INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

OPEN DESIGN PLATFORMS FOR OPEN SOURCE PRODUCT DEVELOPMENT: CURRENT STATE AND REQUIREMENTS

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Abstract

The spread of ICT and cheap low-size production tools like 3D-printers led to the development of open design, i.e. community-based and open source development of physical products. This innovative organization of product development offers a great opportunity for continuous improvement of products as well as formidable a potential for product innovation and incubation of new businesses. However, because of a limited availability of supporting methods and tools, open design projects are still unable to compete with today's standards of industrial product design. The present article aims at providing a state of the art of existing online tools for open source product development and discusses their limitation regarding the challenges raised by what is identified as an emerging design paradigm. This is performed through the definition of an analysis grid through which existing tools have been scanned as well as a case study. It claims for further empirical research in order to describe the phenomenon from a design science perspective, to define appropriate categories and develop new specific online product data management tools.

Keywords: Open Source Design, Information management, Design methodology

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

The spread of ICT and cheap low-size production tools like 3D-printers led to the development of open design, i.e. community-based and open source development of physical products. This innovative organization of product creation based on a new conception of copyright as well as decentralized and voluntary work offers a disruptive alternative to conventional industrial product development. It offers a great opportunity for continuous improvement of products as well as formidable potentials for product innovation and incubation of new businesses.

However, the emergence of open design still suffers from a limited availability of supporting methods and online tools helping to face the organizational challenges raised by distributed collaboration of non-experts, non-professional and non-contractually engaged volunteers. Because of a lack of structuration mechanisms, open design projects are so far restricted to the development of products of low complexity and quality. In order to compete with today's standards of industrial product design, open design shall be provided with adapted methods that ensure significant process efficiency.

The present article aims at providing a state of the art of existing online tools for open source product development and discusses their limitations regarding the challenges raised by open design. Section 2 is dedicated to the definition of the emerging paradigm of open design and attempts to highlight its distinctive characteristics. Section 3 describes the methodology adopted for the review of online tools whose results are presented in section 4. In Section 5, the case of an early attempt to develop an open design platform is reported and analysed, before requirements for further research can be presented in section 6.

2 OPEN DESIGN: AN EMERGING DESIGN PARADIGM

Open design is a phenomenon that emerges since the late 90s, and as such, there is no broadly accepted terminology and definitions. We refer to the term *open design* as defined by Geyer et al. (2012): "the openness of all accompanying documents in a product development process, with the aim of collaborative development of tangible objects". This is considered as an instantiation of the concept of *open source innovation* (OSI), defined by Raasch et al. (2009) as the "free revealing of information on a new design with the intention of collaborative development of a single design or a limited number of related designs for market or non-market exploitation". OSI originates from the domain of software development, namely the field of open source software (OSS). Originally an issue of passionate "hackers" moved by ideals and involved in a non-pecuniary economy, OSS turned out to be an interesting concept of labour organization that created a substantial market. The open source operating system Linux for example has proven to be a "billion dollar business" (Fjeldsted et al., 2012) and nowadays generate not less than a 36$ billion economy (Bauwens, 2009). More recently, due to the digitalization of product development, the concept OSI expanded to the development of physical products. This phenomenon has been indifferently referred to as open design and open hardware. In this article, we use the term open design because it explicitly refers to the process of product development and is more commonly used in academics whereas the term open hardware tends to designate mainly the development of electronic hardware and thus to leave mecha(tro)nical products aside. We define "open source product development process" as the product development process taking place in the frame of an open design project.

2.1 Significance and maturity of the phenomenon

Open design is still an emerging phenomenon but already yielded concrete and successful implementations (Howard et al., 2012; Raasch and Herstatt, 2011). Spearheads company-driven projects are for example the electronic chip-card best-seller Arduino (arduino.cc) and Local Motors (localmotors.com), a car that is registered completely under a Creative Commons license and is manufactured in distributed workshops. Spearheads community-driven projects are for example RepRap (reprap.org), a "self-replicable" 3D-printer, and Open Source Ecology (opensource-ecology.org), a project aimed at developing 40 machines that could provide for the basic needs of a local community. These promising examples as well as the current booming of starting open design projects allow envisioning a similar development path as for open source software.

