Knowledge translation mechanisms in open innovation

The role of design in R&D projects

Simeone, Luca; Secundo, Giustina; Schiuma, Giovanni

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Purpose. This paper investigates the role of design as a knowledge translation mechanism in R&D-oriented open innovation. In particular, the paper intends to look at how design can be used as a means of knowledge transfer among various stakeholders who speak different languages and have divergent needs and interests in a process where knowledge openly flew across the boundaries of a high number of organizations.

Methods. The paper combines the insights from theory with the empirical evidence gathered by adopting an extreme case study approach: the detailed analysis of a case study related to an R&D project funded by the European Commission and aimed to investigate and produce innovative serious games in the area of healthcare. The project gathered a large number of stakeholders and deliberately adopted design processes in order to support an open innovation approach.

Findings. The paper provides insights into the use of design outputs such as artifacts, sketches, visual representations or prototypes in order to translate ideas, theoretical and technical requirements, documents and outputs into formats that can be more easily understood and appreciated by various stakeholders. This supports and favors coordination in open innovation projects where many different stakeholders are engaged.

Research limitations. Although the adoption of an extreme case study approach offers important implications to understand the role of design in R&D-oriented open innovation, the use of single case study represents the basis both to explore hypothesis and to provide first evidences, that need to be further tested with other qualitative and quantitative analysis.

Practical implications. The paper offers practical implications about how design can help individuals and organizations involved in R&D activities to better communicate and share knowledge among various stakeholders by aligning their different needs, interests and languages along the various phases of their project development.

Originality/value. The originality of the paper lays at the intersection of three different fields: open innovation, knowledge management and design for innovation, thus integrating mature, but so far isolated research streams. It provides insights for theory building by explaining the use of design as knowledge translational mechanism and informs the practice by highlighting the power of design as a means to support knowledge flows into open innovation-based R&D projects.

Keywords: Design, knowledge translation, open innovation, R&D projects.

1. Introduction

In a world of ever-changing corporate environments and reduced product life cycles, organizations working in R&D and technology intensive industry cannot always afford to innovate on their own (Chesbrough, 2003; Gassmann, 2006, Gassmann et al., 2010). The complexity of contemporary production pipelines - articulated across multiple sectors and oriented towards fast-changing and somewhat unpredictable market conditions - calls for a new approach based on collaboration and interchange. Hence, organizations open their innovation processes to incorporate knowledge flows originated from or co-produced with external stakeholders (academia, research centers, industry, government, NGOs, public institutions), that interact in specific organizational, social, economic and cultural contexts (Chesbrough and Bogers, 2014; Dahlander and Gann, 2009; Huizingh, 2010; Enkel et al., 2009; Ardito and Messeni Petruzzelli, 2017). Characterizing knowledge in terms of flows means looking at knowledge as "a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information" (Davenport and Prusak, 2000, p. 5). In the past 20 years, scholars have proposed various models that study how knowledge flows across the boundaries of a single organization, for example being produced by multidisciplinary teams brought together to respond to real-world problems and challenges (Nowotny *et al.* 2001; Gibbons 2000; Gibbons *et al.* 2011; Gibbons *et al.* 1994) and by the intersection of multiple reciprocal relationships across academia, government and industry (Etzkowitz 2008; Carayannis and Campbell 2012). Open innovation occurs where knowledge flows beyond the boundaries of a single organization and where a high degree of cross-border organizational collaborations take place (Chesbrough and Crowther, 2006; Grimaldi et al., 2013; Rippa et al., 2016). In the specific case of R&D contexts, this would favor knowledge co-production processes where, for example, end-users, policy makers, industry and academic institutions work together to advance scientific knowledge or to develop new solutions and prototypes. Collaboration among distributed partners allows the creation of something new starting from what already exists (Hargadon, 2002~~;~~ and innovation occurs as a process of searching and recombining existing knowledge elements (Ardito and Messeni Petruzzelli, 2017; Savino et al., 2017).

The difficulties that organizations must face to effectively transfer, integrate and co-create knowledge are widely recognized (Greer and Lei, 2012; Thorpe et al., 2005). An organization needs mechanisms to acquire external knowledge, transfer it internally, and integrate it with existing stocks (Hamel, 1991; Huber, 1991; Leonard-Barton, 1992). In these contexts, problems might arise in relation to the differences among the various organizations and stakeholders involved. There might be differences in terms of interests, needs and languages. Not only it is necessary to recognize and balance the different objectives of each stakeholder, thus ensuring that their needs and wants are systematically addressed and balanced (Garrett-Jones et al., 2005), but also, as noted by Chiesa and Piccaluga (1998), there is a need for knowledge translators between these groups given the different objectives and languages prevalent in the diverse contexts.

Previous studies have investigated how design processes can support knowledge translation in academic entrepreneurship (Simeone et al., 2016; Simeone, 2016). Design can provide a key 'interface' role (Boren et al., 2012) by enabling a better collaboration among stakeholders. As argued by Sainsbury: "The use of design helps scientists to develop commercial applications for their work while it is still at the research stage or at the outset of the technology transfer process" (Sainsbury, 2007, p 151). In particular, design can help in translating ideas, concepts, requirements, needs, interests of multiple stakeholders into visual and physical formats (e.g., a sketch, a graphic representation, a physical prototype), that can be more easily understood and circulated. For example, some computer scientists working with quite complex algorithms in acoustics can explain the key outcomes of their research by producing a visual diagram which is easier to understand. This visual diagram can help translating technical knowledge into a format that can be appreciated also by people without a strong technical background. This paper aims to explore if and how design can support knowledge translation in R&D processes that rely upon open innovation. In spite of the increasing research in open innovation, very few studies have examined the alignment among the different stakeholders' involvement in the knowledge flows supporting the innovation development, especially in R&D projects.

In the attempt to cover this gap, this paper aims to provide an answer to the following question: *How can design support the process of knowledge translation in open innovation processes occurring in R&D projects?* In order to address this question, the insights of a R&D project funded by the European Commission (3D Tune-In, which focuses on the development of innovative serious games in the area of healthcare) build the empirical ground to shed light on how design can contribute to integrate and align multiple stakeholders into knowledge co-creation processes through the enhancement of knowledge translation mechanisms. The findings provide evidences about the role of design as a knowledge translation mechanism to engage a plurality of stakeholders in the development of a R&D project leveraging open innovation practices.

The paper is organized as follows: Section 2 reviews the literature to introduce the relationship between open innovation, knowledge transfer, knowledge translation and design. Section 3 describes the research approach and the research context. Section 4 presents the findings of the study. Section 5 discusses the results. Finally, the last section concludes the paper underlying the practical as well as the theoretical implications.

