HOW AN OPEN SOURCE DESIGN COMMUNITY WORKS: THE CASE OF OPEN SOURCE ECOLOGY

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Abstract

Literature presents a huge number of studies related with the design process, but the open source design may present an environment fundamentally different. The involvement of a large number of people self-organized in the design process may generate some negative effects. Therefore, there is a necessity of better understanding of the open source design process and the tools that aid this process management. The objective of this paper is to increase the understanding on open source design and identifies research questions in this field. In order to achieve the proposed objective was realized an ethnographic case study in a non-profit organization called Open Source Ecology (OSE), which included an extensive document analysis added to about 800 hours of participant observation over a period of three months. We identified some big challenges faced by OSE regarding the design process, community, platform and business, which were deployed in some open research questions. Our findings indicate that, even though many accomplishments have been achieved, the open source design movement still has a low level of maturity, and is far from showing its full potential.

Keywords: Open Source Design, Collaborative design, Design process, Business models and considerations

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1 INTRODUCTION

In the past years, the nature of the relationship between consumers and companies has radically changed. The notion of an organization that produce for passive consumers, i.e. one that only buy and consume the products designed for producers, has been replaced by the concept of consumer-innovator. In this new paradigm, consumers own a central and active role in the design of new products. In some cases there are multiple users collaborating and openly sharing the generated outcomes (Baldwin and von Hippel, 2011, p.1399; Prahalad and Krishnan, 2008, p.3; von Hippel et al., 2011, p.27; Ilan 2011; Troxler 2011; Send et al. 2013, p.542).
Empirical studies confirm this paradigm change and present a variety of innovations that have been developed by users in different industries, e.g. oil refinement (Enos, 1962), scientific instruments (von Hippel, 1976), sport equipment (Shah, 2000; Hienerth, 2006), 3D printing (de Jong and de Bruijn, 2013; de Bruijn, 2010), musical instruments (Ilan, 2011), construction, agriculture and manufacture machines (Thomson and Jakubowski, 2012).
A survey conducted with British consumers concludes that 6.1% of United Kingdom residents, older than 18 year old, (about 2.9 million people) created or modified products used for them during the three years before the survey has been done. It represents an effort about 97,800 people-year, and an annual budget of £3.2 billion (more than 140% of all expenses with R&D in the consumer good industry of United Kingdom) (von Hippel et al., 2011). These authors also identified that most part of the users didn't worried about the intellectual property of their inventions. Instead of that, 17% of them usually share the creations with other users.
The open source software (OSS) movement has proved that a network of volunteers can write a software code as good as professional developers working for a big company. The Wikipedia showed that this strategy could be used to create a free online encyclopedia (Howe, 2006). Instead of only receiving, passively, information through the web, the participation of the users is evolving. They are becoming more active into the design process, creating self-organized virtual communities, sharing information and generating public content on Internet as results of these interactions (Panchal and Fathianathan, 2008).
The proliferation of this phenomenon was only possible due to technological advances that are contributing to break down barriers of cost that separate 'amateurs' from 'professionals' (Howe, 2006). These technologies include powerful personal computers; low-cost communication tools via the Internet; standard design languages, representations and tools; and modular architectures. In a modular architecture, the modules represent the elements of the product structure that provide, independently, one or more functions of the product, and are related with other modules through interfaces (Schuh et al., 2006). Thereby, if there is a change in a module it does not imply modifications in other ones. It allows that different people work on the development of different modules independently and in parallel, dividing a project into multiple tasks (Baldwin and von Hippel, 2011).
The web also provides the technology for this phenomenon. It allows the crowds aggregate diverse and independent ideas, without the riskiness of excessive communication and obligation to get a consensus between parts (Suowiecki, 2005). According to Suowiecki (2005), diversity and independency are very important for collaboration, because the best collective decisions come from disagreement and contestation instead consensus and harmony. De Jong and de Bruijn (2013) add the improvement of the citizen education as a driver that contributes with this phenomenon, since it makes them apt to articulate themselves in communities and get engaged into innovation activities.
We understand a community as "*networks of interpersonal ties that provide sociability, support, information, a sense of belonging and social identity*" (Wellman et al., 2002, p.153). Although user communities are more popular in software development, like Linux, Apache and Mozilla Firefox, they are not restricted only to software. (de Jong and de Bruijn, 2013). There are some initiatives that apply this concept in developing physical products, such as, Arduino, RepRap, OSVehicle, Zoybar, Open Source Ecology, Farm Hack and others.
Open source design practitioners, influenced by the OSS movement, collaborated to create a definition focused on physical products, called open source hardware. According with this definition: *"Open source hardware is a hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design. The hardware's source, the design from which it is made, is available in the preferred format for making modifications*

