Practices in the design of open source products by online communities

Jérémy Bonvoisin, Robert Mies
Technische Universität Berlin, IWF
10587 Berlin – Allemagne
jeremy.bonvoisin@tu-berlin.de

Céline Gros, Jean-François Boujut
Univ. Grenoble Alpes, CNRS, G-SCOP
38000 Grenoble – France
celine.gros@grenoble-inp.fr

Laetitia Thomas, Karine Samuel
Univ. Grenoble Alpes, CNRS, CERAG
38000 Grenoble – France
laetitia.thomas@univ-grenoble-alpes.fr

Rainer Stark, Roland Jochem
Technische Universität Berlin, IWF
10587 Berlin – Allemagne

Résumé— ***The Open source software phenomenon is already well described in literature, but its evolution towards other fields such as tangible hardware product development, remains mostly theoretical. Existing literature has identified that to push the open source product development (OSPD) practice further process support is needed to support the organizational challenges of such projects in the achievement of high quality complex products. The functionalities of this process support have not been characterized yet. The objective of this article is to fill this gap by exploring the practices emerging from OSPD communities to observe current usages in order to collaborate incrementally in the future. To this end, Fjeldsted's framework were activated during a qualitative and comparative empirical study performed with 28 participants of OSPD projects through semi-directed interviews. The preliminary results indicate 3 main needs of these communities in the potential use of the platform which should serve to characterize OSPD projects. They also reveal the importance of the attitude of original founders, namely the capacity for openness and mutual learning, motivation for "hedonism", social entrepreneurship.***

Mots-clés— ***Open innovation, Open Source Product Design, Collaborative design platforms, Product development communities***

I. Introduction [Titre 1]

The rise of participative web technologies and low-cost rapid prototyping machines increasingly enables the general public to take an active part in manufacturing activities. On one side, in the context of the so-called "maker movement" [1], citizens "reclaim the production", that is, contest the monopoly of industry to manufacture products. Supported by open source or inexpensive CAD software, an emerging category of "home engineers" experiment home-based production and share their designs in online CAD repositories. Organized in repair-cafés or maker spaces, citizens learn and teach each other how to produce and repair things on their own. On the other side, value creation in companies tends to become more permeable to inputs from the outside. Under the umbrella of "open innovation" [2] this trend highlights the increased participation of the individual customer in the origination and even the development of the offer.

This context offers a fertile ground for the extension of the open source philosophy to the realms of physical products. Indeed, the last decade has seen the development of open source hardware: "open source hardware is 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" [3]. Clearly different profiles and motivations may lead to the development and publication of open source products. The ease of sharing digital content makes it possible for any product creator to publish their design online so that it can be copied or further developed by spontaneously emerging online communities. Online web technologies further allow distributed product development teams to emerge out of a common willingness of users to shape solutions adapted to their needs. Companies may also take advantage of open source publication in order to encourage the adoption of their products and stimulate market demand.

The objective of this article is to deliver a qualitative description of practices in open source product development (OSPD) from an engineering and management perspective by empirically testing four aspects of OSPD projects: the organisational structure of their surrounding community, their design process, their underling business models and the supporting online tools they use. The next section summarizes published knowledge about OSPD practices with a particular focus on development process and business models and introduces the research gap addressed in this article. The adopted methodological approach—a qualitative empirical study performed with 23 participants of OSPD projects—is introduced in section 3 and is followed by a description and discussion of preliminary findings.

II. What is open source product development

Open source software and open source hardware are categories of open source innovation as described by Raasch et al. [4]: "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." Although originally focused on electronic hardware, the term "open source hardware" is also used to refer to any type of tangible artefacts such as mechanical hardware, construction hardware or textile, as these technologies are gradually impacted by the phenomenon. In the context of this article focused on engineering and management practices, we define open source product development (OSPD) as the process of developing open source hardware.