2. Literature review

2.1 A knowledge-based perspective of open innovation in R&D projects

Chesbrough et al. (2006) propose a quite broad definition of open innovation as the "purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for external use of innovation" (Chesbrough et al., 2006, p.1). Since 2003, there has been an abundance of research conducted into open innovation, even though much of this research has focused on large-scale enterprises, leaving a gap in R&D intensive industry (Kogut, 2000) and R&D projects (Kim et al., 2015). As also Chesbrough et al. (2006, p. 287) noted: "Neither the practice of nor research on open innovation is limited to the level of the firm. Innovations are created by individuals or groups of individuals, usually within organizations, so, the sub-firm level of analysis is particularly relevant in understanding the sources of innovation. The focus on individual R&D project, i.e., the level at which the actual innovation takes place, is particularly important since openness at the organizational level is determined by the openness of individual R&D projects carried out by the organization (Enkel et al., 2009; Kim et al., 2015; Horváth and Enkel, 2014) and no longer as a result of an autonomous and self-managed process (West et al., 2014; Chesbrough and Bogers, 2014). In R&D intensive projects, the open innovation model is based on the use of external knowledge in conjunction with internal R&D (Almirall and Casadesus-Masanell, 2010; Chesbrough, 2003). Innovation is grounded on the creation of something new starting from what already exists (Hargadon, 2002; Lo Storto, 2006). Firms search for knowledge components coming from external partners, such as other organizations or individuals not directly employed by the searching firm, in order to bring together knowledge domains distributed across the world (Benkler, 2006; Dahlander and Gann, 2010; von Hippel, 2001, 2005).

The research on open innovation pointed out that the most relevant sources of knowledge typically include suppliers, research centres, universities, customers, competitors, and companies with complementary offerings (Von Hippel, 1986). Whereas open innovation is based on the premise of 'abundant knowledge,' (Chesbrough, 2003, p. xxv), some form of integration is always needed to integrate the organization's own capabilities with the external knowledge that can be accessed through open innovation (Jaspers and van de Ende, 2010).

There are different forms that companies can use to pursue the open innovation model, including bilateral collaboration, networks, outsourcing R&D (Berkhout et al., 2006), technology in-sourcing (Chesbrough, 2003; Chesbrough, 2006; von Hippel and von Krogh, 2006) and external technology exploitation (Ulrich, 2008). Van de Vrande et al. (2009) articulates the various practices related to open innovation into a paradigm revolving around the two processes of technology exploration and technology exploitation. Table 1 shows a synthetic summary of these practices.

Practice	Definition
Technology exploitation	

Venturing	Starting up new organizations drawing on internal knowledge, and possibly also with finance, human capital and other support services from the parent enterprise.
Outward IP licensing	Selling or offering licenses or royalty agreements to other organizations to better profit from intellectual property, such as patents, copyrights or trade-marks.
Employee involvement	Leveraging the knowledge and initiatives of employees who are not involved in R&D, for example by taking up suggestions, exempting them to implement ideas, or creating autonomous teams to realize innovations.
Technology exploration	
Customer involvement	Directly involving customers in innovation processes, for example by active market research to check their needs, or by developing products based on customers' specifications or modifications of products similar like yours.
External networking	Drawing on collaborating with external network partners to support innovation processes.
External participation	Equity investments in new or established enterprises in order to gain access to their knowledge or to obtain others synergies.
Outsourcing R&D	Buying R&D services from other organizations, such as universities, public research organizations, commercial engineers or suppliers.
Inward IP licensing	Buying or using intellectual property, such as patents, copyrights or trademarks, of other organizations to benefit from external knowledge.

Table 1. The Open Innovation paradigm ((Source: elaborated from Van de Vrande et al., 2009)

In R&D projects, all these practices of open innovation relate to the form of knowledge transferred from one stakeholder to another. Firms participating in R&D alliances should integrate geographically distant but from organizational point of view proximate knowledge. By doing so, firms take advantage of the diversity and novelty that characterise geographically distant knowledge (Capaldo and Messeni Petruzzelli, 2011; Capaldo and Messeni Petruzzelli, 2015). The focus is on how knowledge moves across the boundaries created by specialized knowledge domains (Argote and Ingram, 2000; Gilbert and Cordey-Hayes, 1996; Carlile and Rebentisch, 2003). In other words, it is the conveyance of knowledge from one place, person or ownership to another. The next section will illustrate how knowledge transfer processes occur in open innovation practices.

2.2 From knowledge transfer to knowledge translation in R&D projects

A number of interpretations have been provided for the concept and the process of knowledge transfer, which is acknowledged as one of the key processes of open innovation. The objective of a knowledge transfer process which takes place between two or more actors (individuals or organisations) is to enable an actor to acquire the knowledge of another actor (Albino et al., 1998). Knowledge can be shared through joint engagement in social practices among groups, organizational units, and even the firm (von Krogh, 2012); however, this could be further complicated by the fact that the professional environment is increasingly virtual as globally dispersed organizational and inter-organizational teams collaborate on R&D innovative projects (Angehrn et al., 2009). For this reason, different mechanisms can be deployed in the context of R&D project such as interaction of personnel, patent disclosures, publications, assets and services exchange, and so on. A working definition of knowledge transfer which can be adopted is the one provided by Christensen (2003, p. 14) who considers knowledge transfer as the process of "identifying (accessible) knowledge that already exists, acquiring it and subsequently applying this knowledge to develop new ideas or enhance the existing ideas to make a process/action faster, better or safer than they would have otherwise been. So, basically knowledge transfer is not only about exploiting accessible resources, i.e. knowledge, but also about how to acquire and absorb it well to make things more efficient and effective." According to van den Hooff and de Ridder (2004), knowledge transfer involves either actively communicating to others what one knows, or actively consulting others in order to learn what they know. Successful knowledge transfer means that transfer results in successful creation and application of knowledge in organisations (Nonaka and Takeuchi, 1991). The process of knowledge transfer has been described by many researchers using different models; among these one of the most known is the knowledge conversion model introduced by Nonaka and Takeuchi (1995), distinguishing between tacit and explicit knowledge (Koulopoulos and Frappaolo, 1999; Polanyi, 1975). Where tacit knowledge is subjective and experience-based that cannot be expressed in words, sentences, numbers or formulas, often because it is context specific, involving that it can be transferred only through socialization processes. While, explicit knowledge is objective and rational, then it can be expressed in words, sentences, numbers or formulas and, consequently, it can be transferred through externalization, combination and internalization (Cohendet et al, 1999).

The process of knowledge transfer is not, per se, mere transfer of knowledge (Liyanage et al., 2009). As Seaton (2002) explicates, it requires an additional type of knowledge: "the knowledge about how to transfer knowledge". In those cases where knowledge is transferred across very diverse contexts (e.g., from academia to industry), knowledge needs to be translated in order for it to be still interesting and relevant (Graham et al., 2006). Processes of knowledge translation are particularly important when translating research finding from R&D projects into practice and policy (Grimshaw et al., 2012).

