Open-Design. Modélisation du processus de conception ouverte dans le cadre du développement de produits tangibles

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Open-Design

Modeling the open-design process in the development of tangible products

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Open-Design

Modeling the open-design process
in the development of tangible products

Étienne Boisseau · PhD thesis

Open-Design
Modeling the open-design process in the development of tangible products

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To the memory of Professor Carole Bouchard

Bernard of Chartres used to compare us to [puny] dwarfs perched on the shoulders of giants. He pointed out that we see more and farther than our predecessors, not because we have keener vision or greater height, but because we are lifted up and borne aloft on their gigantic stature.

John of Salisbury
in *The Metalogicon*, p. 167

Dicebat Bernardus Carnotensis nos esse quasi nanos, gigantium humeris incidentes, ut possimus plura eis et remotiora videre, non utique proprii visus acumine, aut eminentia corporis, sed quia in altum subvehimur et extollimur magnitudine gigantea.

Ioannis Saresberiensis
in *Metalogicus* III, 4, col. 900C

Contents

Abstract

Open-source revolutionized the software industry through a public, decentralized, and asynchronous development paradigm that fosters collaboration among peers. New practices and stakeholders disrupted the designing process, yet led to industrial successes. Due to the digitalization and democratization of the designing process, this approach now spreads to the development of tangible artifacts. This is open-design.

However, open-design currently appears as an umbrella term that encompasses from amateur do-it-yourself projects to sector-scale industrial collaborations. It is not clear either, how these practices relate to existing designing approaches. Finally, little knowledge about the open-design process is formalized. This impedes the development of adequate tools for helping practitioners to make the most of it.

Therefore, we investigated how to model the open-design process in the development of tangible products. First, we developed a typology of open-design practices based on a systematic search and review of the scientific literature. Then, we selected one of the types identified and modeled the different facets of the designing process (activities carried out, stakeholders involved, and boundary objects used) in this context, using a grounded theory-based approach.

Through our literature review, we mapped open-design in relation to existing designing approaches, and to coined a new definition thereof. Based on 624 papers indexed in the *Scopus* database, we identified three types of practices — do-it-yourself, meta-design, and industrial ecosystem — which are related to the status (professional or amateurs) of the processes' stakeholders and addressees. We also constructed two models of the 'do-it-yourself open-design' process using semi-directive interviews of 11 project leaders who took part in the *PoC21* innovation camp. They depict open-design as a designing process influenced by both open-source software development and amateur design. We tested the quality of our models and our modeling method via statistical analysis.

This study aims to be a cornerstone for future research on open-design by providing an overview of practices linked to this phenomenon. Our descriptive models should serve researchers for providing practitioners of open-design projects with relevant tools and methods. Our modeling method could also be applied in other contexts to formalize uninvestigated designing practices.

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Résumé

L'open-source a révolutionné le secteur informatique par une nouvelle approche publique, décentralisée, et asynchrone de la conception qui encourage la collaboration entre pairs. De nouveaux acteurs et pratiques ont bouleversé le processus de conception, mais aussi donné lieu à des succès industriels. Cette approche se répand aujourd'hui à la conception de produits tangibles, à cause de la numérisation et la démocratisation de ce processus — c'est la conception ouverte.

Nombre de pratiques hétérogènes sont cependant regroupées sous ce terme. Les liens avec les pratiques existantes ne sont pas non plus clairement identifiés. Enfin, peu d'informations à propos du processus de conception ont été formalisées dans la littérature scientifique. Cela freine le développement d'outils pertinents qui permettraient aux concepteurs d'exploiter pleinement les spécificités de la conception ouverte.

Ainsi, nous nous sommes intéressés à la modélisation du processus de conception ouverte, dans le cadre du développement de produits tangibles. Nous avons d'abord élaboré une typologie des pratiques via une revue systématique de la littérature. Ensuite, via une approche par théorisation ancrée, nous avons construit des modèles mettant en lumière les différentes facettes du processus de conception : phases, acteurs, représentations intermédiaires.