In reference to the "Business Model Canvas" [5], [6] described OSPD projects as a combination of five factors: a platform (a meeting place for contributors), a drive (what motivates contribution), a community (the group of contributors), a development process and a business model. OSPD projects are moreover defined by their degree of openness, which is based on three factors: transparency, accessibility and replicability [7]. Transparency refers to the possibility for any interested person to access without restriction sufficient information to understand the product in detail. Accessibility refers to the possibility for any interested person to actively participate in the product development by editing design information. Replicability refers to the possibility for any interested person to physically produce the product. Bonvoisin et al. [8] analysed the publication behaviour of 76 ongoing and past open source mechanical hardware projects covering product categories such as agriculture machinery, machine-tools, means of transportation, renewable energy technologies or even medical equipment. Their results deliver empirical evidence of the OSPD phenomenon but also underline its heterogeneity, suggesting there may be divergent underlying motivations for going open source, whereas no explanation of this heterogeneity has been delivered.

A. Implication of openness for the product development process

How product development is influenced by the different aspects of openness has been hardly studied so far. Some empirical studies provide insights on the maturity of practices in OSPD projects. They above all underline the current low level of process support [9] [10] [11]. Hansen and Howard [12] as well as Bonvoisin and Boujut [13] highlight the role to be played by online collaboration platforms in providing the necessary structuring mechanisms. Both underline the lack of an appropriate platform designed to help product development communities face their organizational challenges and achieve high quality design of complex products.

Beyond the mere description of the current state of OSPD practices, some theoretical and empirical contributions have been made to identify the intrinsic characteristics of the OSPD process. It has been highlighted that, especially in OSPD projects aiming at accessibility (where participation of every interested person is welcomed), the development process is not characterized by clearly defined inputs, outputs and time-lines, but is more an on-going continuous improvement process [14] [15]. These projects are characterized by a low level of restrictions, self-motivation and self-selection of modular tasks. They are therefore not embedded in formal organisations but rather in communities of practice [16]. Aksulu and Wade's [17] highlight that open source development processes not only aim at generating a functioning technology, but equally at personal development and process learning. While in conventional product development, the technological output is well defined from the start, in OSPD, it tends to be loosely defined at project start and to mature over time.

B. Implication of openness in terms of business models

Early views on open source software actively excluded business ambitions [18]. Initially economists were puzzled by the possibility to capture value based on a collective good [19]. Then, Dahlander and Gann [20] described how open innovations comprise both pecuniary and non-pecuniary interactions. Teece in [21] highlights the lack of study of business models as an interdisciplinary topic in the social sciences or business studies despite their importance in capturing value for project entering new turfs. However, thus far, three different approaches of open source business models have been identified. First, Chesbrough [22] describes them as an amplification effect of innovation. Open innovation lowers the cost in innovation and product development - thus increasing the effectivity of value capture and creation. Second, Osterwalder & Pigneur [23] go beyond the inflow and selling of intellectual property and define open source business models as those were value capture rely on systematic collaboration with outside partners. Last, another perspective on open source business models is to discuss them in the context of market entry [24] [25].

Today, several options to build a business around open source software have been identified that can be applied to open source hardware [26] [27]. Dual licensing, as in the case of freemium models for instance, offers a version of free software as open source and a second version with added functionalities under a proprietary license with revenue. Another example is the service model based on revenues from services such as support and system implementation or consulting. Then, the retailer model sees profits from sales of complementary products such as books or materials. Additionally, distributors create new value by aggregating and optimizing open source material so that it becomes easier to install and use for everyday people. However, as described by Osterloh et al. [28] firms that heavily rely on external contributions from open source software face difficulties when choosing a proprietary business model.

The growing importance of open innovation is tied to distributed contribution, and crowdfunding is a natural development to this [2]. Through crowdfunding "proponents not only receive money, but they also collect suggestions and perform an early market test" [29]. Nevertheless Mollick [30] suggests “several determinants of the effectiveness of crowdfunding", leading to new measures of success in the context of open innovation projects.

C. Reasearch question

Few empirical descriptions OSPD practice have been delivered so far. For instance the functionalities of the process support that would be needed to push existing OSPD practice forward have not been characterized yet. The objective of this article is to fill this gap by exploring the practices emerging from OSPD communities to observe current usages. Based on an empirical approach, it activates Fjeldsted’s [6] framework by providing preliminary answers to the four following questions:

- Q1 - What kind of business models can OSPD projects base on?

- Q2 - What is the organizational structure of a product development community?
- Q3 - How is the product development process organized?
- Q4 - What are the requirements for appropriate online supporting platforms?