Translating knowledge involves processing new knowledge, interpreting it according to the needs and interests of a specific organization and transforming it into forms that are more suitable for the specific organizational context of application. In this sense, translation is a highly applicable analogy to explore and understand the nature of knowledge transfer (Holden and von Kortzfleisch, 2004). Accordingly, this paper focuses on knowledge translation processes occurring in open innovation process in R&D project, and proposes the design as a translation mechanism supporting knowledge transfer among diverse stakeholders. This provides an original contribution to the management literature.

2.3 Design as a knowledge translational mechanism

We refer to design specifically as a symbolic practice where the very act of designing, for example, a logo, a diagram, a prototype, a product or a service is a way to create meaning (Krippendorff, 1989). Design comprises a set of practices and methods – such as user research and user testing, rapid and frequent prototyping, visualization techniques, task-based scenario building, attention to the brand experience – that also mark a distinctive way of thinking, approaching and solving problems (Buchanan, 2004). Designers are clearly recognized as having value in collaborative activity, due to their ability to visualize and think through prototypes and sketches (Brereton and McGarry, 2000). Hargadon and Sutton (1997) explored innovation in an international design firm, and showed that designers might act as technology brokers, due to experience in working across multiple technology fields. Thus, they can transfer ideas and concepts between different technology domains. In a R&D project, typical outcomes of a designerly approach would be, for example, sketches, various visualizations (e.g., 3D renders, data visualizations, motion graphics animations and videos) and prototypes at various degree of refinement. The role of these design artifacts in supporting R&D development projects have been studied by various authors (Bogers and Horst, 2014; Gero, 1990; Jones and Jordan, 1998; Leonard and Rayport, 1997; Leonard and Sensiper, 1998, Rust, 2004; Rust, 2007). None of these authors, though, specifically focused on the construct of translation. Yet, the concept of translation is not new in design research. Some scholars employ the concept of translation simply to talk about translational processes among the languages of different design methods or techniques (Singh and Gu, 2012). Some others adopt translation in another quite commonly used connotation, as to describe design processes and outcomes (such as sketches) in terms of 'translation of ideas' (see for example: Yi-Luen Do *et al.,* 2000; Leblebici-Başar and Altarriba, 2013). In a perspective that also crosses anthropology, a process aimed to transform Taiwan aboriginal cultural features into modern product design is characterized as based on three phases: "identification (extracting cultural features from an original cultural object), translation (transforming these features into design information and design elements) and, finally, implementation (designing the cultural product)"(Lin 2007, p.47). The role of design in building brand value and product identity - also through semiotic processes of translation (e.g., translating the abstract core ideas behind a brand into a visually-designed identity) is also quite frequently praised (Borja de Mozota 2003). These works tend to characterize the translation processes in terms of a linear and quasi-literary sense.

Other studies adopt translation in a more extended sense to describe situations where different stakeholders interact. In a widely-cited work, Leigh and Griesemer (1989) introduce the concept of boundary objects to describe objects that can facilitate the translation mechanisms across different cultural configurations and contexts. Boundary objects are "scientific objects which both inhabit several intersecting social words" and "which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star and Griesemer, 1989, p. 393). Other studies show how participation in design is tied to "problems of interpretation and translation of varying user and expert perspectives" (Reich et al., 1996, p. 177) and argue in favor of "increasing access to technical knowledge and its translation for equal participation in a dialectical process"

(Reich et al., 1996, p.174). Translation is seen as a complex process riddled with negotiations (Cooper et al., 2003; Deni, 2015; Tomes et al., 1998) and where the designers act as "intermediary between disparate ideas, viewpoints and even goals. Being able to translate in this manner is an essential precondition for being able to integrate many things" (Boyer et al., 2011, p.327).

Some studies explore the contribution of design in open innovation, for example studying how organizations can work together with end-users in various open design and manufacturing processes (von Hippel, 2005) or praising the potential of designerly based approach to support open innovation fueled by scientific research (Ito, 2016; Maeda and Ito, 2005). Acha (2008) concludes her report on design for open innovation by stating: "Our analysis indicates that design provides the translation of understanding and expectation between organizations engaged in open innovation practices. The findings demonstrate that firms that actively undertake design activities for innovation and use design to control the innovation process, are more likely to also pursue open strategies for innovation" (Acha, 2008, p. 22). The concept of translation is here not further operationalized and, consequently, the specific way in which design supports translational processes in open innovation remains undisclosed.

Design as a translation mechanism can be seen in accordance with two perspectives: on the one hand as a quasi-linear movement across various stages of design (i.e., a designer who translates his/her idea into a sketch) and, on the other hand, as a more complex and ambiguous interactions and negotiations among various stakeholders and partners. Both perspectives help to frame how design can support processes of knowledge translation for open innovation within a R&D context.

3. Research methods

This paper adopts an extreme case study approach (Eisenhardt, 2002; Eisenhardt and Graebner, 2007; Yin, 1994) which allows to develop a holistic and contextualized analysis. This method is properly suited for the exploratory nature of this research, considering its novelty and complexity (Dell'Era, 2010) as well as the contribution to theory building (Eisenhardt and Graebner, 2007). The focus is a R&D project where design is used as a translational mechanism. The use of case study method allows the identification of key insights through the investigation of a number of examples (Pettigrew, 1990), in a situation where 'how' or 'why' questions are being posed within some real-life context (Glaser and Strauss, 1967; Yin, 1994). This is specifically the case of our research focusing on questioning the 'how' and 'why' of the use of design as a knowledge translational mechanism. Focusing of a real life case study of an open innovation within a R&D project offered the opportunity to gather managerially relevant knowledge (Amabile et al., 2001; Leonard-Barton, 1990). This is consistent with Yin's (1994) view postulating that case based study approach enables: to accommodate single cases or situations with small numbers of cases; to capture process and outcomes in a causal logic model; to gather useful and intermittent feedback to program officials; to adapt to the availability of different types of evidence; to assess outcomes and test causal theories and rival theories; and to develop lessons generalizable to the major substantive themes in a field. These are all elements characterizing the investigated context of open innovation where a number of various stakeholders interacted by transferring and combining complex knowledge dimensions.

3.1 The research context: 3D Tune-In

3D Tune-In is a R&D project funded by the European Commission started in 2015. The specific goals of 3D Tune-In are: (1) to study whether various gamification mechanisms can support healthcare related processes, and (2) to create videogames that can be used by people with hearing aids to fine-tune their hearing devices, either directly on their own or with the help of an audiologist. 3D Tune-In relies upon the idea that gamification mechanisms can be used in non-leisure scenarios for learning and skill acquisition, empowerment and social inclusion. The main idea behind 3D Tune-In is to set up a consortium and bring together as core partners relevant stakeholders from traditional videogaming industries (4 SMEs from Italy, Spain and UK: Reactify, Vianet, XTeam, Nerlaska), research centers (Imperial College London, De Montfort University, the University of Nottingham, the University of Malaga); a large European hearing aid manufacturer (GN); and hearing communities (through NGOs such as Extra Care, Hearing Link, Action Deafness, Accesibilidad y Personas Sordas and Ente Nazionale Sordi) to produce digital games in the field of hearing aid. The number and the heterogeneity of the stakeholders involved in the project, the cross-boundary knowledge flows and the R&D nature of the project characterized the conditions influencing the open innovation processes.