to it. Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open source design tools to maximize the ability of individuals to make and use hardware. Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs" (Open Source Hardware Definition, 2014).

Literature presents a huge number of studies related with the design process, but the open source design may present an environment fundamentally different. In the traditional collaboration, there is usually a main player responsible for the development of a new product that collaborates with some strategic partners along the supply chain. Generally, it occurs through the decomposition of the design problem into sub-problems that are passed on to strategic partners and so on. Thereby, there is a hierarchical team organization, it means that the relationship between players is one to one, according to the design problem breakdown structure, and the information flow is direct. A classic example of a traditional collaboration can be seen in the automotive industry, where automakers are the main player (Panchal and Fathianathan, 2008).

Instead, in the open source design there is a self-organization of the work division, since all project data is available, and the members of the community can choose in which part of the design problem they prefer to work. It is usually orchestrated through a 'publish and subscribe model'. In this model, the community members subscribe for a design problem or for specific task. Whenever someone edits the content related with the design problem/task, everybody that had subscribed for this problem/task receive a notification. Thus, there is an ad hoc team organization and many to one relationship, with the information flow based on the 'publish and subscribe' model (Panchal and Fathianathan, 2008).

Table 1. Differences between traditional collaboration and open source design (adapted from Panchal and Fathianathan, 2008)

Factor	**Traditional Collaboration**	**Open source design**
Work division	Top-down, hierarchical	Self-organization
Team members	Strategic partners	Member of a community
Team organization	Hierarchy and one to one relationship between sub-problem and company	Ad hoc and many to one relationship
Information flow	Direct flow	'Publish and subscribe'

According to Panchal and Fathianathan (2008), the involvement of a large number of people self-organized in the design process may generate some negative effects. The same authors suggest the necessity of understanding the design process in this collaborative environment and the tools that aid this process management. Fjeldsted et al. (2012) corroborate with them pointing out the lack of case studies as a major barrier for the creation of open source design methodologies.

Based on this context, the *objective of this paper is increase the understanding on open source design and identifies research questions in this field*. This is a first step of a larger research project that aims to propose a design process model that meets the particular characteristics of open source design. Thereby, in this paper we face the phenomenon of open source design with a management perspective, according to the conceptual model developed by Fjeldsted et al. (2012). The model is based around a core element: the platform, i.e. the virtual space that allows connections between stakeholders. Around the platform are the other elements of open source design, namely drive (what motivate stakeholders' participation), community (the network of stakeholders, mainly made up of users), development (the collaborative process for product design) and business (the business model that provides viability for open source design). Other perspectives such as sociology, psychology and law are not explored in depth, and we recognize this as a limitation of this study.

Section 2 of this paper summarise the methodology adopted in this research. In section 3 the findings are presented, and the paper concludes in section 4 with a final discussion about limitations of this research and plans for future works.

