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BOUNDARY OBJECTS IN OPEN SOURCE DESIGN: EXPERIENCES FROM OSE COMMUNITY

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Abstract

The open source design (OSD) is an autonomous community dedicated to design new products, peer-to-peer, and with intellectual property copyleft. Boundary Objects (BOs) are objects to aid on the collaboration and they are used as mediators between the proposals and the repertory of each team member. This concept is consolidated on the tangible world of participatory design, but what about the digital world? How the BO had been used in Open Source Design Communities? This study aimed to investigate this aspect in a specific community named Open Source Ecology (OSE). An exploratory research was realized to identify the OSE Design Phases and the main types of boundary objects used, as well the limitations of their utilization. The results identify a gap: the members of OSE indicate low usage of Boundary Objects but considered them as essential for collaboration. The low usage was justified by complexity. The creation of prototypes or mock-ups would require more design skills than is possible for regular user; finally, the study demonstrates an indication that the proposition and use of specific BOs for OSE is a theme that must be addressed by the design management community.

Keywords: Participatory design, Open Source Design, Design management.

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1 INTRODUCTION

Free software known as open-source software (OSS) emerged in the nineties and spawned products such as the Linux system, Apache Web, and Perl. These products represent a new paradigm (Benkler, 2006, p. 60), a particular development strategy in which the product is developed by a network of volunteers. The success of these products has shown that communities can create software products as reliable and functional as those developed by large companies.

Howe (2006a) states that companies such as eBay and MySpace are creating platforms that can generate products from user contributions. In these environments, clients' engagement, which was once passive, is moving toward an increasingly active role, even to the point of customers' being developers themselves (Panchal and Fathianathan, 2008). Roles have changed, resulting in development by means of communities, in which consumer and designer are difficult to distinguish. Functions have become highly flexible, and user authorship and peer-to-peer participation are seen in cooperative ventures (Benkler, 2006, p. 27). These communities develop objects in a collaborative way, which is similar to the process of the open-source software movement. Therefore, their work was labeled as open-source design (OSD).

Many initiatives similar to open-source design have been posted on websites. Some examples are Open Source Ecology, OScar, and Local Motors. One significant difference in the world of software is that hardware, like a machine or car, is materialized in physical form, while software is pure information, which can easily travel across the global Internet network. Employees can download and test components, redesign, and prototype, easily sharing the results of their efforts—tasks that are not trivial to the car development community, for example.

However, the advantage is that in the case of manufactured products (hardware), there is a consolidated theory in design management and participatory design, which is specific about the collaboration between designers and consumers relationship. One fundamental concept of the theory is that of boundary objects (BOs) (Broberg et al., 2011; Lee, 2007). BOs are objects that aid collaboration, serving as mediators for the bids and repertoires of each team member. These objects are critical to successful completion of the design process (Subrahmanian, Reich, Krishnan, 2013). In several areas, such as ergonomics, the type of object and its role in communication are also described (Broberg et al., 2011).

Then, an important issue in OSD is to know what replaces BO in the digital world. What BOs are used in development in OSD communities? What are the limitations and problems that communities are facing?

One way to understand this issue is exploratory research. In this study, we chose to examine the Open Source Ecology (OSE) community (CC-BY-SA licence). This study aimed to investigate the main BOs used in this community and understand how they are used in different situations: to access the result of a development action available on the web, to learn how to build a product already developed by the community, and to comment on the results of the community.

2 OPEN SOURCE DESIGN

The concept of OSD is associated with principles similar to those of the individuals of OSS communities, in which the software is created and refined by volunteers not concerned with profitability (Muller-Seitz and Reger, 2010). Users' needs are heterogeneous, and when users innovate while designing information, this can quickly become a trend. Furthermore, product development activities are more likely to be widespread among users, rather than produced by only a few users-innovators (von Hippel, 2005).

While OSS is a unique software development approach (von Hippel and Lakhani, 2003) that has been extensively studied, little is known about the viability of the same design model for physical objects (Bruijn, 2010). The concept of OSD involves the development of open-source physical products. Many terms are used for this development between users and collaboration via the web, but few characteristics differentiate these terms.