3.2 Data collection and analysis

A combination of methods - ranging from direct participant observation, semi-structured conversations and archival research – have been adopted to gather data. Ethnographic methods such as participant observation and conversations are a common element of recent studies on organizations (Czarniawska, 2012). Following a grounded theory approach, data emerging from the fieldwork was subsequently analyzed in order to identify interpretation patterns. In operational terms, research material was collected and generated through archival research, direct observation, the authors' experience as participants and various conversations with key members involved into the investigated case study across 2015 and 2016. Moreover, official communication tools, like the websites and other social network accounts connected to 3D Tune-In have also been used. Multiple data collection methods were used to exploit the synergistic effects of combining them via triangulation (Eisenhardt, 2002), which consists in the combination of investigative techniques to reduce the bias of a single observation in comparison of multiple data (Tarrow, 1995).

The research was enriched by a dozen semi-structured conversations with various key informants (Kumar et al., 1993), including representatives of 3D Tune-In and external stakeholders. These conversations were based on semi-structured schemas using a flexible approach that allowed the gathering of the informants' perspectives on specific issues, or as a way of checking whether the informant could confirm insights and information the researchers already held (Myers, 2008).

After collecting the data, the processes of data reduction, data display, conclusion drawing and verification (Miles & Huberman, 1994) have been carried out. As argued by Gilmore and Coviello (1999), in case study based investigations, this approach guarantees the highest degree of reliability. The analysis of data followed an inductive and iterative process (Miles and Huberman, 1994; Strauss and Corbin, 1998). The field source materials mainly consisted of notes and approximately 50 design artifacts. This material was edited and organized in a single profile document in which photographs were positioned in sequence with relative caption (date, caption). Notes from direct observations were placed in a loose, thematic narrative structure, and design artifacts were organized accordingly to coincide with this narrative. This resulted in the concise textual and visual documentation of all the material which was subsequently elaborated upon to write the draft of the final report.

The data were subsequently organised into tables to ease comparisons, and the importance of some concepts representing the key elements of the analysis were highlighted. The data was interpreted by seeking out relationships occurring between the different stakeholders and identifying the way through which the translation process was developed using design. Finally, as described by Eisenhardt (1989), a further series of iterations between the data, both secondary and primary, and the literature has been conducted to better ground the theoretical foundations of our investigation into current scholarly work. The Table 2 summarizes the type of data source, data analysis process used in the research and their contribution to the development of case study.

Data collection and analysis	Description	Main contribution
Participant observation	Initial data gathering. A series of about 50 design artifacts (images, videos, 3D models, etc.) are collected. For each design artifact additional notes on how this artifact was used by the various stakeholders are recorded.	Open innovation process in 3D Tune-in 3D Tune-in typologies of Design artifacts
Archival analysis	Additional information in relation to both the artifacts and the stakeholders are gathered from sources such as: project deliverables and the websites of the 3D Tune-In partners.	3D Tune-in typologies of Design artifacts classification
First set of semi-structured conversations	Six semi-structured conversations are conducted with 3D Tune-In stakeholders to collect further information in relation to the design artifacts and their role as seen by these stakeholders.	Process of knowledge translation in 3D tune-in supported by the design artifacts Stakeholders knowledge interactions
Data analysis, reduction, display and identification of interpretation patterns	Data is put into tables and analyzed in light of the theoretical constructs originated from our literature review. The data analysis process is conducted through a combination of sessions where each of the authors works individually and then shares their result with the other researchers. Interpretation patterns emerged from this process. Key findings are identified	Knowledge transfer process in 3D tune-in Design 's role in Knowledge transfer
Second set of	A second set of conversations with other five 3D Tune-	Cross-boundaries flows

semi-structured conversations	In stakeholders allows collecting further evidence, also in relation to the key findings produced in the previous phase.	and knowledge translation in 3D Tune- In among the stakeholders
Further iteration with literature	A second review of key literature allows to better ground the theoretical foundations of our investigation into current scholarly work.	Key propositions about the contribution of design in the process of knowledge transfer

Table 2. Data collection, analysis and contribution

3.3 Validity

Four types of methods proposed by Yin (2009) to improve the validity of a qualitative case research have been adopted: construct validity, internal validity, external validity and reliability. Firstly, construct validity can be executed by utilizing a wide variety of sources of evidence to establish reliable chains of evidence. In our case, we used a combination of data collection methods, from ethnographic observation, up to different types of archival documents, such as websites, articles and printed report and materials. Using these different sources, it was possible to cross-check the findings and, therefore, to create trustworthiness. Secondly, internal validity is assured by identifying causal relationships and patterns in the case research. This is executed by relating empirical data to existing research. Thirdly, external validity is proved by the generalization of the study results. As the research only contains one case, the generalization of the findings could be considered limited. Awareness of these limitations improves the external validity. Finally, reliability has been improved in the following way: all the data utilized in the research has been well documented into archival records eventually accessible by other researchers.

Next sections will present and discuss the findings of the research.

4. Presentation of the case and findings

4.1 Open innovation processes in 3D Tune-In

3D Tune-In is articulated into a research component (i.e., elaborating novel audio algorithms to be combined with gamification mechanisms) and a more applied component (i.e., creating and distributing videogames to fine tune hearing aids). Both these components benefited from cross-boundary knowledge flows, thus characterizing 3D Tune-In as an interesting case of open innovation in R&D. More specifically, these processes were distributed almost across the entire spectrum of open innovation categories provided by the already cited Van de Vrande et al. (2009).