2 METHODOLOGY

This research is based on a qualitative approach, since it aims for a better understanding of the context studied, in order to capture perspectives and interpretations of individuals in their natural environment. Thereby, the research method adopted is the case study with an ethnographic perspective. A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 2003).The case study method has been influenced in this research by the ethnographic approach. It involves immersion of the researcher in the particular culture of the subjects being studied which provides a richness of data and context that simply cannot be obtained using protocol analysis or other formal research methods (Morgan and Tryfonas, 2011). This study cannot be considered a pure ethnographic research since it does not span a long period of time. According to Robson (2002), a true ethnographic research should involve a long time scales, over a period of years.
Figure 1 presents a summary of methodology, divided in four steps. Each step is detailed in the following sub-sections, except the conclusion that is presented in Section 4.

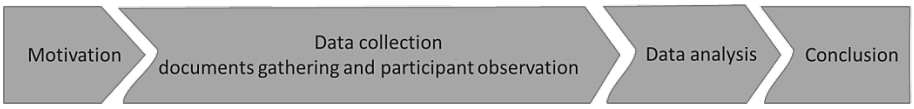

Figure 1. Summary of methodology

2.1 Motivation

This research was conducted in an American non-profit organization called Open Source Ecology (OSE), that has been working with open source design since 2003 and in the past years is passing for a increase of contributions after a widely exposure caused by the publication of a TED talk[1] (Jakubowski, 2011). This organizations aims to develop a set of 50 open source machines and tools, considered by them the most important resources to provide modern comforts and basic material autonomy. This set of machines is called Global Village Construction Set (GVCS) and covers the fields of agriculture, construction and manufacturing. With this, the OSE vision is to provide a minimum set of technologies necessary to create advanced civilization from locally available 'dirt and twigs' starting with a container-load of GVCS tools. To afford this, the products must be designed as a platform composed by interchangeable 'Lego-like modular systems', with a low cost and easy to assemble and customize. Each device should come with complete documentation, as well as manufacturing and assembly videos (Thomson and Jakubowski, 2012).
While looking for open source design initiatives, OSE was identified as the only case which held a design process model available on the internet (Figure 2). This fact drew the attention of the researches and contributed to the selection of OSE as the case of this research.

2.2 Data collection

In this research, there are used two data collection techniques: documents gathering and participant observation. The former is considered an 'inquiry from the outside', since it occurs by examining data generated by the organization. The latter is considered an 'inquire from the inside', once it happens by immersion, being there and becoming part of the phenomenon under study. The participant observation has become increasingly popular in organizational research, as soon as organizations can be faced as societies, with their own peculiar customs and practices (Iacono et al. 2009). While living and working as part of the community, the researcher face everyday limitations what provide a deep understanding not only of the work activities as of the organizational culture, allowing even the transfer of tacit knowledge (Howard-Grenville, 2005).
There were about 800 hours of participant observation between July and October of 2014. In this period of time, the researcher was in touch with about a hundred contributors along the development

[1] TED (Technology, Entertainment, Design) is a global set of conferences run by the private non-profit Sapling Foundation, under the slogan "Ideas Worth Spreading". Available on http://peandme.com/recommended-videos/ted-talks/. The TED talk that presents OSE had been viewed 1,262,502 times until March 12th, 2015.

of four products (a hydraulic power unit that consists of a gasoline engine coupled to a hydraulic pump, a brick making machine, an electric car for one passenger, and a modular house for two residents), each one in different design stages. During this period, a lot of notes were taken in a logbook, as well as photos and videos. All the data collected was analyzed as described in the sub-section 2.3.
The document gathering was initiated two months before, and helped in the preparation for the field research. All documents were collected from online repositories, mainly from the wiki. The collection of documents continued during the field research and also was useful to confirm some observations during the data analysis.

2.3 Data analysis

In this phase of the research, the documents gathered and the logbook containing the notes of the participant observation are reviewed and rewritten in a narrative format. The data analysis aimed to point out the main elements of open source design proposed by Fjeldsted et al. (2012) (platform, community, drive, development and business), and then compare our observations with existing literature. The most interesting findings are described in the next section.