À travers notre état de l'art, nous avons défini et cartographié la conception ouverte et les notions connexes. Par l'étude de 624 entrées de la base de données *Scopus*, nous avons identifié trois types de pratiques : *do-it-yourself*, *meta-design*, and *industrial ecosystem*. Elles sont liées au statut (amateur ou professionnel) des concepteurs et destinataires du processus. Nous avons aussi construit deux modèles du 'do-it-yourself open-design' à partir d'interviews semi-directifs de 11 participants à des projets de conception ouverte. Cette approche apparaît influencée à la fois par le logiciel libre et la conception amateur. La qualité de nos modèles et de notre modélisation a été validée par l'outil statistique.

Cette étude ambitionne d'être une référence pour de futures recherches sur la conception ouverte, en proposant un panorama détaillé des pratiques liées à ce phénomène. Nos modèles descriptifs doivent servir de point de départ pour développer des outils pertinents à l'intention des praticiens. Notre méthode de modélisation peut également être répliquée dans d'autres contextes pour formaliser des processus encore non cartographiés.

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Preface

The purpose of a PhD is to train a research student as an autonomous scientist and a good researcher — i.e. as someone deserving the grade of Doctor. The objective of a PhD thesis is hence to demonstrate to one's peers that its author can be considered in this way by reporting the successful completion of a high-quality piece of research.

Being a good researcher means first to do science well, second to do good science, and third to do a lot of science. Doing science well means following its ethical rules, being thorough, honestly and appropriately reporting one's results, crediting one's peers for their work and acknowledging one's work limitations, using the adequate tools and methods to solve a problem, and doing research that is reproducible. Doing good science means addressing a relevant scientific gap, an issue that is influential, a research problem that matters for science, the society, and the industry. Doing a lot of science means to tackle a large-scale problem, to address subsequent research gaps, to contribute to multiple issues of a coherent sub-field. One must, however, note that these criteria are conditional to one another. Doing a lot of science serves no purpose if one does not do good science. And more importantly, doing good science serves no purpose if one does not do science well.

The aim of this document is thus to demonstrate that I can be considered by my peers as an autonomous scientist and good researcher. It is thus intended for them, and especially for the members of the dissertation committee. Prior knowledge of a few technical words and basic concepts for a researcher in design science might hence be required. Nonspecialist readers could also get tangled up in the thorough and detailed description of my work. However, in order to make my scientific approach and my understanding of what is research explicit, I adopted a didactic tone and did my best to avoid jargon in order to make this thesis as broadly accessible as possible.

To achieve the objective of this thesis, I herewith report a structured description and analysis of most of the scientific work I carried out during the three years I was a PhD candidate in the Product Design and Innovation Laboratory of Arts et Métiers ParisTech. This piece of research aims at addressing the question of the modeling of the open-design process in the development of tangible artifacts.

Acknowledgement

. . . to those who mentored me

First of all, I would like here to express how grateful I am to the late Professor Carole Bouchard for what she taught me during the four years I have been lucky to work with her — first as a Master's student, and then as a PhD candidate. I have decided to undertake a PhD notably thanks to her. May she be thanked for having encouraged and enabled me to pursue this extraordinarily enriching experience.

I would also like to thank Doctor HDR Jean-François Omhover, who supervised this work in tandem with Professor Bouchard. His advice and guidance offered a fresh perspective on my research. I appreciated his inclination to open-source and good science. His continuous and cordial support — even remotely — combined with his high expectations enabled me to proudly defend this thesis after three years of intense work.

I also thank Professor John S. Gero who invited me as Visiting PhD at the University of North Carolina during spring 2017. His global and leading experience of design and of research in design made his advice extremely enriching. His encouragement led me towards even greater strictness and accuracy in my research.

I am honored that Professor Jean-François Boujut and Professor Emmanuel Caillaud accepted to review my work. I am also grateful to Professor Julie Le Cardinal and Professor Marc Le Coq, who accepted to be part of dissertation committee.