Firstly, already starting from the initial phases of technology exploration, the 3D Tune-In consortium was quite permeable. Reciprocal flows of information and knowledge circulated among the various partners (e.g., academic partners were providing cutting-edge research in audio technologies, videogame companies were providing their expertise in gamification mechanisms) both within and beyond the borders of the consortium. One of the main tenets of 3D Tune-In was that a big portion of the software developed during the project would have to be released as open source. This would give the possibility not only to broadly disseminate the results of the project, but also to involve external parties (e.g., organizations and/or developers that were not part of the original 3D Tune-In consortium) in the design and development activities. A specific and quite nuanced licensing strategy would give the possibility for external parties to contribute to the code, maintain authorship and, potentially, also generate revenues through a dedicated commercial licensing track. This dual nature of the open source scheme adopted by 3D Tune-In would allow supporting multiple open innovation processes:

- *External networking*, with the possibility of drawing from the external knowledge of organizations and developers that would decide to build upon the released open source software and branch out in multiple directions. For example, an external open source programmer who was not part of the original 3D Tune-In consortium would download the core 3D Tune-In software and further develop some technical functionalities in order to create a new application. A specific approach toward open source licensing would regulate this external in order for it to keep benefiting the core 3D Tune-In software (e.g., maintaining and further developing functionalities) and, thus, supporting reciprocal flows of knowledge across the core members of the consortium and the external open source community. Github, with its over 12 million users[1], was the Internet platform used to host and distribute the 3D Tune-In software to the open source developers.
- *Inward IP licensing*, with the possibility of embedding in 3D Tune-In existing algorithms and software components, developed by external third party and available within and for the open source community. This happened, for example, in the case of the core engine for the 3D Tune-In software, which – in its final articulation - embedded technological modules developed by third parties.
- *Outsourcing R&D* to external entities. This happened when a 3D Tune-In partner started collaborating with an external research center specialized in sound technologies. What was being produced within the 3D Tune-In consortium was shared with this external research center and this research center offered the possibility to use and build upon its own innovative technologies.
- *Customer involvement.* 3D Tune-In adopted a dual strategy to involve two kinds of customers: (1) end-users (hearing impaired and their families, relatives and friends), who would access the games directly produced by the original 3D Tune-In consortium and (2) external creative industries (e.g., videogame companies) that would create new games and software applications based upon the 3D Tune-In software. End-users were quite heavily involved in iterative participatory design processes (various cycles where software specifications, visual interfaces and core functionalities were collaboratively designed, tested and refined). As for the second type of customers – the external creative industries - in a spirit of open innovation 3D Tune-In decided to release for free also various wrappers (i.e., specific interfaces that allow also non-programmers to use the main functionalities of the 3D Tune-In software). For example, one of

the wrappers is a plugin that integrates the core 3D Tune-In functionalities (Head-Related Transfer Function binaural spatialization algorithm, sound sources distance simulation and full-3D environmental simulation) into the popular videogame development platform Unity[2]. Unity is a massively distributed software platform that can be used also by non-programmers who want to create videogames. In other words, any of the 4.5 million active users of Unity[3] would be able to use the 3D Tune-In wrapper, access to the 3D Tune-In core technological features and, potentially, contribute to the project by producing additional software applications or games aimed at hearing impaired.

In relation to the technology exploitation, a dual strategy in terms of intellectual property management – both supporting free distribution and commercial distribution – allowed to keep the door open not only to *outward IP licensing*, but also to *venturing*, by giving the chance to various 3D Tune-In partners to start new companies and/or non-profit organizations starting from what was being created in the project.

4.2 The role of design for knowledge translation in 3D Tune- In

The 3D Tune-In's open innovation processes saw the collaboration of a large number of stakeholders, both internal and external to the consortium: academic institutions, small videogame companies, a large hearing aid manufacturer, other companies working in healthcare, NGOs, audiologists, hospitals, people suffering from hearing loss, policy makers, external developers from the open source community. The interplay of these stakeholders was often troubled by differences in terms of interests, needs and languages. Ultimately, each of these stakeholders was looking at the project from their own perspective and building upon their own specialized knowledge: the companies were much more expert in processes of commercial exploitation, but knew nothing or very little in relation to hearing aid technologies; academic partners were quite expert in advancement in sound technologies, but not so much versed into defining business plans; the audiologists were quite at ease with the components of the project more tied to health care issues, but could not always follow the scientific and business technicalities, and so on. In a project that relies upon open innovation dynamics – and, consequently, upon a quite high number of external stakeholders – these differences can be an important obstacle to overcome. It was a quite common condition to have stakeholders who would speak different languages; for example, audiologists would tend to frame the challenges of 3D Tune-In using quite technical acoustics concepts, such as 'binaural spatialization'; other stakeholders were not familiar with these concepts and had difficulties in understanding them. It was also quite common to have stakeholders with contrasting needs and interests. For example, some stakeholders from academia would be in favor of releasing almost all the software algorithms developed in 3D Tune-In as freely available open source; conversely, some other stakeholders – namely, some of the companies of the consortium – wanted to keep a good portion of the software for internal use and avoid massive open source distributions. At times during the project, these differences created troubles in communication and in coordination.

In these cases, 3D Tune-In adopted design as a mechanism for knowledge translation. Throughout the open innovation practices, a great attention was put in consistently using a designerly approach to 'translate' ideas, theoretical and technical requirements, documents and outputs into various formats: sketches, various visual representations including motion graphics videos, prototypes. These design-based translations were mostly performed by the core members of the initial 3D Tune-In consortium. The decision to use design methods was deliberate and based upon previous specific experiences of some partners of the consortium.

Already during the first year of the project, the 3D Tune-In partners of the consortium started presenting the project to external stakeholders, calling for their collaboration in the spirit of open innovation. One important element to present was some detail on the technological advancements of the project (e.g., the binaural spatialization engine and the hearing loss and hearing aid simulators). These technological advancements were initially codified in written language (e.g., in technical deliverables such as system requirements or scientific papers). Subsequently, these technological advancements were translated into various other formats in order for them to be simultaneously presented to various target groups: (a) a motion graphics video and (b) some early sketches, both targeted to a wide audience, including press representatives; (c) some design-based artifacts (personas), which were the main characters of short stories illustrating the advancements of the project and which were used while explaining 3D Tune-In to end-users; (d) a visual diagram – termed 'traffic light' – where the technological work behind 3D Tune-In was framed in relation to various interactions among open source license schemes. This visual diagram was mostly targeted to organizations interested in exploiting 3D Tune-In. Figure 1 provides a representation of the various translational processes occurred during the first year of 3D Tune-In.