3 FINDINGS

Open Source Ecology run most part by a single person, full time dedicated on site, and supported by a virtual community of engineers, programmers, architects, designers, farmers and entrepreneurs interested in open source, do-it-yourself, technologies. The main communication channel of the community is a wiki, besides that there are a photo[2] and a video[3] repositories, another repository for building instructions[4] and also an active social media page[5], focused on external relationships. To visualize the majority of content of this communication channels people don't need to become a member of the community, they just have to browse. To become a member of the community is very simple though, and anyone is allowed. Those interested just have to create an account on the wiki and start to edit its content. However, people usually have difficulty in finding relevant information.
There is no unified vision about how the wiki should be organized and its content has not been evaluated by a curation. It is reflected on the large amount of categories on the wiki (about 500), and even so a lot of uncategorized pages (about 5000) and files (about 7000); the quantity of orphan pages[6] (about 3400); and the quantity of dead-end pages[7] (about 5200). There are other problems that hinder the wiki usage, like two different pages (or even more) on the same topic, but with very specific titles; some pages read like a conversation someone had years ago; and some pages that are just a single link to a resource or to an organization. There are also a lot of pages with incomplete and outdated information. Therefore, the current situation of the wiki, even linked with other platforms, has not been able to support the product data management.
We also observe that the majority of contributors were not familiar with the OSE design process, presented in the Figure 2. According to this process model, their design process consists in an iterative process comprising six phases: (1) Research and Initial Design, (2) First Pass Design Review, (3) Design Refinement, (4) Design Review, (5) Build and Documentation, and (6) Project Review. The deliverables presented under the phase title are only a summary of the main deliverables. An extensive list, with about 80 deliverables, is presented in combination with the process model. This list includes deliverables such as product requirements, modules, interface design, diagrams, industry standards, bill of materials, CAD files, CAM files, etc.
According to the literature, one of the purposes of design process models is to help in organizing process knowledge, i.e. documentation and registers of design process data/information about the work and how to do it (Amigo et al., 2013). As we observe, in OSE the design process model is not

[2] Available at https://opensourceecology.trovebox.com
[3] Available at https://www.youtube.com/user/marcinose
[4] Available at http://opensourceecology.dozuki.com
[5] Available at https://www.facebook.com/OpenSourceEcology
[6] An orphan page is a page that has no link to there on the wiki.
[7] A dead-end page is a page without a link for other page on the wiki.

widespread among contributors, data has been created in a disorganized way and people usually have difficulty in finding relevant information.