This work was funded by héSam Université, via a doctoral grant of the 'Paris Nouveau-Monde' program. I am grateful to this institution for having trusted me and enabled the realization of this thesis.

The journey towards this peer recognition as scientist has not started with the PhD. I would hence like to thank Dr.-Ing. Zäzilia Seibold, who guided my first steps in scientific research at the Karlsruher Institut für Technologie, as well as in the amazing world of LaTeX. I also thank Carole Favart, Daniel Esquivel, and Dr. Alexandre Gentner who taught me applied research during my Master's thesis in the Kansei Department of Toyota Motor Europe. I thank Jean Pollono who mentored me and gave me insightful comments before and throughout this thesis. Finally, from the bottom of my heart, I thank Dr. César Rodríguez who knew before anyone that I would do a PhD. His opinions, and above all his friendship, are a delight to me.

…to those who helped me

This work was also supported by those who gave some of their time to the project. I thank participants to the experiments and notably organizers of PoC21, as well as members of the different projects studied: Antoine, Audrey, Benjamin, Daniel, Guillian, Hugo, Jason, Johan, Joscha, Mathieu, Matthieu, Milena, Tristan, Trystan, and their communities.

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This particular piece of work has also been enabled by the work of multiple contributors to open-source software and packages who decided to freely share their work. I am indebted to them. They hence genuinely deserve to be thanked here: Donald E. Knuth for TeX; Leslie Lamport for LaTeX; Ross Ihaka and Robert Gentleman for R; David P. Carlisle for afterpage, graphicx, tabularx, and tabulary; the American Mathematical Society, Frank Mittelbach, Rainer Schöpf, Michael Downes, David M. Jones, and David Carlisle for amsmath and amssymb; Johannes L. Braams and Javier Bezos for babel; Philip Kime for biber; Philipp Lehman, Philip Kime, Audrey Boruvka, and Joseph Wright for biblatex; Simon Fear for booktabs; Kresten Krab Thorup, Frank Jensen, and Chris Rowley for calc; Axel Sommerfeldt for caption; Peter Wilson and Will Robertson for chngcntr; Toby Cubitt for cleveref; Philipp Lehman and Joseph Wright for csquotes and etoolbox; Javier Bezos for enumitem; Will Robertson for environ; Jean-François Burnol for etoc; the LaTeX team for fontenc; Mark Wooding for footnote; Hideo Umeki for geometry; Nicola L. C. Talbot for glossaries; Sebastian Rahtz and Heiko Oberdiek for hyperref; Scott Pakin for hyperxmp; Ted Gould, Bryce Harrington, Nathan Hurst, and MenTaLguY for inkscape; Alan Jeffrey and Frank Mittelbach for inputenc; the JabRef team for jabref; Bob Tennent for libertine; Carsten Heinz, Brooks Moses, and Jobst Hoffmann for listings; R. Schlicht for microtype; Bruno Le Floch for morewrites; Piet van Oostrum, Øystein Bache, and Jerry Leichter for multirow; Ulrich Michael Schwarz for nag; Matt Swift for newclude; Michael Sharpe for newtxmath; Donald Arseneau for nth, placeins, and url; Hàn Thế Thành for pdfTeX; Heiko Oberdiek for pdflscape and accsupp; Andreas Matthias for pdfpages; Till Tantau and Christian Feuersänger for PGF and TikZ; Joseph J. Allaire for rstudio; Andy Thomas for sidenotes; Joseph Wright for siunitx; David Kastrup for suffix; Thomas F. Sturm for tcolorbox; Benito van der Zander, Jan Sundermeyer, Daniel Braun, and Tim Hoffmann for TeXstudio; Markus Kohm, Frank Neukam, and Axel Kielhorn for the Koma-Script bundle; Frank Mittelbach for varioref; Uwe Kern for xcolor; Josselin Noirel for xifthen; Enrico Gregorio for *xpatch; David P. Carlisle and Morten Høgholm for xspace; many forgotten ones; as well as the StackExchange community that gave me so much time to help me smooth issues that came across my way.*

...to those I worked with

Being in academia does not only mean doing research and expanding mankind's knowledge, but also passing on existing knowledge to next generations. I am thus grateful to Prof. Philippe Loron, Dr. Xavier Merle, and Dr. Camille Gaudillière for having trusted me for this exciting mission that is teaching; as well as to Dr. Renaud Pfeiffer for his great help on many occasions.