III. Methodology

In order to address the above mentioned questions, 23 interviews with initiators of OSPD projects were conducted. The criteria used for the selection of OSPD projects were:

• The product is a tangible and discrete manufactured product. Products of food, process industries and software products have been excluded. A large panel of technologies was considered from mechanical to electronic hardware to textile.

• The product is of minimal complexity and contains at least several parts. Products such as business card holders or cell phone cases made of one unique 3D-printed part do not fulfil this criterion.

• The product is labelled as open source by its surrounding development community and satisfies or aims to satisfy the criteria of transparency, i.e. blueprints and/or CAD files are publicly available.

Interviews were led following a semi-structured scheme: discussion was guided thematically through open questions in order to let unforeseen topics emerge. Interviewers were free to jump on one topic and to ask spontaneously further questions in order to grasp these new topics as long as all themes of the interviews were addressed at the end. Interviews were conducted by two people in order to increase the potential of live analysis and recorded so to maximize the potential analysis of ex post analysis. After each interview, a summary of findings was written collaboratively by both interviewers in order to identify the most salient themes.

Altogether 29 people were interviewed (for some project, more than one person was interviewed and some interviews were made with more than one interviewee). The average age was 33 years with a minimum of 23 and a maximum of 64. 86% of the interviewees were male while 14% were female. Five interviewers took part to the interview campaign. The interviewees were based in France, Germany, England, the United States, Finland, Spain, and Estonia.

IV. Currents findings

The present section depicts the preliminary results structured around the four research questions formulated in section 2.

A. *Business models*

High degree of customization. The perpetual dialogue with the community broadens the range of products and services. Contemplating the possibility of mass customization, interviewees specified that the open source movement is less about mass-manufacturing what is average and works for most, but rather what is optimum and works best for each context. For instance, depending on the project and the product, there is a "full spectrum" of potential products to be developed: a product to build from scratch, a final product, or a kit, including many options for personalisation. In this perspective the most pragmatic financial approach seems to be either workshops or ready to buy products. Because "a lot of people want to have the product but they are not so knowledgeable about how to make it on [their] own", the sales revenues will serve as a lifeline to support the project development.

Revenue models. The revenue streams of projects interviewed mainly come either from personal means, from external foundation grants or from crowdfunding sources. Crowdfunding, described by one interviewee as "one of the largest innovations in finance in the last century or more", is considered as a way to decentralize innovation and to allow anyone to develop their ideas. Some projects adopt on purpose a non-commercial strategy and aim at merely sustaining their activity. Some other projects consider a commercial strategy (e.g. based on product selling) as a way to strengthen their activity as well as the open source movement as a whole. When looking for financing, the interviewed projects find that banks will shirk away from the open source concept, and that venture capitalist's culture is too distant from their own, as they are mainly focused on securing income through protection of intellectual property.

Legal statuses. A third of the projects interviewed are non-profit, four are not legally set-up (hobbyists) and four are established companies. Five are "mid-goal entities" a blend of profit and non-profit, or Community Interest Companies (CIC) aimed to use their profits and assets for public good. Some projects shifted statuses during their development, until they found a suitable mid-goal entity. Open source projects have been reported to be challenging to classify legally.

Licensing. The same difficulty is faced with licensing (i.e. proprietary versus commercial) and patents. Protecting projects guarantees that they stay open, and that competitors do not seize-and-freeze the innovations. But it is confusing to choose the right one amid the different existing licences. The choice is ultimately tied to the project's overall vision. Furthermore, intellectual propriety is also a concern. Although most projects would be honored to see that their innovations are of use to others, it appeared common courtesy to at least acknowledge the original inventor. When asked about what they felt about competition, interviewees generally felt stimulated in the sense that a competitor's presence justified the need they were trying to meet. Surprisingly many concurred that if an outside company managed to do something similar in a better and more affordable way, that would be a victory, and they would even love to collaborate with them.

Normative pressure towards openness. There was a general dissatisfaction with projects such as a Makerbot who closed after receiving external funding. This was perceived as opportunistic, not in agreement with the open source philosophy and disappointing to the community. Starting closed and then opening seemed more chivalrous. True innovation was understood to be transparent, and even empowering as anyone can have access to the blueprint and knowledge to replicate. In this light, dual licensing can be considered as a realistic option.