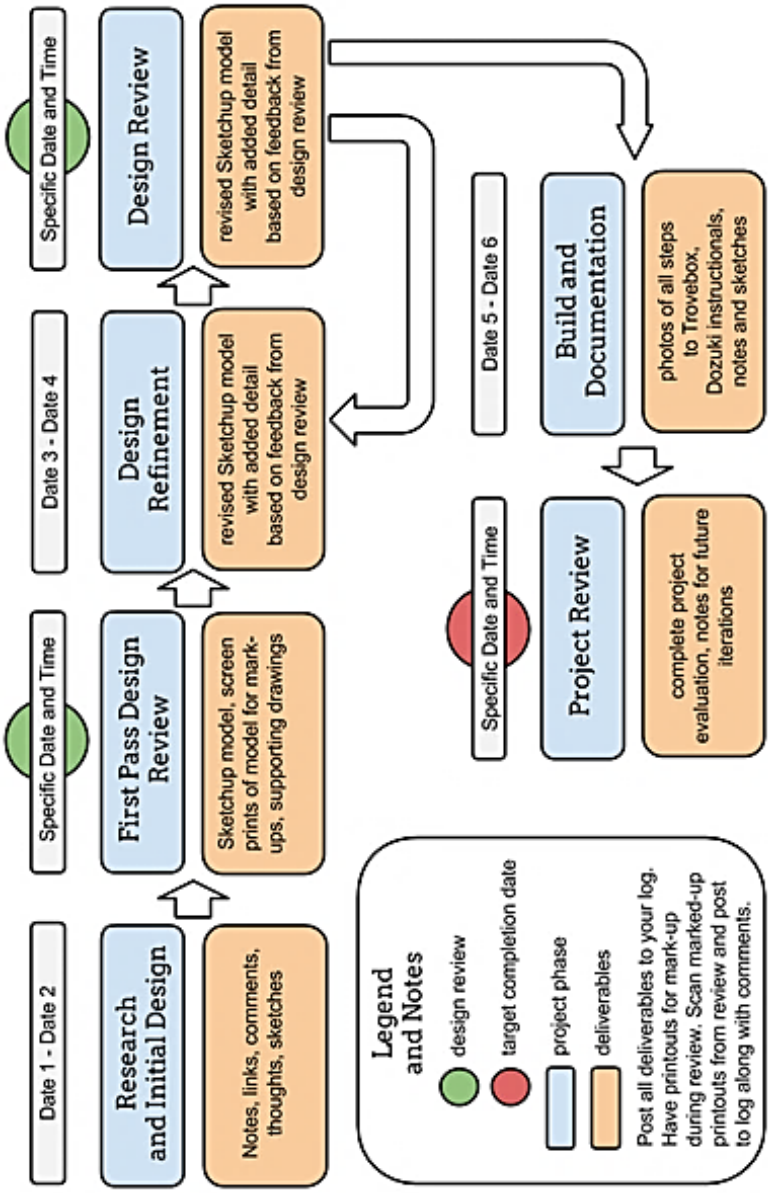

Figure 2. OSE design process model[8]

All projects that we have been involved had already the Research and Initial Design done. So, we don't have much information about how this phase is conducted. What we noticed, observing the outcomes of this phase, was that both the Research and Initial Design are realized with a heightened focus on the product itself, instead a human centred approach. In general, they aim to develop products that are robust, modular, low-cost, durable, easy to build and maintain. Issues like safety, sustainability, ergonomics and aesthetics are not priorities.

As shown in Figure 2, the phases labeled with a green circle consist in design reviews. These phases can be considered 'gates', defined by Cooper (2001) as a quality-control checkpoints after each phase where the path forward for the next phase is agreed. In the period of participant observation, we witnessed nine phase transitions and, in only one of them, a design review was done. Even in this case, it happened in a non-systematic way, with no criteria against which the project would be judged. This might be caused by a lack of knowledge in business process management and tight schedules. The

[8] Available at http://opensourceecology.org/wiki/Development_Template_-_November_2013

absence of a systematic approach increases the likelihood that errors and mistakes will not be correctly identified. In this way, opportunities for design improvements are not well explored.

In the next phase, Design Refinement, we had the opportunity to closely follow three projects being executed. According to our observation, this phase consists primarily in developing the 3D CAD model. Two of the observed projects were conducted mainly by a single contributor, with almost no collaboration in this phase. The other project got some collaboration during the Design Refinement, on the other hand, the generated outcome presented some failures that would hardly be committed by an expert. Some good practices, such as simulations and failure mode and effect analysis (FMEA), were neglected even in the design process model. When properly conducted FMEAs should lead to improve the quality, reliability and safety of products, and also serve as a form of documentation of risks and actions for future designs and processes (Stamatis, 2003).

The skills needed to participate in an open source design project have already been pointed out as a barrier by Send et al. (2013). In our experience, the organization's ability in attracting, retaining and managing skilled contributors proved to be an issue. Usually, many people are interested in open source projects. They interact in the social networks, make suggestions, and criticize, but actually only a few aims to help with some design task. Of those, many still have e lack of knowledge in engineering and no experience in designing products. These issues, added to the lack of leadership skills and the overloading of project leaders, make effective collaboration a big challenge.

The collaboration is also hampered by the absence of appropriate open source ICT tools (e.g. Computer-Aided Design tools, Finite Element Modeling tools, manufacturing process planning tools, etc.) to support the collaborative design, as well as the lack of standards for information exchange between tools (Panchal and Fathianathan, 2008). One alternative found by OSE was to promote video conferences in which all interested contributors simultaneously work on specific tasks, each one in an independent file, which are then merged manually by the project leader. These online meetings are called by them 'Design Sprints'.