While "openness" applies only to intellectual production; the production of physical products still requires the support of actual physical manufacturing systems. Manufacturing shows evolution that supports the emergence of open design as well. Some authors identified an emerging production paradigm they denominate with terms such as “open manufacturing” (Heyer and Seliger, 2012), “open production” (Wulfsberg et al., 2011), “crowd manufacturing” (Send et al., 2014) or “peer-production” (Benkler and Nissenbaum, 2006; Kostakis and Papachristou, 2014). Although there is no recognized leading term, the questions these concepts address are clear: Who can produce open source products and how to create economic value with those products? Several experimental decentralized manufacturing systems support community members in fabricating products by themselves. Fabrication Laboratories (FabLabs) (Gershenfeld, 2007) are open manufacturing workshops providing machines and skilled animators that allow people to realize their own projects of product creation. Alternatively, manufacturing as a service (MaaS) (Yip et al., 2011) companies can produce customized products on-demand and in small number (ex: i.materialize.com). Further concepts can support decentralized and community-based production. The CubeFactory (Mannan and Muschard, 2013) for example is a one cubic meter autonomous and mobile production system integrating four essential modules: production, closed-loop material supply, energy supply and knowledge transfer. Mini-factories are manufacturing systems that can fit in a shipping container that can be moved from one place to another to allow local value creation (Postawa et al., 2012).

From a business perspective, empirical evidence and economic theorists (Brynjolfsson and McAfee, 2014; Rifkin, 2014) suggest that the preconditions for a substantial role of open participatory settings for value creation are present. As a matter of fact, an increasing number of firms defy the dominant logic of generating and capturing value by product development and succinct value capture through intellectual property rights.

Open design is hence a significant phenomenon, is supported by trends in manufacturing technology and organization, and is therefore a promising field for business. On the other side, it faces significant challenges that may be of interest for several scientific disciplines. For example: understanding the dynamics of online communities and defining the concept of community itself, developing motivation models for contributors, identifying business models that allow to create sustainable economic value with open source products, understanding the decision processes at stake in horizontal work organizations, clarifying legal issues of intellectual property, identifying ways to ensure and validate product quality, liability and safety. Open Design and more largely OSI have been in focus of research works in business economics (e.g. Chesbrough and Appleyard, 2007), innovation management (e.g. Raasch et al., 2009) and competition law (e.g. Dreier and Leistner, 2013), but remain uncovered by design sciences.

2.2 On the concept of openness

What first characterizes open design is the concept of "openness" of product development projects, a concept that consists of more shades than initially obvious. Openness refers to the use of non-pecuniary inbound and outbound flows of information/expertise/resources, i.e. from inside the project team to the public domain and the other way round (Dahlander and Gann, 2010). It applies more particularly to two aspects of product development: the process and its outcome (Huizingh, 2011). While the classical model of product development is characterized by both closed process (involving a defined team within the company) and outcome (the product definition is “hidden and protected” (Fjeldsted et al., 2012) by the use of patents), crowdsourcing is characterized by an open process but a closed outcome and OSI is characterized by both open processes and outcomes.

How open a product development project is, is further determined by three factors (Balka et al., 2010): transparency (access to sufficient information to understand the project details), accessibility (possibility for community members to take an active part in the development) and replicability (possibility of self-assembly of the product). Openness is moreover a gradual concept: projects are not either completely open or closed. On the contrary, actors of open design projects generally consciously choose which parts of the product they reveal in order to protect their core competences and businesses (Balka et al., 2010).

Geyer et al. (2012) empirically further distinguish open source projects that are driven by a company from those who are emerging from a community. In community-driven projects, all phases of the product development are performed by an undefined crowd of members: product ideation, development, prototyping and production. In contrast to this, company-driven projects are aimed at developing new products or improving existing products to finally be produced and sold by the company. A further level of complexity is considering the temporal transformation of projects within the open/closed and company/community ranges. Some projects for example may start as totally open and community driven and turn to partially closed and company driven, as the famous example of MakerBot shows.

2.3 Characterization of open design projects

The openness in product development projects results in fundamental differences compared to conventional industrial product development. As open design is based on open access to product-related information and voluntary participation in the product development, contribution of project members is not sealed by a contractual agreement but instead is motivated by individual objectives that can cover a large range of motivations, from professional networking to political action or even fun (Depoorter, 2013; Send et al., 2014). The organization of work in open design projects is characterized by a low level of restrictions, self-motivation and self-selection of tasks (Müller-Seitz and Reger, 2010). In this context, the product development can no more be seen as a defined project with clearly defined inputs, outputs and time-line, but rather as an on-going process of continuous improvement by a community of interested people (Bonvoisin et al., 2013; Geyer et al., 2012). This leads to an amalgamation of the development and production phases of the product lifecycle (Raasch et al., 2009): many open source development projects do not stop after attaining a completed product but enter a continuous improvement process (Balka et al., 2009). As a consequence, open source product development can be understood less as a project than as a *community of practices* (Müller-Seitz and Reger, 2010). This is a crucial aspect of open design regarding design science, as it contrasts with traditionally considered design processes and raises new challenges for knowledge and product data management as well as sharing of common representations.