Some of the terms identified in literature are “communities of creation” (Rullani and Haefliger, 2013), “co-creation” (Tu and Zhang, 2013), "user communities" (Hienerth and Lettl, 2011), “open-source software” (Müller-Seitz and Reger, 2011), “open-source development” (Bruijn , 2010), “user innovators” (von Hippel, 2007), “commons-based peer production” (Benkler, 2006), “web-based interactive innovation" (Wei, 2013), and "mass collaboration" (Panchal and Fathianathan, 2008). These terms are defined below.

- Creation communities: These communities resemble a community of practice through the shared trait of a social space in which the production of knowledge and the social process governing the interaction are strongly intertwined (Rullani and Haefliger, 2013).
- Co-creation: The value co-created through the interaction and emotion of community members (Tu and Zhang, 2013).
- User communities: a specific type of social network where users from different backgrounds but with a common interest in a specific field share their experiences and exchange diverse information and knowledge (Hienerth and Lettl, 2011).
- Open-source software: Any individual is allowed to study, change, improve, or distribute unmodified or modified software (Müller-Seitz and Reger, 2011).
- Open-source development: This involves many individuals or organizations that share the workload, while the properties of the public good are preserved in the results (Bruijn, 2010).
- User innovators: Users in an innovation process can innovate independently of the producers. This occurs when at least some users have sufficient incentive to innovate and disclose information voluntarily, allowing others to reproduce their innovations; however, the users' self-production can compete with production and commercial distribution (von Hippel, 2007).
- Commons-based peer production: This has the characteristics of cooperative ventures, in which the input and output of the process are shared freely and conditionally on a production system that is dependent on the actions of individuals and is self-selected and decentralized (Benkler, 2006).
- Web-based interactive innovation: This portrays the mechanisms through which innovative ideas or designs without intellectual property protection come from consumers through the web (Wei, 2013).
- Mass collaboration: This reveals the collective activity of a large number of people who perform a task (Panchal and Fathianathan, 2008).

Through this framework of concepts, the current paper defines OSD as an autonomous community in which the user plays a central role in the design, the network architecture is peer-to-peer, the people involved are allowed to modify contributions from others, the call for participation of people in the development of a project is made public, and the regime on intellectual property is copyleft. However, the result of the final design should still be a physical product. Collaboration is a core requirement, and the prototype acts as a BO to represent, understand, and transform knowledge along the functional, hierarchical, and organizational boundaries.

3 BOUNDARY OBJECTS: CONCEPTS AND TYPES

BOs are objects that are adaptable to the local needs and constraints of the several parties that employ them, and are robust enough to maintain a common identity across sites. BOs are poorly structured for common use but become strongly structured in individual-site use. They can be abstract or concrete. They have different meanings in the diverse social worlds, but their structure is sufficiently common so that more than one world makes them a recognizable meaning in translation.

The creation and management of BOs is key in developing and maintaining coherence across the intersection of social worlds (Star and Griesemer, 1989). Carlile (2002), Juhl and Lindegaard (2013) describes BOs as objects that are shared and shareable across different problem-solving contexts. According to Carlile (2004), a BO (1) establishes a shared syntax or language that individuals can use to represent their knowledge, (2) proves a concrete meaning for individuals to specify and learn about their differences and dependencies across the boundary, and (3) facilitates the process whereby individuals can jointly transform their knowledge.

In their research at the Berkeley Museum, Star and Griesemer (1989) identified four types of boundary objects: repositories, ideal type, coincident boundaries, and standardized forms. Repositories refer to "stacks" of objects that are indexed in a standardized form, such as museums and libraries. Ideal types are objects, such as charts and atlases, which do not accurately describe the details of any place or thing. Coincident boundaries are common objects that have the same boundaries but different internal contents. Standardized forms refer to objects as methods of common communication across dispersed workgroups. Carlile (2002) examined BOs in studies of product development and classified them into

three types: repositories (continuing the concept presented by Star and Griesemer, 1989); standardized forms and methods depicting the fourth kind, also presented by Griesemer and Star (1989); and a third kind—objects, models, and maps—which had greater reach, incorporating objects that aid communication and problem solving.
Wenger (2000) studied BOs in the social learning theory, identifying three types of objects: artifacts, discourses, and processes. Artifacts correspond to standardized forms; methods for troubleshooting; or sketches, prototypes, or simulation. Discourses refer to the existence of a common language that allows people to communicate and negotiate across boundaries. Processes include explicit routines and procedures in the organization.
Based on these studies and a survey of a specific population in approximately 15 years of research, Broberg, Andersen, and Seim (2011) categorized BOs for participatory ergonomics (PE). Some of the examples given by the authors for each object are as follows:

1. Repositories: Unidentified processes in PE.
2. Standardized forms and methods: Diagrams, charts, interviews with focus groups, and questionnaires.
3. Objects, models, and maps: Prototypes, animation, 2D, 3D, and game production.
4. Discourses: Conditions of questioning, self-confrontation, dialogue model, and video recordings of the study.
5. Processes: Prototyping new forms of testing and visits to other departments or workstations.

