitted that knowledge management plays an invaluable role in innovation, in that it fosters a knowledge-driven culture and assists in creating tools, platforms and processes for tacit knowledge creation, sharing and leverage, which play an important role in the innovation process (Adamides & Karacapilidis, 2006; du Plessis, 2007).

Key knowledge management (micro)processes (i.e. retrieving, sharing and developing knowledge) ensure informed decision-making and stimulate organizational learning. Recent research suggests that the ICT tools for facilitating such processes should (i) attract wide participation, however in a controlled manner, (ii) simplify collaboration towards knowledge co-creation, (iii) enable a formal knowledge structure for re-use and reasoning purposes, and (iv) support a sophisticated collection and analysis of associated big data mostly coming from related social media (del Giudice & della Peruta, 2016; Hrastinski et al., 2010; Mount & Martinez, 2014). Below we present and comment on the main ICT-based practices and associated tools for building this type of OI capabilities.

Web 2.0 collaboration

The emergence of the Web 2.0 era introduced a plethora of collaboration tools, which enable engagement at a massive scale and feature novel paradigms. These tools cover a broad spectrum of needs ranging from knowledge exchange, sharing and tagging, to social networking, group authoring, mind mapping and discussing. *Facebook* and *LinkedIn* are representative examples of social networking tools that facilitate the formation of online communities among people with similar interests; tools such as *MindMeister* and *Mindomo* aim to collectively organize, visualize and structure concepts via maps to aid brainstorming and problem solving; *Debatepedia* and *Cohere* (http://cohere.open.ac.uk) are typical tools aiming to support online discussions over the Web; *phpBB* and *bbPress* are Web 2.0 applications enabling the exchange of opinions, focusing especially on providing an environment in which users can express their thoughts without paying much attention to the structure of the discussion.

Generally speaking, the above technologies enable the massive and unconstraint collaboration of users; however, this very feature is the source of the *information overload* problem. The amount of information produced and exchanged and the number of events generated within these tools exceeds by far the mental abilities of users to: (i) keep pace with the evolution of the collaboration in which they engage and (ii) keep track of the outcome of past sessions. Current Web 2.0 collaboration tools exhibit two important shortcomings making them prone to the problems of information overload and cognitive complexity. First, these tools are "information islands", thus providing only limited support for interoperation, integration and synergy with third party tools. While some provide specialized APIs with which integration can be achieved, these are primarily aimed at developers and not at end users. Second, Web 2.0 collaboration tools are rather *passive media*, i.e. they lack reasoning services with which they could actively and meaningfully support collaboration. In other words, they concentrate more on encoding the user and exchange operations than on information aggregation and computability.

Overall, Web 2.0 collaboration support tools can contribute directly to the development and support of processes associated with the collaboration (COLB) capability, and indirectly to those associated with knowledge exploration (KXPL), knowledge exploitation (KXPT), knowledge retention (KRTN), and social integration (SINT). In many cases, through sophisticated mechanisms for user profiling and networking, they can also support the development of the partner relationship management (PREM) capability.

Argumentative knowledge construction

Collaborative knowledge co-creation and learning processes are often based on written argumentative discourse of various stakeholders, who discuss their perspectives on a problem with the goal to resolve it and acquire knowledge (Weinberger & Fischer, 2006). As far as argumentation related processes are concerned, various technologies focusing on the sharing and exchange of arguments, diverse knowledge representations and visualization of argumentation have been developed. Tools such as *Araucaria* (Reed & Rowe, 2001), *Reason!Able* (van Gelder, 2002) and *Compendium* (http://compendium.open.ac.uk) allow users to create issues, take positions on these issues, and make pro and contra arguments. They can capture key issues and ideas, and create shared understanding in a team of knowledge workers; in some cases, they can be used to gather a semantic group memory. However, these argumentation support tools exhibit the same problems with the aforementioned Web 2.0 collaboration tools. They are standalone applications, lacking support for interoperability and integration with other tools (e.g. with data mining services foraging the Web to discover interesting patterns or trends) limiting information aggregation, computability and exchange. They also cope poorly with voluminous and complex data as they provide only primitive reasoning services. This makes them also prone to the problem of information overload. Argumentation support services recently developed in the context of the Dicode project (Karacapilidis, 2014) address the majority of these shortcomings through innovative virtual workspaces offering alternative visualization schemas that help stakeholders control the impact of voluminous and complex data, while also accommodating the outcomes of external web services, thus augmenting individual and collective sense-making (Lau, Yang-Turner, & Karacapilidis, 2014).