2.4 Crucial issue: structuring the open source product development process

Because of today's lack of adapted methods and IT-tools, the vast majority of open design projects is still restricted to the development of products of low complexity and quality. Methods and tools are required in order to allow open design to reach the quality standards of conventional industrial product development (Hansen and Howard, 2013).
This first requires a re-conceptualization of the product development process (Howard et al., 2012) – as traditionally described by the well-anchored models of e.g. Pahl & Beitz (Pahl and Beitz, 1988) or Ulrich & Eppinger (Ulrich and Eppinger, 2011), and on which existing product development methods and supporting tools are based. In order to offer systematic product development methods dedicated to open design projects, existing models have to be challenged and adapted to the specific constraints of open design, in particular:

- Product modular design. The ability to structure the product in a modular way has been identified by several authors as a critical point for the success of open designs projects. Modular product design may allow collaboration in loosely-coupled organizations (MacCormack et al., 2012), enable parallel and frequent release policy (Raasch and Herstatt, 2011), self-selection of tasks by project members (Müller-Seitz and Reger, 2010), partial protection of intellectual property (Li and Mirhosseini, 2012) and reuse of already existing modules (O'Grady and Liang, 1998).
- Process effectiveness and efficiency. Considering open design as community of practices, the ability to ensure individual contributions converge effectively and efficiently towards a finished product design is challenging in a context where decisions are made in a decentralized way. Validation mechanisms ensuring the approval or rejection of individual contributions and helping the coordination of individual efforts in the community are required. The possibility to validate designs (Howard et al., 2012) and to perform replicable real-life tests of product parts and to capture and disseminate the results among the community (Müller-Seitz and Reger, 2010) also are a challenge.

Open design projects, because they are depending on interactions on the Internet, further require adapted collaboration platforms. Howard et al. (2012) stated that "Open Design is waiting for its very own Source Forge" (Source Forge is an internet platform that serves as structuration platform for open source software projects). A collaboration platform is the core element of an open design project around which a community can emerge (Fjeldsted et al., 2012; Müller-Seitz and Reger, 2010).
Although to date there is no integrated open design platform, the expansion of open design projects is supported by a wide range of existing collaborative IT-tools. Various online tools already available

provide functionalities giving partial solutions for these challenges. Platforms have been developed to support information exchange in online communities, and some open design projects have developed their own rudimentary collaboration platforms. But the functionalities offered by these existing tools are rather limited to basic functions like data repository, and still fail to support an efficient collaborative development of complex products. The concept of an appropriate open design platform is hence to be developed and implemented in order to fulfil the practical needs of open design communities (Hansen and Howard, 2013). Such a platform shall notably:

- implement methods for systematic open source product development in order to guide individual efforts of community members towards a finished product design;
- provide online tools enabling collaborative engineering, thus supporting simultaneously the three functional spaces of collaboration (Brissaud and Garro, 1998): communication (e.g. chat, wiki), cooperation (e.g. concurrent text editing) and coordination (e.g. task allocation through workflows).
- Enable knowledge management and expertise sharing among the community. This implies notably enabling project members to ‘broadcast’ problems and solutions among the community and to comment on someone else’s ideas (Müller-Seitz and Reger, 2010). Define a modular product data structure to help rationalizing product-related information, managing a high number of product variants, supporting efficient distribution of design and manufacturing tasks and supporting configuration management.

In the next sections, we present a systematic study of existing online tools and platforms in order to assess to what extent they cover the needs of open design communities and to identify improvement potentials for further research and development.

3 ANALYSIS OF EXISTING IT-TOOLS FOR OPEN DESIGN

In this section, we identify tools that can be used in the frame of open source product development and establish an analysis grid in order to evaluate their potential contribution to the needs of open design projects.

3.1 Existing tools

Open design is characterized by an amalgamation of the product lifecycle phases and shall less be seen as a form of project organization than as a community of practices. It therefore encompasses a larger range of activities than the product development process itself. It is therefore relevant to consider openness in a product lifecycle perspective (Gürtler et al., 2013). And actually tools to support all phases of the product lifecycle exist: product planning, product development, prototyping, production, maintenance and retail. In figure 1 on next page, different tool categories the authors identified for each phase of the life cycle are listed and provided with one example.