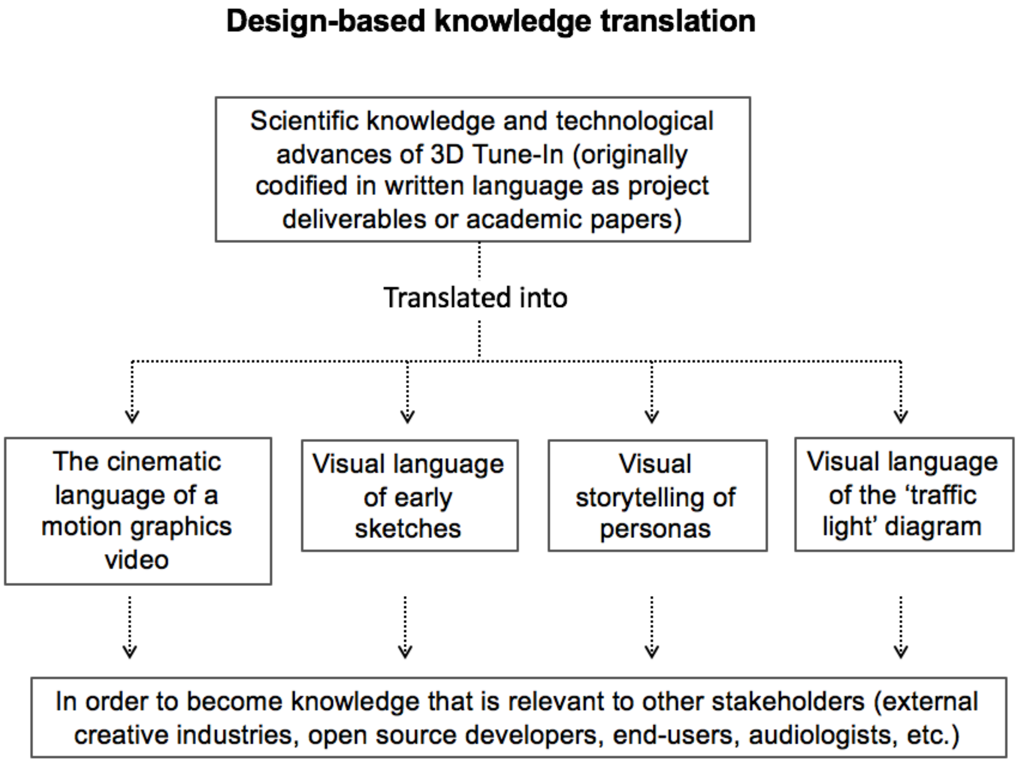

Figure 1. Design-based translational processes occurred during the first year of 3D Tune-In

All these outcomes were aimed at different external stakeholders (other academics, audiologists and medical personnel, videogame companies, policy makers from the European Commission, open source developers) and, as such, were translating the technological advancement of 3D Tune-In (as originally formulated in the written language of the initial proposal) into various formats and languages: graphic representations, the cinematic language of the motion graphics video, the visual storytelling of the personas.

Figure 2. Early visualization of a videogame built using 3D Tune-In technologies (courtesy of Vianet, one of the partners of 3D Tune-In)

Figure 2 shows one of these translations, an early visual representation of the user interface for a videogame, where the player has to catch a mosquito that flies around a room. During the game, the player (a) wears a virtual hearing aid (that simulates hearing loss) and (b) cannot see the mosquito and, therefore, can only count on her hearing to find the exact position of the mosquito. Figure 2 was the result of various iterations of interaction and visual design processes performed by various partners of 3D Tune-In, including various SMEs and academic centers. A visual representation like Figure 2 might 'speak' in a different way to an audience of software and game developers, if compared to the language used in the academic paper contextually written: "a custom binaural 3D audio engine will be developed and implemented, including functionalities such as binaural reverberation, Head Related Transfer Function selection and hearing loss and hearing aid simulation" (Picinali et al., 2015). Figure 2 is a visual representation (a visual translation) of the same technological advances described in the paper as embedded into the user interface of a videogame. Our analysis Our processes of data analysis, reduction, display and identification of interpretation patterns (described in Table 2) allowed to see how design artifacts such as Figure 2 translate the outcomes of 3D Tune-In into a language that can be more easily understood and appreciated by (1) the various internal partners of 3D Tune-In (e.g., SMEs not specialized in acoustic technologies); (2) by the multitude of external videogame companies potentially interested in the project, and (3) by the end-users (e.g., videogame players suffering from hearing loss). In line with what the literature on design for open innovation suggests (von Hippel 2005), these end users were actively involved since the earliest stage of 3D Tune-In, through a series of collaborative sessions where they were actively engaged not only in testing 3D Tune-In applications, but also in contributing to the design and development stages at various levels.

Figure 3 is another visual diagram, which looks at the technological advancements of 3D Tune-In from a different perspective: the legal implications connected to various open source licensing schemes.

	General specification	Redistribution	Modifications of the original source code or software	Patents allowed and protected	Allows to derivate proprietary software	Allows trade mark ™	GNU compatibility	Certified
GPL	Open license with strong copyleft approach: the author/s preserves her/his own intellectual property rights. If he/she integrates a new solution with GPL software under another license type, the final source code should be under GPL.	YES	YES	INDIRECT FOR GPL v2 DIRECT FOR GPL v3	NO	YES	YES	YES
BSD	Non-copyleft permissive license; includes an advertising clause. Incompatible with GPL. Mention to original authors and provide the source code is non-obligatory	YES	YES	NO[2]	YES	NO	NO (BSD modified, YES, with GPL)	YES
Mozilla	Limited copyleft. Open source. Non compatible with GPL	YES	YES	YES	YES	YES	NO	YES
MIT (X11 License)	Premissive open source license with limited copyleft	YES	YES	NO	YES	NO	YES	YES
Apache	Open source, permissive and non-copyleft licence. Patents are allowed. Incompatible with GPL	YES	YES	YES (Apache 2)	YES	YES (v1) NO (v2)	NO	YES
Eclipse	Open Source and weak copyleft. Incompatible with GPL	YES	YES	YES	YES	YES	NO	YES
Affero	Derived from GPL GNU. Copyleft. Aims to ensure the community cooperation for web-based software	YES	YES	YES	NO	YES	-	-

Figure 3. Visual diagram representing interplay of various open source licensing schemes (courtesy of Nerlaska, one of the partners of 3D Tune-In)

A visual diagram like Figure 3 can translate quite technical legal frameworks into formats, which are easier to understand and more relevant for external open source developers. In the diagram, various colors – green, orange and red – are plotted into a matrix to show potential conflicts in the application of various licenses and the interplay among the licenses and various legal applications of use. Figure 3 originated from visual design processes mostly carried out by a company within the 3D Tune-In consortium. Figure 3 'translated' a quite long written document where these legal conditions where carefully studied. This document was written in a language that was not easy to understand by people without a specific background in copyright law and, therefore, the visual diagram was created in order to represent the key elements of the document into a simplified format.

Figure 2 and Figure 3 represent two examples of the many design-based translation that has occurred in 3D Tune-In. Moving from the recursive process of data analysis, data display and of interpretation of patterns (see Table 2), and on the basis of the above findings and reasoning, the following proposition is advanced:

> *P1. In the context of a R&D-oriented and open innovation project, where multiple stakeholders speak different languages and have different needs and interests, design artifacts can support processes where knowledge is translated into formats (e.g., sketches, mock-ups, videos, prototypes) that can be more easily understood and appreciated by these different stakeholders.*

4.3 Cross-boundaries flows and knowledge translation in 3D Tune- In

3D Tune-In saw the collaboration of a large number of stakeholders, which contributed to the project offering their specific expertise and building upon their specific experience. Knowledge flew across the boundaries of the single organizations and the individuals involved in the project. In some of these occasions, knowledge was simply transferred, for example when a document internally produced by the 3D Tune-In core partners (e.g., a written document containing system specifications) would be circulated to external stakeholders. In some other occasions, knowledge needed to be translated before being transferred. For example, if some documents internally produced were too technical or too academic or too detailed for an external audience, then the 3D Tune-In consortium would translate them into a different format (e.g., a simplified visual diagram). Figure 4 shows a representation of the various internal and external knowledge flows in 3D Tune-In.