Armed with the latter functionalities, argumentative knowledge construction support tools contribute significantly to the support of knowledge exploration (KXPL), knowledge exploitation (KXPT), and knowledge retention (KRTN) capabilities. However, they have a few shortcomings that make them more suitable for use principally in "OI toolkits" strategies. Their emphasis on providing fixed and prescribed ways of interaction within collaboration spaces make them difficult to use in more "open" models as they constrain the expressiveness of users, which in turn results in making these systems being used only in niche tool-proficient communities.

Informed decision making

Data warehouses, on-line analytical processing, and data mining have been broadly recognized as technologies playing a prominent role in the development of current and future Decision Support Systems. They may aid users make better, faster and informed decisions, and consequently develop the desired organizational decision making (DMKG) capability. However, there is still room for further developing the conceptual, methodological and application-oriented aspects of computer-supported decision making. A holistic perspective on computer-supported decision making is still missing, and there is a growing need to develop applications by following a more human-centric (and not problem-centric) view (Karacapilidis, 2006). Decision making has to be considered as a social process where human interaction is of primary importance (Smoliar, 2003). The structuring and management of this interaction, especially in network organizations, requires the appropriate technological support and has to be explicitly embedded in the solution offered. At the same time, much of the available data is often underutilized in the decision making process due to a lack of proficiency in data analysis; there is much progress to be made when it comes to analysing data to drive innovation.

The above requirements delineate a set of challenges for further decision support technology development. Such challenges can be addressed by adopting a knowledge-based decision-making view, while also enabling the meaningful accommodation of the results of the social knowledge and related mining processes (Tsiliki, Karacapilidis, Christodoulou, & Tzagarakis, 2014). According to this view, which builds on bottom-up innovation models, decisions are considered as pieces of descriptive or procedural knowledge referring to an action commitment. In such a way, the decision making process is able to produce new knowledge, such as evidence justifying or challenging an alternative or practices to be followed or avoided after the evaluation of a decision, thus providing a refined understanding of the problem. On the other hand, in a decision making context the knowledge base of facts and routines alters, since it has to reflect the ever-changing external environment and internal structures of the organization.

An effective decision making toolset for OI should be able to integrate (aggregate) and manage (store/retrieve) in a single repository all the relevant data, metrics, and objectives; moreover, to properly share them across and beyond the organization and use them as basis of end-to-end decision making processes (exchange/transformation operations); in addition, to embed cognitive capabilities so that users will be aided in their data search, collection and analysis. It is stressed that knowledge management activities such as knowledge elicitation, representation and distribution influence the creation of the decision models to be adopted, thus enhancing the decision making process, while evaluation of contributions in the decision making process may act as a reputation mechanism and provide incentives for engagement (Anadiotis, Kafentzis, Pavlopoulos, & Westerski, 2012).

Social media monitoring and analytics

Social media monitoring and analytics is an evolving marketing research field that refers to the tracking or crawling of various social media content as a way to determine the volume and sentiment of online conversation about a brand or topic (Bekkers, Edwards, & de Kool, 2013). Their added value lies on the fact that such processes can be performed at real time and in a highly scalable way (high aggregation and computability functionality). Representative tools of this category include *Social Mention*, *Sysomos*, *Hootsuite*, and *Trackur*. Such tools are able to reveal the issues, ideas and arguments that can best contribute in an open innovation process. In addition, they can support the required "attention mediation" (Klein & Convertino, 2015), by providing a structured way to represent the "big picture".