This study specifically investigates BOs of the third kind: objects, models, and maps (Broberg, Andersen and Seim, 2011). The justification is that these objects are regarded as essential to collaboration but difficult to share in a virtual environment.

4 METHOD

The community investigated was the Open Source Ecology. The main role of OSE is to create the open-source economy. They are currently developing a set of open-source blueprints for the Global Village Construction Set – a set of the 50 most important machines that it takes for modern life to exist – everything from a tractor, to an oven, to a circuit maker. OSE intends to develop a modular, scalable platform for documenting and developing open source, free hardware – including blueprints for both physical artifacts and for related open enterprises.
The research questions are as follows:

- How does an OSD community act in relation to BOs in the context of product development?
- What are the main BOs used?
- What media (text, photo, video, or accelerated video) are used to obtain information about the product?
- What media (text, photo, video, or accelerated video) are used to contribute to the community?

The main BOs used in Open Source Ecology were analyzed to understand the form used by members of the communities to access/obtain results of products already developed by the community, learn how to build/replicate a product, and contribute, based on their experiences, to community results. As an exploratory study, it was limited to concrete BOs, which are related to how to represent the products, avoiding some that are abstract (in the understanding of Star and Griesemer, 1989) with regard to sharing ideas. The BOs analyzed were objects, models, and maps (Broberg, Andersen and Seim, 2011).
An efficient economy which increases innovation by open collaboration. This research was developed according to the steps shown in Figure 1. Initially, a literature search was conducted to better understand the term "boundary objects," as shown in section 3. From these concepts, it was possible to identify the main variables for the preparation of a questionnaire, which was made available to community members via Google Forms and was added to the community's Facebook page.
Five community members with experience in projects answered the questionnaire, and based on their answers, a qualitative analysis was performed. The questionnaire included 21 questions (open and closed). Two descriptive questions were aimed at understanding the experience of the respondent in the community, and six questions were designed to identify the frequency of use (4 = always; 3 = regularly; 2= sometimes; 1 = rarely; 0 = never) of each BO (sketches, mock-up scaled down, mock-up of a part, mock-up in full scale of a complete product, and prototype of a complete product, as shown in Figure 2).