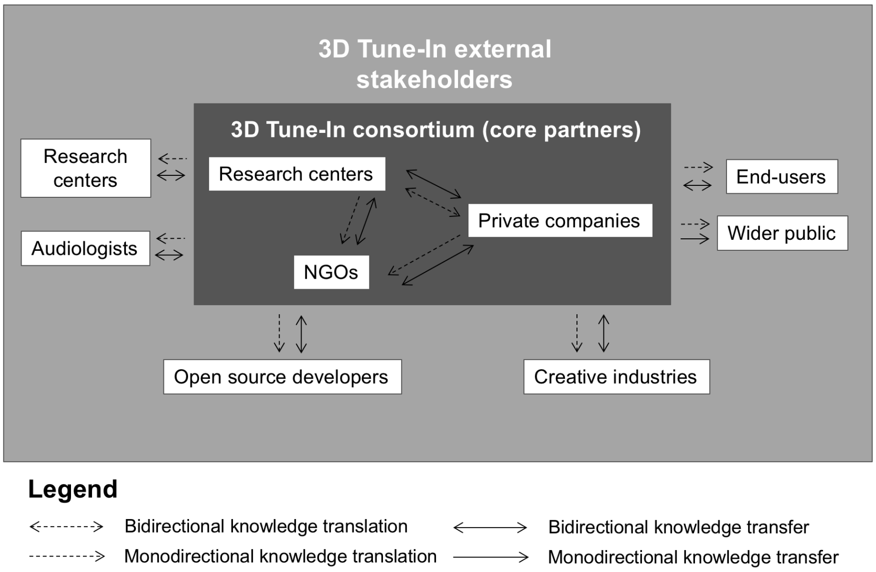

Figure 4. Cross-boundary knowledge flows in 3D Tune-In

Within the 3D Tune-In core partners, both bidirectional knowledge transfer and bidirectional knowledge translation were occurring between research centers and private companies. Both types of organizations were not only transferring their specialized knowledge to each other, but were also translating this knowledge in order for it to be more easily understood and/or relevant to the other partners (for example, producing design-based translations like visualizations or prototypes). Both the research centers and the companies were also using these translations while interacting with the NGOs (i.e., the associations for hearing impaired). Thanks to these translations, these NGOs could be more easily engaged into the project and could transfer their specialized knowledge (e.g., their specific expertise with hearing aids) to the other partners. This knowledge was generally transferred participating to some meetings and workshops or answering to some questionnaires. The NGOs did not directly perform any design-based translation, but were only the recipient of translations performed by research centers and private companies.

While within the 3D Tune-In consortium the knowledge translation flows were bidirectional, as most of the partners were actively producing and sharing visual artifacts among them, the knowledge translation flows directed toward external stakeholders were monodirectional. The 3D Tune-In consortium created various design-based translations like videos, visual diagrams and prototypes to interact with all the external stakeholders (other research centers and audiologists, open source developers, creative industries, end-users and wider public). These translations were important mechanisms to engage these stakeholders and activate mostly bidirectional knowledge transfer flows, where these external stakeholders were not only receiving knowledge assets from the 3D Tune-In consortium (e.g., new software algorithms for binaural reverberation or strategies for Head Related Transfer Function selection), but were also giving back knowledge to the consortium (e.g., an external research center would offer its specialized knowledge on specific music file formats or an external programmer would branch out and further develop some software functionalities in an open source spirit).

The above findings suggest the following proposition:

> *P2. In the context of an open innovation R&D-oriented project where multiple stakeholders interact, different cross boundaries knowledge flows can be at play: monodirectional and bidirectional knowledge transfers and monodirectional and bidirectional knowledge translations.*

5. Discussion

Open innovation relies upon knowledge flows across the boundaries of single organizations (e.g. Benkler, 2006; Chesbrough, 2003; Perkmann, and Walsh, 2007; von Hippel, 2001). The knowledge transfer which takes place between two or more actors (individuals or organisations) requires appropriate mechanisms to align the potentially different needs, language and interests of these actors (Acha, 2008).

The illustrated case study of the 3D Tune-In R&D project shows how the gathering, sharing and disseminating of project-related knowledge is quite challenging in relation not only to the vast number of final potential end-users (according to the World Health Organization over 360 million people worldwide currently suffer from hearing loss), but also to the massive amount of users, which could build upon 3D Tune-In technologies (e.g., 4.5 million Unity users; 12 million GitHub users; several thousand audiologists).

In a project like 3D Tune-In, what is important is not only to transfer knowledge to these users, but, instead, to actively involve them into joint processes of knowledge creation, where, for example, external GitHub programmers can branch out and further develop the 3D Tune-In engines, or where Unity programmers can deploy these engines in multiple contexts of use. The activity of these external users – the knowledge developed by them while working on 3D Tune-In technologies - needs to be captured and processed by the core members of the consortium in order, for example, to get feedback on the technological components to be further developed or to get additional ideas for exploitation. In order for these knowledge flows to happen across the various organizational boundaries (Chesbrough and Bogers, 2014), it is important to translate specialized knowledge from and to different domains. Stakeholders located in these domains (e.g., videogame companies, audiologists, computer scientists, etc.) speak different languages and might have divergent needs and interests. Translational processes are needed to help these stakeholders in understanding each other and profitably working together.

Within this context, why is it that design artifacts were important for 3D Tune-In? The consortium might have produced only written translations, for example creating various texts that translated from the academic language or from the legal language into a language more easily understood by layperson (e.g., through written summaries or paraphrases). Why is it that these 'written' translations were not enough and design-based translations were also needed?

Firstly, design would give the possibility to complement the written language producing a variety of artefacts, spanning from visual representations to more tangible prototypes (e.g., when some virtual reality demos were created). These design-based artifacts translated the written, academic language in which 3D Tune-In was originally formulated into forms that could be engaging, playful, easy to understand and easy to circulate. These design-based artifacts could be quickly disseminated across various communication channels, also the ones that build upon a combination of images and/or videos and short texts (i.e., YouTube, Twitter, etc.). These channels were of great importance to ignite and sustain interactions with external stakeholders, where knowledge was transferred and exchanged.