The employment of these tools supports the knowledge exploration (KXPL) and decision making (DMKG) capabilities. However, despite their enormous potential, so far, they have not been widely – and meaningfully – adopted, basically due to: (i) the poor quality and reliability of the existing solutions, and (ii) the difficulty of integration into the existing company structures and marketing procedures. In the OI settings, data sources are associated with various types of information, each of them covering distinct aspects. A systematic way is needed to generate different points of view for such kind of data. Contemporary approaches need to help users utilizing complex multi-source data in a reasonable way by supporting them in finding relevant information and by providing personalized recommendations (Bugshan, 2015).

Another category of requirements concerns the exploration, delivery and visualization of the pertinent information. These should be based on: (i) an intelligent semantic annotation, structuring and aggregation of voluminous and complex data, (ii) the meaningful analysis and exploitation of data patterns and interrelations, (iii) the capturing of stakeholders' tacit knowledge, as far as information analysis and problem solving are concerned, through a social web approach, and (iv) the exploitation of particular user and group characteristics to properly direct or adapt data (Karacapilidis, Loeffler, Maassen, & Tzagarakis, 2012; Karacapilidis, Tzagarakis, & Christodoulou, 2013).

Opinion mining

Opinion mining (or sentiment analysis) technologies employ natural language processing, machine learning, text analysis and computational linguistics to extract relevant information from the huge amounts of human communication over the Internet or other (offline) sources. Hence, they exhibit a high degree of computability. In fact, the propagation of opinionated data has caused the development of web opinion mining (Marrese Taylor, Rodríguez Opazo, Velásquez, Ghosh, & Banerjee, 2013) as a new concept in Web Intelligence, which deals with the issue of extracting, analyzing and aggregating data about opinions. The analysis of users' opinions, known as sentiment analysis, is important because through them it is possible to determine how people feel about a product or service and know how it was received by the market. We can distinguish between two types of tools in this category: those that provide a framework for data mining algorithms, e.g. *Rapidminer*, *WEKA*, and *KNIME*, and online platforms that can visualize (in real time) opinion mining analytics on predefined Web 2.0 Sources, e.g. *sentiment viz* and *Socialmention*.

Opinion mining methods and tools make possible for organizations to reach crowd's opinions about diverse topics of interest. As holds for social media monitoring and analytics, they support the development of the knowledge exploration (KXPL) and decision making (DMKG) capabilities. Generally speaking, traditional opinion mining techniques apply to social media content as well. However, there are certain factors that make Web 2.0 data more complicated and difficult to be parsed. An interesting study about the identification of such factors was made by Maynard, Bontcheva, and Rout, 2012, in which they exposed important features that pose certain difficulties to traditional approaches when dealing with social media streams, such as the short length of messages, the existence of noisy content, and the disambiguation in the subject of reference.

Intellectual property management

The intellectual property management (IPMA) capability concerns the tracking of trademarks, patents, copyrights, and other

Table 2
OI models and associated operational capabilities.

Model of Open Innovation	Main operational capabilities required
Innovation markets	• Collaboration (COLB) • Knowledge exploration (KXPL) • Knowledge exploitation (KXPT) • Decision making (DMKG) • Knowledge retention (KRTN)
Innovation communities	• Collaboration (COLB) • Knowledge exploration (KXPL) • Knowledge exploitation (KXPT) • Social integration (SINT) • Decision making (DMKG) • Intellectual property management (IPMA) • Knowledge retention (KRTN)
Innovation contests	• Collaboration (COLB) • Knowledge exploration (KXPL) • Knowledge exploitation (KXPT) • Decision making (DMKG)
Innovation toolkits	• Collaboration (COLB) • Knowledge exploration (KXPL) • Knowledge exploitation (KXPT) • Partner relationship management (PREM) • Decision making (DMKG) • Intellectual property management (IPMA) • Knowledge retention (KRTN)

intellectual property, as well as to decide what to disclose. In addition to decision-support tools, organizations utilize diverse ICT-based tools to manage the related databases, automate forms and correspondence for new and ongoing intellectual property ownership, and track potential violations of legal rights. These tools, which are often integrated with case management tools to streamline the lifecycle of intellectual property procurement and litigation, aid organizations in maintaining up-to-date client information, license agreements, and diverse intellectual property material in a single repository. Representative tools of this category include *Inteum*, *Anaqua* and *FoundationIP*.