Low cost innovation. Many of the projects interviewed saw the main advantage of open innovation as a means of lowering the cost in innovation and product development. The lowered cost structure of OSPD projects means that "you don't need much capital, you can start with an idea and develop it and afterwards it grows and everything is much better, more efficient and more effective from an innovation part to the economical part". Some even argued that this approach will lead to a positive societal transformation, in the sense that disciplines such as medicine will be more transparent, more efficient, involving more people trying to find solutions to a given problem. Perhaps, the natural propensity of open projects to develop communities and strategic partnerships serve as a value catalyzer. At times, what was first conceived as a product evolves into a pedagogical approach, which takes on a whole other dimension, when the project's holders realize that they were literally and positively changing the lives of others. Other times, the input from the community serves to create novel uses for a given product. Many interviewed projects mentioned that this constant iteration, between developers and community members leads to a perceived enhanced quality of OSPD products.

B. Organizational structure of communities

Two project archetypes. Projects seem to range between two archetypes: isolated innovators and development communities. Isolated innovators are characterized by a low willingness to co-design. They tend to publish their design only after they reached a first stable state, to strive at transparency and eventually replicability but not accessibility. As a consequence, their surrounding community leans towards a community of followers, replicators or users rather than a community of developers and there is a small number of stable members in the developing team. This team isn't much influenced by outside contributions and keeps the control on design decisions. On the contrary, development communities are characterized by high willingness to co-design with the surrounding community. They appear to adopt an early release policy, both for working documents regarding the product and the product development process. As a result, the development team usually consists of a core team and a dynamic and rather unstable participation of voluntary community members. Therefore, the originators of the project may have limited control over decisions as the design is highly influenced by the outside. However, the limit between these two extreme archetypes is blurred by factors such as the success in building a community. Indeed, some projects -- though willing to collaborate and hence striving at accessibility may experience difficulties in reaching their target audience and raising development communities--get stuck in the state of involuntary isolated innovator.

Division of work. No evidence of common organization schemes has been found beyond the existence of a small core team and of a larger group of unbound contributors in the case of development communities. Depending on the size of the project and its degree of collaboration, the activity of the core team may include participation in the collaborative product development process as well as management activities, such as facilitating the work of the community and ensuring the project goes on track. Beyond the scope of this core team, affiliation to a community appears fuzzy in terms of quality and quantity. First, the activity that defines affiliation may be understood in different ways depending on the project: who follows the project, who uses, buys the product, who gives feedback, who promotes the product, and who participates in the design. Second, active participation in a development community is voluntary and therefore characterized by a high turnover: people who come and go and may not finish their tasks. In other words, intensity of participation is fickle, and extremely flexible in time. Finally, communities may involve a part that is visible from the core team but also autonomous pockets whose activity is not visible. One often encountered pattern is that the core team may not be aware of the number of times the product has been replicated and eventually further developed. Keeping off-track activity visible without creating a centralized organization is therefore one challenge of core teams. Furthermore, there is no clear figure about the repartition of workload within development communities. However, there may be a significant workload imbalance in the visible part of communities, with the core team making the largest part of the work and the rest of the community performing little work. A challenge for the core team and the platform may then be to stimulate collaborative activity in order to correct this natural imbalance.

Diversity of motivations. Motivations to either create or contribute to a community may be diverse and difficult to categorize. However, two types of contributors in development communities can be cautiously identified. On the one side there are people directly interested in using the product for their own needs (i.e. for running and eventually improving their daily work in the case of agricultural machine or machine-tools). These people tend to be more and constantly involved and their contribution is seen as crucial for the progress of projects. On the other side there are people who may be more interested in the process of making an open source product than on the final product itself. Motivations may be diverse: boredom, affinity for a technology, enjoy the social aspect of working together, enrich a CV, or training. The contribution of these people tend however to be more volatile, may lack of continuity and may not form the sufficient basis for bringing projects forward.