Carrying out a PhD is a long and difficult journey. It was, however, more enjoyable thanks to the company of LCPI's other PhD candidates (and former ones): Floriane, Paula, Hakyoung, and Anne-Lise with whom I had the pleasure to share the office #38 and the day-to-day life along the PhD journey, as well as Amal, Amanda, Brahim, Djamel, Everton, Francis, Jessy, Kerstine, Kévin, Malte, Oscar, Oussama, Pathum, Pierre-Emmanuel, Théo, Thibault, and Vincent. I am also grateful to the LCPI team, and would like to thank especially Dr. Claude Gazo, Séverine Fontaine, as well as Hélène Zimmer for their kind and warm support.

...to those who were there beside work

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I would like to finish by thanking my kin who shaped and supported me.

And, above all, my nearest and dearest whom I am for, for who she is.

Declaration of authorship

I hereby declare that this thesis entitled "Open-Design: Modeling the open-design process in the development of tangible products" *and the material presented in it are my own original work performed under the guidance and advice of my faculty advisers, the late Professor Carole Bouchard and Doctor HDR Jean-François Omhover. I have also been advised by Professor John S. Gero from February to June 2017.*

I certify that, to the best of my knowledge: This work was done wholly while in candidature for a PhD degree at Arts et Métiers ParisTech; Where I have consulted the published work of others, this is always clearly attributed; Where I have quoted from the work of others, the source is always given — with the exception of such quotations, this thesis is entirely my own work; I have documented all methods, data and processes truthfully; I have mentioned all persons who were significant facilitators of the work.

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- Boisseau, Étienne, Carole Bouchard, and Jean-François Omhover (2015). "Open Design : Un état de l'art". In: *Proceedings of CONFERE 2015.* 22e Colloque des Sciences de la Conception et de l'Innovation. (July 9–10, 2015). Lisbon, POR.
- Boisseau, Étienne, Carole Bouchard, and Jean-François Omhover (2017). "Towards a model of the Open-Design process: Using the Grounded Theory for modeling implicit design processes." In: *Proceedings of the 21st International Conference on Engineering Design.* (ICED17). (August 21–25, 2017). Ed. by Anja Maier, Stanko Škec, Harrison Kim, Michael Kokkolaras, Josef Oehmen, Georges Fadel, Filippo Salustri, and Mike Van der Loos. Vol. 2: Design Processes, Design Organisation and Management. pp. 121–130. Vancouver, CAN. ISBN: 978-1-904670-90-2.
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Acronyms

B2B	Business to Business.
B2C	Business to Consumer.
C2C	Consumer to Consumer.
CAD	Computer-Aided Design.
CAE	Computer-Aided Engineering.
CAM	Computer-Aided Manufacturing.
CNC	Computer numerical control.
DIY	Do-It Yourself.
DTM	Design Theories and Methodologies.
ENSAM	École Nationale Supérieur d'Arts et Métiers.
ETH	Eidgenössische Technische Hochschule.
F/LOSS	Free/Libre Open-Source Software.
fab lab	Fabrication Laboratory.
FSF	Free Software Fundation.
GENIUS	GENeration Innovation User-centred System.
GNU	GNU's not UNIX.
GPL	General Public License.
HDR	Habilitation à Diriger les Recherches.
HTTP	HyperText Transfer Protocol.
ICT	Information and Communication Technologies.
IDE	Integrated Development Environment.
IP	Intellectual Property.
IT	Information Technology.
LCPI	Laboratoire Conception de Produits et Innovation.
MaaS	Manufacturing as a Service.
MCA	Multiple Correspondance Analysis.
MFA	Multiple Factor Analysis.
MIT	Massachusetts Institute of Technology.
MOOC	Massive Open Online Courses.
NDA	Non-disclosure Agreement.
OKF	Open Knowledge Fundation.
OSE	Open-Source Ecology.
OSH	Open-Source Hardware.