3.2 Analysis grid

We identify and define hereafter four dimensions that are of prime importance for the success of a product development project and that are particularly challenging in open design projects.

3.2.1 Community management

Acquisition of project members and creation of a community is a preliminary step for collaboration - a step that may be continued all along the course of the project. A community consists of the few core committed individuals, occasional contributors and a larger crowd of followers/users (Heyer and Seliger, 2012). Gathering members requires the ability to advertise the project, raise interest and create contacts. Among the features a platform can provide to support the management of a project community are:

- Project showcasing, i.e. presenting the objectives and current state of the project in a condensed and catchy way;
- Social network capabilities, i.e. the possibility for community members to create a profile and so to advertise his/herself, to formalize connections with other members and engage in communication as well as to declare their interest for projects ("like" or "follow");

- organization of challenges that may create external motivation (e.g. material or symbolic reward) for project contributors.

3.2.2 Convergence of the development process

Open design projects are based on voluntary participation and follow organizational models that are far away from the strongly directed and hierarchic industrial product development methods. Nonetheless, a certain degree of organization of the individual contributions is required, and the ability of the community to integrate them is crucial for the convergence of the project. Among the features a platform can provide to support distribution and integration of design tasks are:

- Clear product-related information standards, e.g. a form that indicates through its structure the type of information that has to be shared;
- Integration of the product modular structure in the information model, e.g. structuring information according to the product bill of materials;
- Identification of tasks and allocation to project members;
- Identification and attribution of roles and specific competences;
- Definition and execution of workflows;
- Broadcasting of events through notifications;
- Supporting tools for specific design tasks (e.g. CAD tool);
- Integration of decision making mechanisms, e.g. "thumb up" voting.

3.2.3 Knowledge and quality management

Reaching a continuous improvement requires an ever increasing consistency and structuration of generated knowledge as well as an ever increasing connection between product definition and actual needs. Quality assurance and knowledge management are broadly established fields in industry, but remain challenging to implement in a decentralized decision system. Among the features a platform can provide to support quality and knowledge management are:

- Allowing a clear expression of requirements;
- Support for testing, protocoling and adopt tests;
- Compilation and broadcasting of generated knowledge (e.g. best practices, findings, learnings);
- Versioning and configuration management system;
- Ability to reuse already developed parts or sub-systems.