Qualification. No evidence of lack of qualification or amateurism of project members has been found. On the contrary, people contributing tend to be highly qualified and specialized people (e.g. physician, engineer, and filmmaker). The level of formal education of the interviewed people is quite high (several masters, some PhDs).

C. Design process organization

Community momentum. Project initiators who would like to tap into the potential of co-design are presented with the challenge of building a development community. A lack of structuring mechanisms can prevent the emergence of a collaborative process, when collaborative tools and methods are not readily available or sufficiently understood, or dedicated resources for community management and required technological knowhow are lacking. This may result in a discrepancy between the initiators' intention to collaborate and the actual organisation of the design process. In some cases initiators may also want to involve volunteers and insist on maintaining exclusive ownership on their projects at the same time, thus limiting the available room for action. A crucial prerequisite to successfully create the necessary momentum for the emergence of a development community is the acceptance of a relative loss of control over the project; this loss of control being required for the emergence of the distributed organisation of work based on self-selection of tasks.

Process continuity. As mentioned earlier, product development communities are characterized by a high turnover of people, which majorly impedes process efficiency. Indeed, short involvement periods imply a higher ratio between the time spent for getting started and time spent on productive work as well as a higher rate of unfinished tasks. In order to offset the poor process efficiency related to the lack of stable staff, development communities tend to promote continuity and team awareness. They strive to ensure that new members who join become quickly accustomed to the current state of the project. In addition they ensure that information is not lost when people leave. The following strategies are implemented by core teams in order face these difficulties:

- Decrease process learning time by defining clear processes that can be quickly understood, publishing process-related information and providing training to newcomers.

- Increase team awareness by promoting the documentation of day-to-day activities (e.g. through work-logs) and facilitating project-related as well as social communication in order to bridge the geographical distance and strengthen social ties.

- Overcome turnover by rewarding individuals' contributions to encourage further involvement of the volunteers and therefore lower turnover and creating interfaces beyond product design issues (e.g. interfaces with other development communities).

Evolutionary design process. In a collaborative environment based on volunteer work and without effective operational structures, the essential instruments employed in heavyweight processes that ensure convergence fall short of accountability. Indeed, design briefs, milestones, or roadmaps have been observed to play a marginal role in the design activity. On the contrary, OSPD projects embedded in development communities implement a rather evolutionary design process. This process is driven by the formulation of requirements which are broken down in modular tasks, eventually embedded in a Kanban board, an issue tracking system or another project management tool. The objective is to reach the right level of granularity allowing a self-selection of tasks by the community members. This self-selection of tasks replaces conventional assignment mechanisms in a context where there is no operative hierarchical structure. How the contributions of community members are then gathered and combined depends on the collaborative development platform used and its versioning logic. For example, platforms based on the versioning software Git embed workflows allowing a central quality assessment of members' contributions performed by the core team with formally or informally stated criteria. Platforms such as wikis tend on the contrary to support what could be called a "do-ocracy" (with Depoorter [31]), i.e. a governance model allowing for anyone to initiate ad-hoc solutions as long as they are willing to provide them. In this case, the decision process tends to be implicit or even inexistent: the member who performed the changes being the one who decides of their integration, until his/her contribution is overridden by some other contribution. From a time perspective, external events such as maker fairs set a scene for presenting projects results and therefore tend to replace project milestones as a motivation driver to get tasks done.

Differentiation and convergence. Although the evolutionary design process described above seems lacking of structure, it has been reported to lead to sufficient process convergence. What enables coordination and integration of contributions towards convergence and eventually stable products is the provision of general project standards to set minimum requirements. Different levels of detail are structured in the form of vision statements, design guidelines, manuals or simply templates for task setting or contributions. In case of design conflict, a new avenue of development can branch off from the main project, leading to variations being simply pursued in parallel and ultimately leading to product differentiation. The emergence of spin-offs from a given project happens to be seen as a sign of proliferation not dissent. It results from this a possibility for every community member either to work towards process convergence or differentiation.