When a complete release is achieved, it's time to move on to the next phase: Build and Documentation. This phase consists in prototyping the products and generating build instructions, i.e. a step by step guide, highly detailed, to allow a group of amateurs replicate the products. For each step, it should be informed the expected time, quantity of people required, the skills needed, beyond the description of the activity accompanied by an explanatory picture. Based on our experience, this phase usually takes one week, and happened on a workshop model. In the period of our participation, contributors from all over the world got together on site to work on this phase. It was the moment of most intense collaboration and knowledge exchange. However, we observed that there was difficulty in registering all suggestions and lessons learned by the contributors since most part of them happened in an informal way through conversations. Aiming to systematise the register of improvement opportunities a simple online form was used (Figure 3). This form allowed people to send suggestions from smartphones, tablets or laptops at the same time they were identified. Even being a good practice, it has not been widely adopted. Holding meetings, preferably supported by an appropriate method such as FMEA, might be a better alternative to systematise the register of improvement opportunities (Stamatis, 2003).

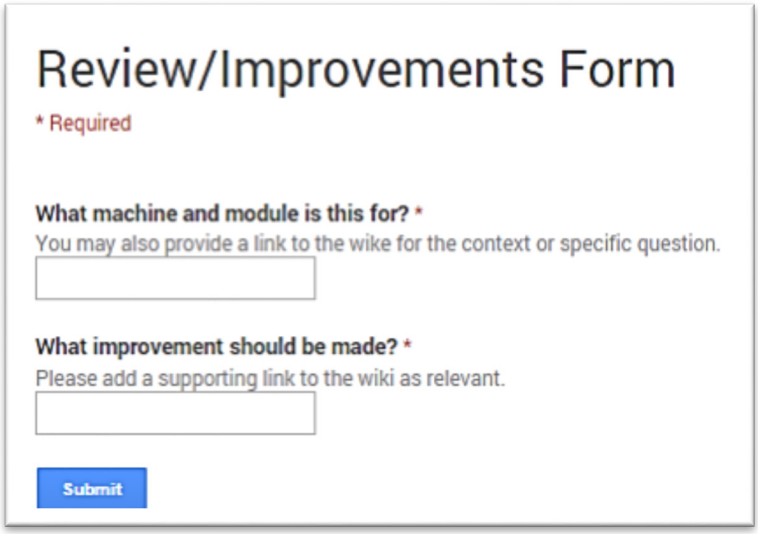

Figure 3. Review/Improvements form used by OSE

The workshop model, in which is based the Build and Documentation phase, represent an opportunity of revenue for its provider. Fjeldsted et al. (2012) suggest different possibilities of revenue stream for the open source design, such as consulting, advertising, governmental contracting, subscriptions, in-house manufacturing and distributing, and service sales. In the case of OSE, the registration fee for the workshops was, beside grant funding and donations, a representative revenue stream. Moreover, the sale of the prototypes developed becomes another source of revenue when there is demand for them. In the period of our participation, one prototype that we built was sold. On the other hand, as opposed to what happened in the OSS, to prototype physical products are required materials and components, as well as a workshop and tools (Send et al., 2013). Furthermore, it is of no use without skilled people on site to operate the machines, and a supply chain capable of providing what is needed. Those conditions are associated with a high investment and maintenance costs which represent a barrier for contributors to prototype/replicate the products by themselves.

After the Build and Documentation phase, according to the design process model, the product development project would be finished with a Project Review. We did not witness it happening. In practice, after completion of the prototype some tests were performed. However, in all projects which we had contact with, there were no experiments planning, not even a systematic way to collect and analyze the data. This may be due to the lack of knowledge of design methods, such as Design of Experiments (DOE) that has been utilized during the design process for efficient experiments and analysis of the results (Park, 2007). The absence of test as phase in the design process model is also an evidence that it has been neglected by the organization. As result, we witnessed products in use often breaking, sometimes a recurrence of the same failure.