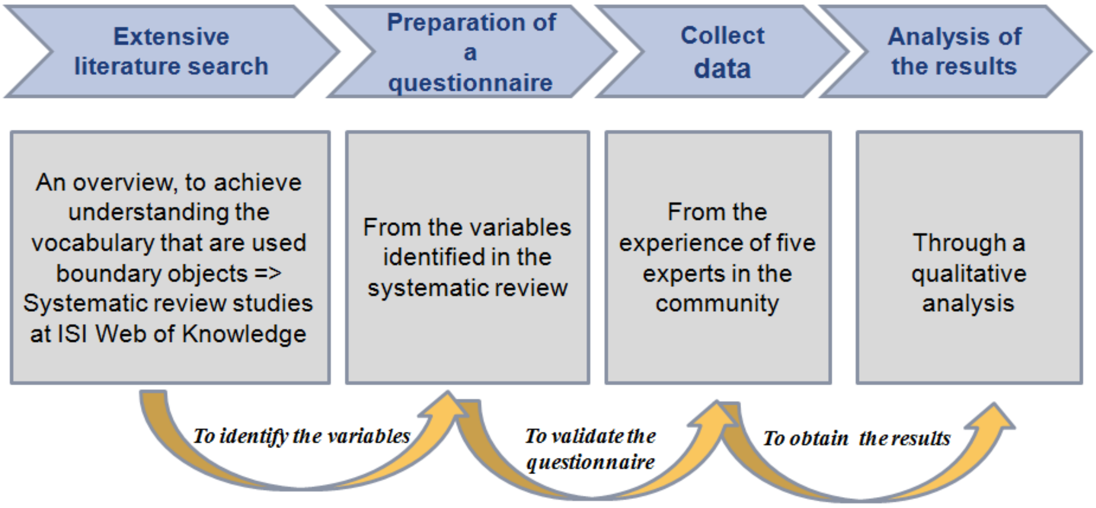

Figure 1. Method

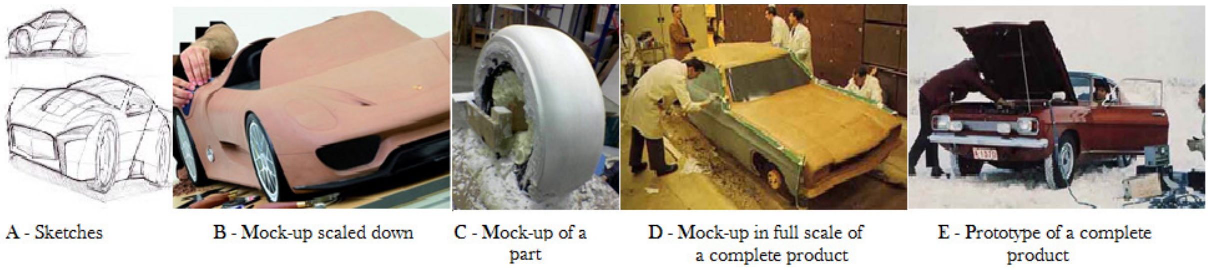

Figure 2. Boundary objects investigated (LINEWEIGHTS, 2010; VISEUDESIGN,2010; GTSPIRIT, 2010; BESTCARS, 2001)

The frequency of use of the BOs was identified for each phase of the cycle of collaborative community product development according to the community's internal reference model: Stage I, production selection; Stage II, OSD rationale (OSR); Stage III, 3D drawing and bill of materials; Stage IV, review/bids; Stage V, prototyping and testing; and Stage VI, production.

This starts with the selection of the product to be developed (Stage I), followed by Stage II (OSR), which is viewed by the community as the main phase of the process, since at this stage, there should be transparency about the technology used so that what is being developed can be replicated. Stage II is nothing more than an explicit list of decisions made during the design process and the reasons why these decisions were made. The objective of this model is to support designers by providing a means to record and communicate the argumentation and reasoning behind the design process. It should, therefore, include the following:

- The reasons and justifications for the decisions throughout the design process
- Other alternatives considered
- The evaluated trade-offs
- The arguments that led to the decisions (OSE, 2009)

In Stage III (3D drawing and bill of materials), there must be the ability to convert the OSR into a 3D digital design and to come up with a list of parts for manufacturing the object. The bill of materials determines the performance cost of the technology. The project then moves to Stage IV (review/bids), which is a review by recognized experts from boards and other groups. The review by third parties should show the interested parties that the project is feasible. Stage V (prototyping and testing) aims to demonstrate the OSD, and therefore the possibility of replication by others, before it goes to production (Stage VI) (OSE, 2009).

The questionnaire also included 10 questions to identify advantages and barriers/difficulties encountered in the use of each BO and three other questions to identify the mainstream media (text, photo, video, or accelerated video) used by community members to obtain information available on the web about the development of a product, replicate a product already developed, and contribute to the community.

5 RESULTS AND ANALYSIS

The information collected by the questionnaire showed that all respondents participated in the development of some kind of (physical) product within the Open Source Ecology community. The results of the frequency of use of each BO per phase of product development are presented in Table 1. The data indicate the pattern illustrated in Figure 3.

Table 1: The total points

Boundary objects (BOs)	Stage 1 Product Selection	Stage II Open-Source Design	Stage III 3D Drawing & Bill	Stage IV Review/Bids	Stage V Prototyping & Testing	Stage VI Production
A - Sketches	16/20	11/20	13/20	3/20	4/20	6/20
B - Mock-up scaled down	7/20	6/20	4/20	3/20	4/20	4/20
C - Mock-up of a part	3/20	2/20	6/20	3/20	6/20	4/20
D - Mock-up in full scale of a complete product	2/20	3/20	7/20	3/20	6/20	3/20
E - Prototype of a complete product	8/20	1/20	2/20	3/20	11/20	12/20