D. Overview of used supporting IT tools

Lack of integrated solution. In order to reach process efficiency and convergence in a context of voluntary work, defining product development processes striking the right balance between stability and flexibility is not enough. These processes also need to be supported by appropriate collaborative software tools. Different online platforms dedicated to OSPD exist already and have been reported to be used. However, a number of the interviewed practitioners underscored the limits of existing supporting software. There first seems to be a tension between an overabundance of specialized IT-tools on one side and the lack of an integrated solution for supporting the OSPD process on the other. The high diversity of used tools having conflicting functionalities, creates double work, or cannibalizes each other's communication channels. The abundance of tools is also reported to create a work overload, since tools have to be tested in order to find the appropriate ones and maintained. There is a noticeable improvement potential in terms of tool selection for appropriate functionalities and technical solutions; and the integration of such. The most frequent comment regarding the existing supporting tools is the lack of a “Github for hardware”, Github being a portal based on the open source versioning software Git and widely used in the open source software community. General purpose platforms such as wikis are considered as good candidates to integrate the necessary supporting functionalities. The advantage of these platforms is that they can embed additional modules extending on demand needed functionalities. They can also integrate documentation templates, which lowers the entry level for novices and generally reduce workload since they offer a predefined structure of data to be stored. Wikis were however reported to be messy, lacking structure and therefore requiring constant attention.

3D model integration. Among functionalities that have been identified as supportive for the OSPD process and that could be advantageously embedded in an integrated platform, the in-browser integration of 3D models is the most frequently cited one. This encompasses: 3D models viewing with interaction features (rotation, zoom, annotation, section, exploded view, version comparison), interoperability (compatibility with all types of 3D file formats), online and concurrent editing.

Predominance of open source software. Open source tools tend to be preferred to proprietary tools. A first reason is a normative pressure towards the ideal of a complete open source tool chain, i.e. that not only the result of the work is made open source, but also that the work is performed with open source tools. A second reason is the increased control over one's own data and the independence from software vendor or online portal providers. Keeping one's own data on her/his own servers prevents other stakeholders to suppress access to it, as in cases which have been reported in the interviews.

V. Discussion and outlook

The present article constitutes a first attempt to provide a detailed quantitative description of the emerging phenomenon of open source product development (OSPD) based on empiric data. The deeper knowledge gained on OSPD practices provides the necessary basis for the future development of methods and tools supporting OSPD communities in the efficient development of high quality and complex product. It also allows deriving more precise questions for further research. The observations reported in the previous section are summarized in table 1 (next page) together with the identification of corresponding challenges for practice.

Some of the observations reported in the previous section confirm, extend or clarify previous academic contributions. In terms of business models, the uncertainty in choosing the appropriate revenue model and intellectual property licensing scheme in order to launch or sustain their activity fits with the lack of clarity previously highlighted by Teece [21]. Regarding community structure, the identification of two OSPD project archetypes (development community and isolated innovator) delivers an interpretation to the heterogeneous behaviours of OSPD projects in terms of product-related data sharing first observed in Bonvoisin et al. [8]. Regarding design process organisation, the phenomenon of self-selection of modular tasks described by Müller-Seitz and Reger [16] has been identified as a feature of an evolutionary product development process implemented by development communities. Regarding supporting IT tools, this study clearly confirms the lack of integrated software support identified by Hansen and Howard [32] as well as Bonvoisin and Boujut [13]. Furthermore, it suggests that distributed IT-architecture and open source software are two characteristics which can positively influence the adoption by OSPD communities - an aspect that tends to be overlooked by the existing offer and by previous academic contributions such as these from Hansen and Howard [32].

The chosen methodology allows to cover a broad scope of topics and to get an overview of practices that are believed by the authors to be of upcoming relevance. A drawback of this methodology is that it does not allow drawing definitive and generally applicable conclusions. It should be noted as well that, due to its emergent nature, the studied phenomenon may be subject to rapid evolutions. Nonetheless, the quantity of performed interviews ensures that the results are representative of the current state of development of OSPD and highlight critical aspects from the perspective of various actors in the field.

The material presented in the previous sections is to be considered as starting hypotheses for further research, i.e. for further qualitative studies on a precise topic or for quantitative data acquisition. It is therefore hoped to open new research perspectives in the engineering and management research communities.