OSI	Open-Source Initiative.
OSS	Open-Source Software.
P2P	Peer-to-peer.
PCA	Principle Component Analysis.
PLM	Product Life-cycle Management.
PoC	Proof of Concept.
RFID	Radio Frequency IDentification.
TRENDS	TRends ENabler for Design Specifications.
UCD	User-Centered Design.

Chapter 0
General introduction

Prior to detailing the research we conducted during our PhD, we aim to give the reader an overview of the common thread of our study. This chapter depicts the context and motivation for our work, the research question we addressed, experiments we carried out, as well as the major contributions of our research.

0.1 Context and motivations

The so-called open-approach comes from the Free/Libre and Open-Source Software (F/LOSS) movements that appeared in the software industry in the late 1970s. These movements impacted how software is designed via the arrival of new stakeholders (mostly amateur end-users) and new practices (asynchronous, decentralized, and peer-to-peer collaboration). Software developed in this way offer specific benefits: shorter development cycles and bug patching times, increased flexibility and stability, pooled maintenance and support, etc. These benefits lead to industrial successes in the software industry (e.g. GNU/Linux and most other current programming languages). Encompassed in the concept of *open-approach*, the underlying principles of F/LOSS (free access to sources, as well as right to modify and broadcast them) then spread over multiple sectors.

Due to the digitalization of the designing process and the democratization of product development, the designing process of tangible products is now also impacted by open-approach. We call the application of open-source principles to product design *open-design*. Open-design is notably characterized by the presence of amateurs taking part in the designing process, both by decentralized and asynchronous online collaboration and by the broadcasting of sources of the designed product under permissive licenses.

The open-design process shares similar characteristics with the F/LOSS designing process. We thus expect the same benefits. However, an intrinsic difference between software and hardware impedes the duplication of F/LOSS best practices into the designing of tangible products: the fact that atoms, unlike bits, cannot be duplicated free of cost and sent instantaneously across the globe. Therefore, there exists a need for practitioners of specific and dedicated tools and methods in order to make the most of open-design. Little knowledge is yet reported in scientific literature about the open-design process. Yet observed practices in open-design projects seem singular, due to specific characteristics of open-design. Thus, existing models of the designing process seem irrelevant when describing such practices.

0.2 Research question and aim of the experiments

To make the most of open-design, practitioners need dedicated tools and methods that consider specifics of this new approach to design. For that, we must better understand the open-design process, notably by constructing descriptive models of this process. Such models are rare in scientific literature, and are not detailed enough.

This research is therefore driven by the question: *How to model the open-design process, in the development of tangible products?*

To be relevant, models must summarize a homogeneous set of practices. Open-design remains an umbrella term that encompasses a wide variety of practices. Our first objective is then to refine our understanding of open-design by outlining the different sets of practices it gathers. The hypothesis we put forward and test in our first experiment is then: *A systematic search and review of scientific literature enables the formalization of a typology of open-design practices.*

Given a homogeneous set of practices (that is, given a type of open-design), our second objective is to construct models of the open-design process. As this process appears singular, traditional modeling methods do not seem to be adequate in this context. On the contrary, the grounded theory is intended to construct knowledge rooted on facts. It has not yet been used for modeling designing processes. The hypothesis we put forward and test in our second experiment is then: *Using a grounded theory-based approach enables the construction of models of the designing process for a given type of open-design practices.*

0.3 Contribution and originality of this study

This study is among the first to investigate the open-design process from the perspective of the science of design.

Its first contribution is the definition of open-design we coin, after having mapped this new paradigm regarding other forms of designing usually reported in scientific literature such as user innovation, open innovation, co-design, downloadable design, etc. This new contextualization should better outline the topic of open-design and thus foster further research.