Each of five respondents scored the frequency of use of each BO (4 = always; 3 = regularly; 2= sometimes; 1 = rarely; 0 = never). The maximum score the frequency of use for a given BO is 20 (5 "respondents" * 4 "always"). For example, in the second column "Stage I" of Table 1, the respondents evaluated the use of "C- mock-up of a part". The respondent A noted the frequency of use as "2- sometimes", the respondent B evaluated the frequency as "1 – rarely" and the respondents C, D and E marked 0 - never, so in this case, the total points is: ((1* 2)+ (1 * 1) + (1 * 0) + (1 * 0) + (1 * 0))/20) = 3/20

Table 1 indicates that in stage I, stage II and stage III the most commonly used boundary objects are sketches with 16/20, 11/20 and 13/20 of total points, respectively. The use of boundary objects in the stage IV reveals that they are almost unused. However, the prototype of a complete product is the most used in the stage V and VI. Figure 3 summarizes the Table 1.

Figure 3 shows that in the early stages, sketches are predominant, probably because of the low cost associated with the use of BOs and the lack of available time for their production. Another relevant factor is the absence of BO use in the testing phase and review/bids, showing an important gap in this community. The project is forwarded to expert volunteers, who perform theoretical analyses with limited resources to test understanding of the project. They then directly proceed to production of a complete prototype. Collaborative design literature (Campbell and Beer, 2005) suggests that a BO is essential in the evaluation process, particularly in the use of physical models as prototypes.

Finally, stages V (prototyping and testing) and VI (production) revealed that the prototype of the finished product is the one most frequently utilized among the studied BOs, supporting the objective of this phase of the cycle of collaborative development of Open Ecology.

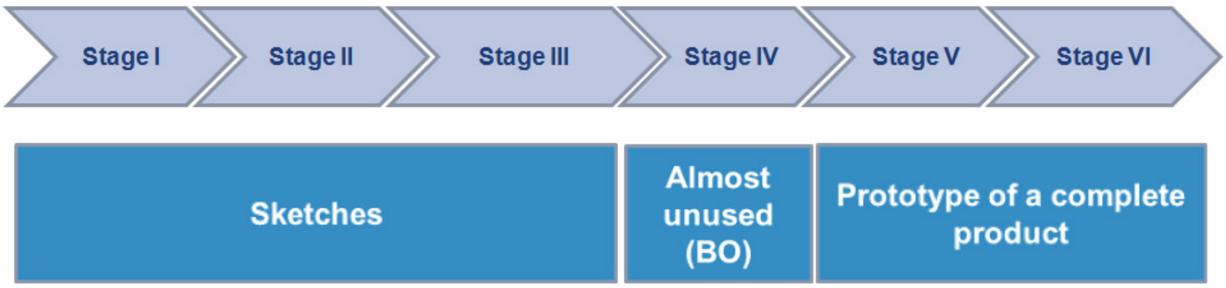

Figure 3. BO application at each design stage

Table 2. Main obstacles to using the boundary objects

Order of importance	Sketches	Mock-up scaled down	Mock-up of a part	Mock-up of a complete product (full scale)	Prototype of a complete product
1	High-level skill	High-level skill	Cost	Cost	Cost
2	Limited to 2D		Time	Time	High-level skill

Table 2 summarizes the main obstacles to the use of BOs indicated by the community members. The high level of skill required and the limitation of two dimensions (2D) are principals. Similarly, the use of the scaled-down mock-up reveals skill level as a major constraint on usage. Seeing how the community deals with volunteers of different skills, the availability of people with the right know-how in performing certain activities is difficult to guarantee.

The fact is that visual representations act as ways of organizing the production process, serving as “social glue” between individuals and groups (Henderson, 1995). Besides, the sketches are essential to generate concepts, outsource and visualize problems, organize cognitive activity, assist in solving problems, and review and refine ideas, besides representing the artifacts from the real world (Do et al., 2000).

When it comes to the use of the mock-up of a part and mock-up of a complete product (full-scale) in the design process, the respondents reported the same characteristics: cost and time. Since the community depends on volunteer work and financial donations for its continuity, resources are limited. However, there is a mismatch with the theory that discusses mock-ups as being fundamental in the design, since its role differs from sketches by providing access to richer information and because it supports more specific decisions on development (Yang, 2005).

The obstacles in the way of product prototypes are cost and the high level of skill required for construction. In the final phases, the prototype design acts as a process of evidence, demonstrating that the methods of production and materials can result in the desired product, and a proof of production for indicating if the complete manufacturing process is effective (Ullman, 2003).