	Observed practice	**Challenges**
Q1 - Business models	• High degree of customization • Need of funding • Normative pressure towards openness	• Clarity in terms of which commercial of proprietary license to use • Find the appropriate legal status • Understanding of staged openness which would help articulate both incoming revenues and patents
Q2 - Organization structure of communities	• Two types of projects: isolated innovators and development communities • Core team surrounded by a community of contributors with diverse roles and working paces • Workload imbalance between core team and community • Two types of contributors: contribute for fun or contribute to fulfill a day-to-day need	• Create momentum so a community of developers emerge, if wanted • Facilitate the work of the community • Ensure the visibility and the convergence of activities • Mitigate the work imbalance • Settle the fickle contribution of hobby contributors
Q3 - Design process	• Discrepancy between level of wished and actual collaboration • High turnover decreasing the process efficiency • Diversity of strategies for ensuring continuity • Evolutionary design process • Tension between project convergence and differentiation	• Accept losing ubiquitous control on the project • Get access to sufficient supporting methods and tools • Ensure continuity • Ensure both pace and convergence of the design process
Q4 - Supporting IT tools	• Concurrent use of specialized IT tools creating double work and communication channels • Normative pressure and practical incentives to use open source tools	• Finding the appropriate tools for supporting the project. • Need for an integrated solution, a "GitHub for hardware" • In-browser integration of of 3D-Models required • Open source tools that can be deployed on the project's own server

Table 1. Observed practices of OSPD and corresponding challenges

VI. References

[1] C. VOIGT, C.S. MONTERO, M. MENICHINELLI. "An Empirically Informed Taxonomy for the Maker Movement", in: Bagnoli, F., Satsiou, A., Stavrakakis, I., Nesi, et al., (Eds.), Internet Science, Lecture Notes in Computer Science. Springer International Publishing, 2016, pp. 189–204.

[2] M. BOGERS, A.-K. ZOBEL, A. AFUAH, E. ALMIRALL, et al.. "The Open Innovation Research Landscape: Established Perspectives and Emerging Themes across Different Levels of Analysis" (SSRN Scholarly Paper No. ID 2817865). Social Science Research Network, Rochester, NY, 2016.

[3] Open Source Hardware Association. "The Open Source Hardware Definition" [WWW Document]. URL http://www.oshwa.org/definition/ (accessed 3.30.16), 2016.

[4] C. RAASCH, C. HERSTATT, K. BALKA. "On the open design of tangible goods". R&D Management, 2009, 39(4):382–393.

[5] A. OSTERWALDER, Y. PIGNEUR. "Business model generation: a handbook for visionaries, game changers, and challengers". John Wiley & Sons, 2010.

[6] A.S. FJELDSTED, G. ADALSTEINSDOTTIR, T.J. HOWARD, T.C. McAloone. "Open Source Development of Tangible Products-from a business perspective". Presented at the NordDesign 2012, Aalborg, Dennmark, 2012.

[7] K. BALKA, C. RAASCH, C. HERSTATT. "The Effect of Selective Openness on Value Creation in User Innovation Communities". Journal of Product Innovation Management 31(2), 2014, pp.392–407.

[8] J. BONVOISIN, R. MIES, R. JOCHEM, R. STARK. "Theorie und Praxis in der Open-Source-Produktentwicklung. Presented at the 1". Interdisziplinäre Konferenz zur Zukunft der Wertschöpfung, Springer, Hamburg, Germany, December 14-15, 2016.

[9] C.A.C. AFFONSO, D.C. AMARAL. "Boundary objects in open source design: experiences from OSE community". Proceedings of the 20th International Conference on Engineering Design (ICED 15), Vol 3 (Organisation and Management), Milan, Italy, July 27-30, 2015, pp. 447-456.

[10] V. MACUL, H. ROZENFELD. "How an open source design community works: the case of open source ecology". Proceedings of the 20th International Conference on Engineering Design (ICED 15), Vol 3 (Organisation and Management), Milan, Italy, July 27-30, 2015, pp. 359-366.

[11] M. PAULINI, P. MURTY, M.L. MAHER. "Understanding collective design communication in open innovation communities". Journal of CoCreation in Design and Arts, 2011.

[12] HANSEN, A., HOWARD, T.J. "The Current State of Open Source Hardware: The Need for an Open Source Development Platform", in: Chakrabarti, A., Prakash, R.V. (Eds.), ICoRD'13, Lecture Notes in Mechanical Engineering. Springer India, 2013, pp. 977–988.