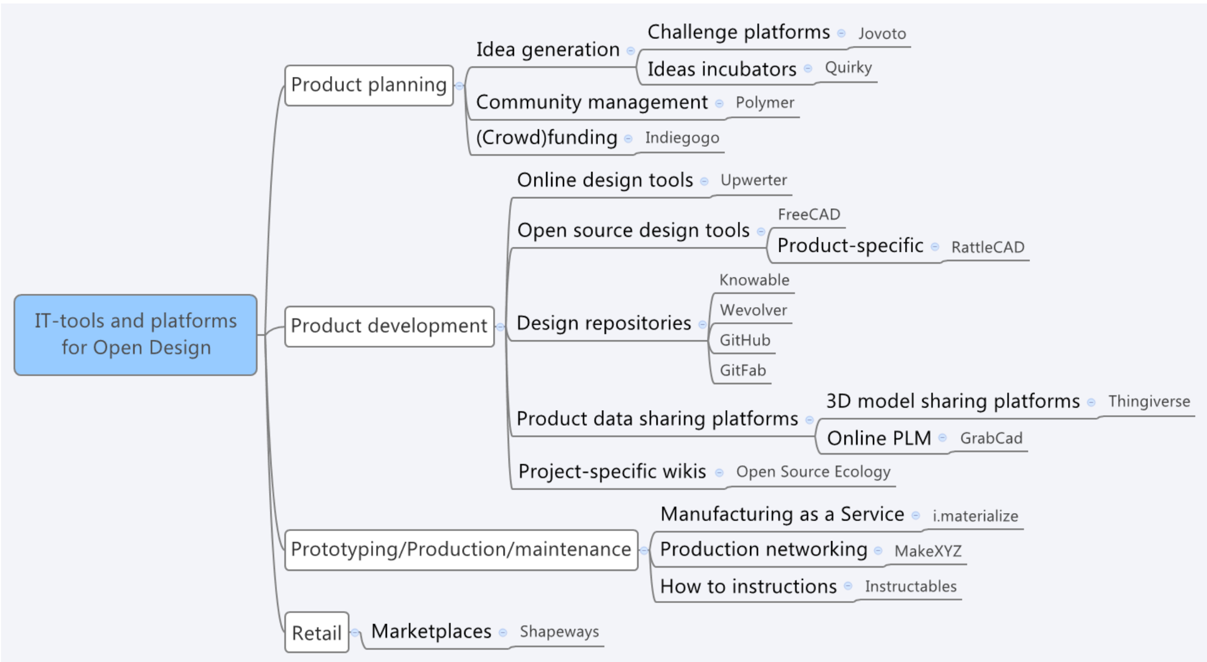

Figure 1. IT-Tools and platforms for open design

3.2.4 Supporting co-creation

Open design projects, as any collaborative project, call for a large number of interactions, including information exchange, discussions, debates and conflicts. Co-creation requires being able to exchange and work on shared objects and representations. Among the features a platform can provide to support co-creation are:

- Synchronous and asynchronous interpersonal communication and media sharing, e.g. mailing or chatting;
- Synchronous and asynchronous context-related communication, i.e. the ability to comment and discuss given information, (e.g. make annotations and sketches on 3D or 2D models or highlight text in a text file) or the ability to see and act on objects simultaneously (e.g. shared desktop);
- Open communication spaces, e.g. commenting on a project as a whole, forums.

In the following section, existing tools are evaluated with respect to their degree of contribution to the four critical dimensions identified in sections 3.2.1 to 3.2.4. Further, their appropriateness to support the two dimensions of openness (outcome and process) defined by Huizingh (2011), i.e. whether the tool allows integration of volunteers in collaborative work and if the outcome is aimed at being open source, is assessed. It is further distinguished if the tools are themselves open source and/or free of use. Finally the degree of maturity of the tools is evaluated (alpha, beta, run).

4 RESULTS

The result of the application of the analysis grid on the examined tools is shown in table 1. The tools are written in lines and the functionalities they may offer in columns. A cross ("x") marks whether a tool offers a given functionality. A dash ("-") indicates that the functionality is partially covered.

Table 1. Evaluation of existing IT-tools for open design

	Status			Openness				Features																					
								Community mgt.			Convergence of the product development process									Knowledge and quality management					Supporting co-creation				
Tool name	Alpha	Beta	Run	Open outcome	Open process	Open source tool	Free to use	Project showcasing	Social networking	Organization of challenges	Information standards	Product modular structure	Tasks	Roles and competences	Raise and follow issues	Workflows	Notifications	Supporting design tools	Decision making mechanisms	Expression of requirements	Testing	Compilation of knowledge	Part library	Versioning	Sync. interpersonal communication	Async. interpersonal communication	CR async. communication	CR sync. communication	Open communication space
Jovoto			x				x	x	x	x																			x
Quirky			x		x		x	x	x	x									x										x
Indiegogo			x				x	x	-																				x
Upwerter			x	x			x	x				x	x				x	x					x	x	x	x	x		
Free CAD			x			x	x											x											
RattleCAD			x			x	x											x											
Knowable		x		x	x		x	x	x				x	x			x					x					x		x
Polymer		x					x	x	x																				
Wevolver		x		x	-		x	x	x			x										x							x
GitHub			x	x	x		x	x	x						x		x							x			x		x
GitFab	x			x	-		x	x	x													x							x
Thingiverse			x	x			x	x	x																				x
GrabCAD			x	-			-	-	x			x	x				x	x					x	x			x		x
Open Source Ecology Wiki			x	x	x	x	x	x	-			-										x		x			x		x
I.materialize			x																										
Make XYZ			x				x																-						x
Instructables			x	x			x		x													x							x
Shapeways			x				x	x	x														-						x

Social networking, project showcasing and open communication spaces are the most widely represented functionalities. Among social networking features is the possibility to create a profile, declare competences and search for other people according to targeted competences (e.g. Knowable, Polymer) as well as watch projects and follow people (e.g. GitHub). Project showcasing generally allows editing text with embedded media (photos, videos) in order to present the project. Open communication spaces are most of the time represented by the possibility to comment on projects and react to these comments. An exception is the platform used by Open Source Ecology, which is based on a wiki and offers more complex interaction.

Other functionalities are significantly less represented, but sometimes interestingly implemented. Regarding the convergence of the product development process, some tools provide ways to assign and follow tasks (e.g. Upwerter, Knowable), to create teams (e.g. GitHub), to embed decision making features (e.g. Quirky), to make change propositions and to follow up issues (e.g. GitHub). Regarding knowledge and quality management, several tools provide document versioning (e.g. grabCAD, Open Source Ecology Wiki). Other allow for gathering and compilation of data/knowledge, without however offering sufficient versioning, with the exception of Open Source Ecology Wiki. Tools generally offer few features supporting co-creation, with the exception of some interesting annotation (e.g. Upwerter, GrabCAD) and commenting (e.g. Knowable) possibilities.