Table 2 summarises the above discussed capabilities with respect to open innovation models.

Integration issues

The vast majority of ICT tools presented above have been originally designed to work as standalone applications. However, in complex contexts such as that of OI processes, these tools need to be integrated and meaningfully orchestrated. In most cases, this is a hard and challenging issue, which depends on many factors, such as the type of the resources to be integrated, performance requirements, data heterogeneity and semantics, user interfaces, and middleware (Ziegler & Dittrich, 2007). At the same time, OI stakeholders are confronted with the rapidly growing problem of information overload; they need to efficiently and effectively collaborate and make decisions by appropriately assembling and analysing enormous volumes of complex multi-faceted data residing in different sources. Admittedly, when things get complex, we need to aggregate big volumes of data, and then mine it for insights that would never emerge from manual inspection or analysis of any single data source (Karacapilidis, 2014).

The above requirements can be fully addressed by an innovative web-based platform that ensures the seamless interoperability and integration of diverse components and services. The proposed solution should be able to loosely combine web services to provide an all-inclusive infrastructure ('single-access-point') for the effective and efficient support of diverse OI stakeholders. It will not only provide a working environment for hosting and indexing of services, seamless retrieval and analysis of large-scale data sets; it will also leverage Web technologies and social networking solutions to provide stakeholders with a simple and scalable solution for targeted collaboration, resource discovery and exploitation, in a way that facilitates and boosts OI activities. Much attention needs to be paid to standardization to make existing data and software reusable with the minimum effort and without introducing new standards. Interoperability issues should be considered from a technical, conceptual and user interface point of view. When necessary, the foreseen platform should exploit rich semantics at machine level to enable the meaningful incorporation and orchestration of interoperable web services in customized OI-related workflow settings, aiming to reduce the data-intensiveness and smooth the associated workloads to a manageable level.

The proposed integration can be based on established technologies and standards of a service-oriented architecture. Application Programming Interfaces (APIs) allow different applications to connect and interact with each other, while web services provide a standardized way of integrating web-based applications using open standards such as XML, SOAP, WSDL and UDDI. Such an integration approach has been fully adopted in the context of the *Dicode* EU project (http://dicode-project.eu/), where a widget-based solution was conceived to deliver diverse web services to end-users, a dedicated registry of services served location and recommendation purposes, and alternative service integration modes were proposed and thoroughly tested in the project's use cases. It has been shown that this approach, namely the *Dicode Workbench* (de la Calle, Alonso-Martinez, Tzagarakis, & Karacapilidis, 2012), ensures a flexible, adaptable and scalable information and computation infrastructure, and exploits the competences of stakeholders to properly confront information management issues, such as information characterization, classification and interpretation, thus giving added value to the underlying collective intelligence. Moreover, it facilitates knowledge sharing and knowledge co-creation, and assures better-informed collaboration. At the same time, such an approach pays much attention to the issues of usability and ease-of-use, not requiring any particular programming expertise from the end users.

Conclusions

In this paper, based on an organisational capabilities perspective, we discussed ICT as enhancer of strategic- and operational-level processes of OI. As it has been made clear in the previous sections, ICT support for the two levels differs significantly, as far as the human–machine relationship is concerned. Strategic processes are creative, complex, and highly subjective processes that cannot be automated and objectified. Hence, ICT support is focused on the microfoundations of dynamic capabilities: "opening" mental models and on the development of social capital through collaboration and knowledge management. ICT artefacts, such as computer simulation models, play the important role of "transitional objects". On the other hand, support for encoding the user, aggregation and computability through machine-reasoning and data processing is required in OI operational processes for supporting the corresponding capabilities. Nevertheless, even at this level, for exploiting knowledge from diverse sources, for switching fast between external partners, and most of all, for developing absorptive capacity and active transparency, flexibility and "breadth" are more important than rigid integration and "depth". The technologies and tools discussed in this paper address these requirements; through their flexible and meaningful integration for aggregating and transferring information to construct meaning, they can act as enablers of the entire OI process. The extent to which this is true in successful OI implementations is under investigation by the authors, by pursuing empirical research and analysing data of published cases at both national and European level.

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