Secondly, design would give the possibility to get to various degrees of accuracy or ambiguity. Some visual artifacts were created with the idea of describing the key elements of the project with great precision (e.g., Figure 2 or the motion graphic video published on the home page of the 3D Tune-In website). Some other artifacts were, in nature, more ambiguous, such as Figure 3, which could only hint at the complexity of the legal interrelations among the various licensing strategies. The color schemes used to represent potential incompatibilities among various open source licenses only offered some preliminary indications, which from a legal perspective resulted quite ambiguously specified. This ambiguity allowed each stakeholder to interpret Figure 3 considering their own ideas as regards the exploitation of the 3D Tune-In R&D results. Ambiguity is not necessarily something to fight for the sake of clarity. On the contrary, in some cases, ambiguity can help and support coordinated action among various stakeholders. Ambiguity creates some adaptability, where stakeholders with different needs and interests can interpret the same situation from their own viewpoints, thus finding the way to collaborate despite the divergences. This was the case of the legal framework of 3D Tune-In as captured in Figure 3 and its relatively low level of stringency. The ambiguity of that representation allowed the various organizations interested in the exploitation processes to look at the project through their own perspectives and follow their exploitation trajectory according to quite flexible and adaptable legal constraints.

It is also interesting to look at the various degrees of accuracy or ambiguity of design artifacts in relation to different phases of the 3D Tune-In project. Figure 2 was an accurate representation that emerged from the interaction (and the periodic face-to-face meetings and Skype calls) of various internal partners of the 3D Tune-In consortium. Figure 2 was created and shared already during the early phases of the project. The level of accuracy of this figure offered a precise representation of the technological possibilities of 3D Tune-In. Consequently, Figure 2 might have played a role in aligning the various stakeholders involved in the project providing them with clear indications in relation to the technological potential of the project. Conversely, Figure 3 was created at a later stage of the project. Its ambiguity was meant to give the project stakeholders the opportunity to find their own exploitation trajectory. While Figure 2 supported convergence and alignment of various stakeholders, Figure 3 fueled organizational and individual divergences in exploitation strategies. Both artifacts translated knowledge in a way that could be shared among and appreciated by different stakeholders, but, in different phases of the project, the specific stringency of translation - oscillating between various degrees of accuracy and ambiguity – was peculiar and oriented toward supporting convergence and divergence among stakeholders. This reasoning brings us to the final proposition:

> *P3. The specific translational possibilities offered by design allow varying between different degrees of accuracy and ambiguity in translation. Varying the specific stringency of translation gives the flexibility to adapt the processes of knowledge translation in relation to the need or the opportunity to support convergence or divergence among the stakeholders in different phases of open innovation in R&D-oriented projects.*

6. Conclusions

Prior studies have indicated that an important opportunity to broaden the scope of open innovation is to take into consideration the contexts of R&D intensive industry and R&D projects (Kogut, 2000; Kim et al., 2015). Effectively managing transfer, acquisition and co-creation of knowledge among different stakeholders and partners is therefore pivotal to make open innovation a valid practice (e.g. Lichtenthaler, 2011; Natalicchio et al., 2014), thus requiring effective knowledge transfer mechanisms. This study meets this gap by integrating the open innovation and knowledge transfer literature through a contribution deriving from design research. The concept of translation allows looking at the strong complementarity that exists between these three research fields.

Open innovation occurs where knowledge flows beyond the boundaries of a single organization and where a high degree of cross-border organizational collaborations take place. Scholars have identified the external sources of knowledge suitable for fostering knowledge creation: customers, suppliers, competitors, institutions and universities (Fabrizio 2009; Sofka and Grimpe 2010). The main contribution of this paper is precisely in relation to how design can support open innovation processes since it gives the possibility to translate knowledge flows among different stakeholders in multiple ways. At different stages of the R&D project and in relation to different stakeholders, various design artifacts (sketches, data visualization and prototypes) can oscillate between different degrees of accuracy, stringency and ambiguity. This creates some sort of fluctuations in the interpretative processes, where the various stakeholders can appropriate, adapt, recombine and transform the knowledge in a way that is more relevant to their own needs and interests. The analysis of our case showed how a visual diagram representing various open source licenses was plastic enough to make 3D

Tune-In simultaneously appealing for both an academic center strongly advocating for free software distribution and for a company more interested into commercial exploitation. Another design artifact - a visual representation of the user interface - was plastic enough in order to work as a technological demonstrator for a sound engineer specialized in hearing loss technologies and for an end-user who does not have any specific competency in this field. In other terms, design gives the possibility to translate knowledge as to accommodate for potential divergences among the various involved stakeholders. As such, design-based translations can support open innovation within a R&D context in various ways. Translating the key outcomes of research into various formats that can be easily interpreted by the various stakeholders in light of their own perspectives and fuel convergence and divergence. Consequently, these stakeholders can carve their own focus of interest and can be more motivated towards collaborating in the project. Since these design-based artifacts can easily circulate not only across various organizational boundaries but also through various media channels (e.g., videos and visual representations can be widely disseminated through YouTube, Flicks, Instagram, etc.), they are particularly suitable in relation to the high number of stakeholders involved in open innovation.

Ultimately, design-based translations help streamlining openly distributed research and development processes by coordinating and aligning a high number of stakeholders and their divergent needs and interests.

Implications for theory and practice

This paper provides insights on how design can be deliberately used in an R&D context characterized by cross-boundary knowledge flows. Scholars can use this study to understand some key issues (such as the degree of accuracy and ambiguity) when looking at design as knowledge translation mechanisms in R&D projects and, more specifically, in the context of open innovation. This study also provides practical suggestions to organizations and individuals interested in adopting open innovation processes for their R&D projects. Creating design artifacts at various levels of accuracy and/or ambiguity can play an important role in supporting knowledge transfer and translation.

3D Tune-In is not a limited and isolated case as regards the adoption of open innovation approaches and the involvement of a large number of stakeholders. Various institutions - including the European Commission and the US National Science Foundation – are pushing scientists and researchers to adopt open innovation processes. The analysis provided by this paper suggests that design can help research projects in better communicating with various stakeholders and in aligning their different needs, interests and languages. As such, these translations are a way of expressing meaning in different languages (e.g., translating state-of-the-art scientific advances into the visual language of a sketch or the tangible language of a physical prototype), which can be more easily understood by diverse stakeholders. Research coordinators, administrators and researchers can, therefore, consider the possibility of hiring professional designers or of adopting design methods in their projects. By studying flows of design-based knowledge translations across a networked R&D project, distinct literature streams are taken together: open innovation, knowledge management and design research. By integrating these three different fields of study, this paper aims to provide an original contribution to the understanding of design as a knowledge-based translation mechanism to support knowledge transfer and combination in open innovation.

Limitations and future research

We acknowledge that the use of a single case study can constrain the generalizability of the research implications; however, it is important to point out that the insights of this study are the result of an in-depth analysis of a three years' R&D-oriented open innovation research project, in a segment of application (hearing technology), which has provided a significant context of investigation to explore the role of design as a knowledge-based translation mechanism in open innovation. We call for further investigations to contribute to theory building and empirical testing about the role of design as a knowledge translation mechanism supporting knowledge processes in open innovation. Particularly, the oscillation between accuracy and ambiguity in translation deserves more attention and need to be more closely scrutinized as various modes of using design as translation.

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