Respondents were asked specifically about the role of physical prototypes during development in the community. These statements, in Table 2, show concern for these boundary objects. Another aspect to note is that the most frequently mentioned function is that of testing. This may suggest that, in the minds of members of the community, the only function is to test the final result, corroborating with Figure 3. In other words, they do not value the role of objects as a collaborative tool “during” development. This situation is reinforced again in the results of Table 3, on the contribution of each BO in common collaboration activities.

Table 3. The best media to get, learn, and contribute

Order of importance	The best way to					
	GET the result of the product		LEARN how to make a product		CONTRIBUTE to the results of a prototype	
	Media	Frequency	Media	Frequency	Media	Frequency
1	Photo	4	Text	4	Text	3
2	Video	1	Photo	1	Video	2

Among the media (text, photo, video, or accelerated video), it is observed in Table 3 that community members are restricted to using only photos and text, except to contribute to the results of a prototype, that the members use text and video, showing the reduced exploitation of these resources.
When asked about the role of physical prototypes inside the developer community, the result is seen in Table 4.

Table 4. The role of physical prototypes inside the developer community

Order	Member (designer) phrase
1	"proof of concept"
2	"proof of replicability "easy to replicate"
3	"functionality"
4	" maintanance"
5	"grabbing people's attention that this is real"
Generally speaking	"Physical prototypes are required whenever we are at the stage of validating the extreme production model—to answer if the product can be produced at the cost, speed, and performance desired." "This is required if you want to develop a quality product" "Always needed before production"

Table 4 shows some member´s phrases about the role of physical prototypes, in fact the prototype has several roles. Ullman (2003) describes a proof-of concept prototype is used to better understand what approach to take in designing a product, and a proof-of-product prototype demonstrates a design´s physical embodiment and its functionality, at same time proof-of-production prototype clarifies that the complete manufacturing process is effective. That community of members recognizes the role of physical prototypes inside the community.

6 CONCLUSION

Upon the investigation of the main boundary objects (BOs of the third kind as mentioned in section 3) used in Open Ecology, three points of reflection can be pointed out. First, the results show that while community members recognize the importance of BO usage, their use is still limited. This is primarily because BO usage is restricted to only two types of objects: sketches and prototypes. The respondents do not use the prototypes as a medium in the testing process, given that the most used boundary object, among those investigated in the early stages, was the sketch; and despite having specific characteristics, a complement with other types of BOs becomes necessary. In the collaborative cycle of product development in the Open Ecology community, there is a gap in the view of what the boundary objects indicate as important for collaboration: the lack of use of more complex objects as prototypes for this purpose (Acuna and Sosa, 2011; Broberg et al, 2011; Campbell and Beer, 2005; Carlile, 2004; Star and Griesemer, 1989). In this sense, the question is how to facilitate the use of boundary objects in open source design communities, as the literature considers them essential in collaborative processes.
The second aspect is the obstacle regarding the required skill level, corroborating with Yang and Epstein (2005). According to members of the community, the low usage would be mainly due to the complexity because the creation of prototypes or mock-ups requires a set of design skills and time commitment. The Open Ecology community highlights that in Stage III, the key to 3-D design is the ability to determine that the design supports functions as it should, making it possible to achieve a project with materials prepared from a 3-D design. At this point, if the cost is unacceptably high, the project should be examined for possible material changes in the design. Only when specific materials

are considered, can changes be made. How can the effectiveness of this stage be guaranteed if the notorious lack of ability to build a BO is noted?

By understanding the media used by the members of this community, there was a predominance in the use of photos and text, creating the third point of reflection: the boundary objects address the cooperative work defined as joint work (Subrahmanian et al., 2003). Which would be the most appropriate media to organize the peer-to-peer collaborative work for the development of manufactured products?

It is important to note that a limitation of the study is the small sample size, so it is not possible any kind of generalization. Future research seeking a larger sample is needed. It is also suggested as future research: a full study on all types of BOs for in-depth analysis and thus generate new variables; a study about the little use of CAD/CAE in communities OSD when compared with sketches/photos, investigating if it relates to skill level or lack of an open-source CAD standard.

The study demonstrates an indication that the proposition and use of BOs is a barrier that must be addressed by the design management community, which is keen to work with product development in OSD communities.

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