[13] J. BONVOISIN, J.-F. BOUJUT. "Open design platforms for open source product development: current state and requirements", Proceedings of the 20th International Conference on Engineering Design (ICED 15), Vol 8 (Innovation and Creativity), Milan, Italy, July 27-30, 2015, pp. 11-22.

[14] M. GEYER, C. REISE, F. MANAV, N. SCHWENKE, S. BÖHM, G. SELIGER. "Open design for manufacturing – Best practice and future challenges". Presented at the 10th Global Conference on Sustainable Manufacturing, GCSM2012, 2012.

[15] T.J. HOWARD, S. ACHICHE, A. ÖZKIL, T.C. McALOONE. "Open Design and Crowdsourcing: maturity, methodology and business models". Proceedings of the 12th International Design Conference, 2012, 181–190.

[16] G. MÜLLER-SEITZ, G. REGER. "Networking beyond the software code? an explorative examination of the development of an open source car project". Technovation 30(11/12), 2010, 627–634.

[17] A. AKSULU, M. WADE. "A Comprehensive Review and Synthesis of Open Source Research". Journal of the Association for Information Systems 11(11/12), 2010, 576-656.

[18] R. STALLMAN. "Viewpoint: Why “Open Source” Misses the Point of Free Software". Communications of the ACM 52(6), 2009, 31–33.

[19] G. VON HIPPEL, E. VON KROGH. "Special issue on open source software development". Research Policy Editorial. 32, 2003, pp. 1149–1157.

[20] L. DAHLANDER, D. GANN. "How open is innovation". Research Policy 39, 2010, pp. 699–709.

[21] D. TEECE. "Business models, business strategy and innovation". Long range planning 43(2), 2010, 172-194.

[22] H. CHESBROUGH. "Open Innovation: Where We've Been and Where We're Going". Research-Technology Management 55(4), 2012, 20–27.

[23] A. OSTERWALDER, Y. PIGNEUR. "An eBusiness model ontology for modeling eBusiness". Presented at the 15th Bled Electronic Commerce Conference eReality: Constructing the eEconomy, Bled, Slovenia, 2002.

[24] A. BONACCORSI, R. LAMASTRA, CRISTINA, S. GIANNANGELI. "Adaptive Entry Strategies under Dominant Standards - Hybrid Business Models in the Open Source Software Industry" (SSRN Scholarly Paper No. ID 519842). Social Science Research Network, Rochester, NY, 2004.

[25] S.M. DAVEY, M. BRENNAN, B.J. MEENAN, R. McADAM. "Innovation in the medical device sector: an open business model approach for high-tech small firms". Technology Analysis and Strategic Management Journal, 23 (8), 2011, pp. 807-824.

[26] N.A GERSHENFELD. "Fab: the coming revolution on your desktop--from personal computers to personal fabrication". Basic Books, New York, 2007.

[27] P. TROXLER. "Commons-Based Peer-Production of Physical Goods: Is There Room for a Hybrid Innovation Ecology? " (SSRN Scholarly Paper No. ID 1692617). Social Science Research Network, Rochester, NY, 2010.

[28] M. OSTERLOH, S. ROTA, M. VON WARTBURG. "Open source - New rules in software development, 2001.

[29] M.G. COLOMBO, C. FRANZONI, C. ROSSI-LAMASTRA, et al. "Cash from the crowd". Science 348, 2015, 1201–1202.

[30] E. MOLLICK. "The dynamics of crowdfunding: An exploratory study". Journal of Business Venturing 29(1), 2014, 1–16.

[31] G. DEPOORTER. "La ‘Communauté Du Logiciel Libre’ : Espace Contemporain de Reconfiguration Des Luttes? " In Résister Au Quotidien ?, B. Frère and M. Jacquemain (eds.). Paris: Presses de Sciences Po, 2013.

[32] A. HANSEN, T.J. HOWARD. "Conceptualization of an Open Source Hardware Collaboration Platform - Creating a Web-Based Collaboration Platform That Supports Community-Based Development of Tangible Objects". M.Sc. Thesis in Management Engineering. Technical University of Denmark, 2012.