Some features haven't been found at all: provision of information standards, implementation of workflows, support for the expression of requirements and for product validation as well as content related synchronous communication features.

Finally, this analysis confirms the observation of Hansen and Howard (2013) that no existing platform integrates sufficient features to cover the needs of open source product development communities yet. This is notably shown by the fact that GitHub remains the most developed and used tool for community based product development, although it is a tool created for software development. Hence, the support of open design through online collaboration platforms is still in its infancy and further developments are required to develop an open design platform that could embed or integrate the dimensions defined in the analysis grid introduced here. The development of such a platform shall be supported by research on the open source product development process aimed at empirically describing the phenomenon and defining appropriate categories in order to develop useful methods for systematic open source product development.

5 CASE STUDY: CROWDSPIRIT

The case of an early attempt to develop an open design platform will help illustrating the introduced analysis grid. In 1997, at a time where the concept of open design was very new, a start-up located in the area of Grenoble, France, undertook the development of an open and collaborative product design platform: Crowdspirit. The idea was to support the whole creation process, relying on the crowd for all the major steps of product creation and commercialisation. The company focussed on electronic products and aimed at providing the market with products created and supported by a community of online developers. The ambition of the originator was "to become a flexible and agile new brand able to design, develop, produce, distribute, market & support innovative electronic products for generating significant margin with the full involvement of the crowdsourcing community”. Based on the model of the fabless company, Crowdspirit was ambitioning to create a new development model based on the intervention of communities at every step from product design to commercialization. Although the platform attracted a large number of potential contributors and therefore succeeded in generating a community, the venture collapsed soon after the creation because it failed to come to a real product.

Besides other issues that may exceed the field of product data management and product development, several shortcomings in product data management can be identified in this early and innovative attempt that could have contributed to its failure.

First, the idea generation phase was poorly organized and based on a simple structure of message threads with possibilities to attach images. Even for further design phases, discussions were only supported by forums and no design features, like 3D viewers, annotation functionalities, were available. Therefore, technical possibilities to express and exchange representations simultaneously or asynchronously may have been missing.

Second, no convergence mechanisms, for example including explicit task definition and allocation or workflows, had been implemented. In contrast to this, a relatively large range of roles had been defined (e.g. inventor, contributor, ambassador, investor), but only a few of them were used in reality and anyway were not assigned with any specific task or competence. This may reflect the difficulty to understand the motivation and activity patterns of contributors to open source product development projects and, as a result, to offer appropriate workflows and motivation mechanisms.

Third, the individual contributions failed to be compiled by an effective knowledge management and to converge to a consequent corpus of information. Parallel message threads on equal topics bringing separate complementary (or overlapping) information weren't avoided. No real collaboration or co-design occurred instead rather parallel and unarticulated contributions were provided.

Another more general reason possibly explaining this platform and community failed in delivering a product is the unclear position between open design and crowdsourcing adopted by the company. That may have led to confusion among contributors. The platform aimed at producing closed outcome with reward mechanisms for the participants. The product was supposed to be distributed by Crowdspirit under its own brand. However, there were no clear decision making mechanisms in order to manage the transition from public space to private development space. Although the tricky management of the border between open and closed exceeds the scope of this paper, the field of methodological and technical solutions to support this management could be explored by design science as well.

6 CONCLUSION

In this article, we attempted to characterize the open design paradigm from a design science point of view. We underlined the differences between open design and the conventional industrial model of product development on which methods and tools for product development are based. In line with previously published research, this led us to claim that, in order to allow open design to emerge further, online collaborative design platforms adapted to the disruptive characteristics of this paradigm should be developed. We identified the list of features such a platform could provide and reviewed the existing online, open source or freely available tools that implement these features. This review confirmed that the support of open design through online collaboration platforms is still in its infancy. No integrative platform has yet been developed that offers significant methodological and technical support for the management of the community, the convergence of the development process, knowledge management and co-creation. Further empirical research is required in order to understand the open source product development process and to shape adapted methods and tools. The study of the case Crowdspirit illustrated the difficulty to dispose of clear concepts to describe the phenomenon and to develop tools that provide the right balance between flexibility and convergence of the development process.

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