4 DISCUSSIONS AND CONCLUSION

The objective of this paper was to increase the understanding on open source design. This was achieved based on the experience that one author had while living and working with an open source design community added to a period of document analysis and literature review. In this section, as part of the discussions, there are presented some open research questions, followed by the conclusion of this paper.

As result of this case study, we identified some big challenges faced by OSE regarding the design process. The Figure 4 summarise these challenges in a cause-and-effect diagram, in which the main effect is the low quality of the products designed by the community. According to our findings, we hypothesized five causes for the development of low-quality products: (1) there is difficulty in managing product data; (2) the design process is not widespread; (3) design methods are not widespread; (4) there is difficulty in getting effective collaboration; and (5) the requirements to prototype physical products are a barrier for contributors to prototype/replicate the products by themselves. Beyond these causes, we highlight the importance of interpersonal relationships and social

skills of the community leader/project leaders to keep contributors motivated in working with open source design.

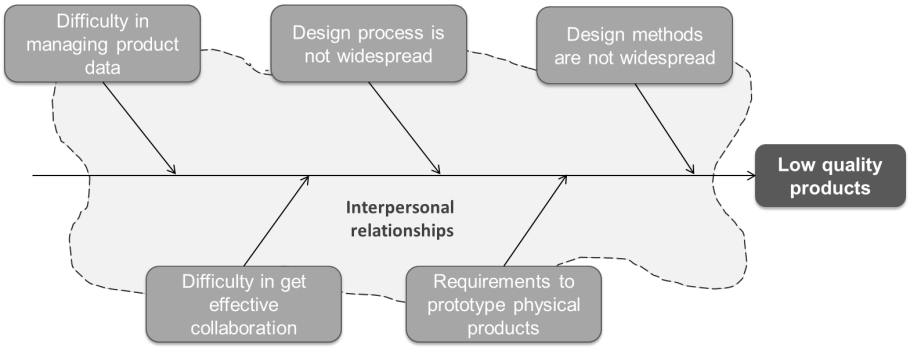

Figure 4. Main challenges faced by OSE

As presented in the preceding section, OSE has developed some practices aiming to overcome these challenges. We highlight the design sprints, focused on improve the collaboration; and the workshop model, focused on work around the barrier imposed by the requirements associated with prototyping physical products.

Our findings indicate that even though many accomplishments have been achieved, the open source design movement still has a low level of maturity, and is far from showing its full potential. We corroborate with Panchal and Fathianathan (2008) in stating that the open source design presents an different environment from the traditional collaborative design, but we believe that many of the traditional design practices can be applied in its context. It is up to the design academy together with open source design communities to find out which are the necessary adaptations. Although, researches on open source design are at an early stage, and more exploratory study is needed. For feature work, we suggest more qualitative researches to provide a deeper understanding of the open source design process and confirm the challenges identified for us. These challenges can also be deployed in some open research questions, such as: *How should be the platforms to support the product data management of open source design projects? Should the open source design process model have different views for different contributors? How detailed the open source design process models should be? What is the maturity level of open source design initiatives in design process management? Which design methods are they applying? Which adaptations are required to apply some design method in open source design initiatives? How should be the ICT tool to support the mass collaboration in open source design initiatives? How to encourage skilled people to participate in open source design initiatives?*

As emphasized in the introduction of the paper, a limitation is that the research is focused on the design process management perspective, and other important perspectives such as sociology, phycology, economics and law are not explored in depth. Other limitation inherent in the participant observation is that data is usually collected in a non-systematic manner through informal personal communications. This makes each observation unique and non-replicable (Iacono et al., 2009). Furthermore, in this research we only study a single case of open source design, and each of our conclusions might be biased by the organization's characteristics and context, and cannot be generalized. There was also a lack of participation in the first stages of the design process, since the period of time of participant observation was not enough to cover an entire project, since the initial design until the test of the product.

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