A second contribution is the typology of open-design we define in our first experiment. This typology clarifies the various practices gathered under this term. These types are notably related to the status of stakeholders taking part in the designing process (amateurs or companies), as well as the one the design is dedicated to (idem). We identified three types of open-design: *do-it-yourself*, *meta-design*, and *industrial ecosystems*. They correspond to Consumer to Consumer (c2c), Business to Consumer (b2c), and Business to Business (b2b) relationships, respectively. Better understanding practices gathered under the term open-design and outlining homogeneous sets of projects should enable future researchers to develop more accurate tools and methods for them.

The third contribution of our research is the three models of the open-design process we constructed. The first two models (the stakeholders and the activities model) are the outcome of the second experiment. In a later phase, we combine them into a third model that details the three main characteristics of the designing process: the activities carried out, the stakeholders involved, and the boundary objects[1] used. This model shows that the open-design process share the same set of activities as traditional models of designing processes. Only the last step, the broadcasting of the outcomes, is singular to open-design. The stakeholder structure resembles that of open-source projects with a small core of strongly involved project leaders, around which gravitates layers of less involved contributors. The open-design process appears yet more centralized than Free/Libre Open-Source Software (f/loss) designing projects. Finally, we observed a low usage and formalization of boundary objects, due to the lack of tools and methods adapted by amateur stakeholders.

0.4 Thesis outline

Part 1 — *Context and motivations* commences this thesis with a recalling of the context of our work. It serves to set the scene of our research, notably through a historical perspective. It also details the reasons why we decided to investigate the modeling of the open-design process in the development of tangible products.

[1] Boundary objects are media used to convey information about the design among stakeholders. For example: sketches, drawings, 3d models, bill of specifications, etc.

Part 2 — *Literature review* contains a review of current scientific literature. This part serves to define major concepts and methods later used in our research, to outline limitations in the actual understanding of open-design, and to support the definition of the research question addressed in this study as well as of related hypotheses.

Part 3 — *Research positioning* lays the foundations for our study. First, it formulates the question we addressed in our research. Then, it presents the hypotheses tested in the experiments we conducted.

Part 4 — *Experiments* describes how we tested the hypotheses we put forward. It presents protocols followed, result obtained, and the analysis of the latter.

Part 5 — *A global model and other contributions* presents the global model of 'Do-it-yourself open-design' we constructed based on results of the experiments. It analyzes it regarding models of other forms of designing described in the literature. Furthermore, it details the other contributions of our research.

Part 6 — *Conclusion and future work* concludes this thesis with a summary of key findings and contributions, as well as suggestions for future work.

In addition to the body of the thesis, the reader will find supplementary material in the *Back Matter*. The bibliography can found at the beginning of the supplementary material, on page 197.

1

Context and motivations

This first part aims to introduce the 'research gap' that motivated our research, as well as to answer why we decided to address it. We use a historical perspective to highlight the major themes our research pivots on: product designing, the open approach, and the emerging paradigm of open-design. We point out the relevance of the need for modeling the open-design process. Once the research gap and its temporal dynamic has been presented, Part 2 will then review the current literature on the topic and investigate the work already done for addressing this question.

Part 1 Context and motivations

Chapter 1.1
On designing products

Our research falls within the framework of the science of design. We here remind about concerns of this framework and notably why there are (as well as why one needs) different models of designing depending on the type of product developed.

1.1.1 Product, development, design, manufacturing: preliminary definitions

Existing objects can be classified according to their origin: they can be natural — i.e. produced by nature — or artificial — i.e. man-made (Simon, 1996). We define *artifacts* as man-made objects — in opposition to *natural objects*. As for *products*, we define them as artifacts created to fulfill functions more effectively than other objects. The difference with artifacts lies in the deliberate design of the former.

New products are developed to answer unsatisfied needs. Hence *product development* is the process that takes a need as input, and aims at providing a product that answer this need as output. This process is constituted of two parts: *product designing* and *product manufacturing* (Ulrich, 2011). The former aims at conceiving — i.e. defining — the product, when the latter aims at realizing it — that is making it real, or producing it, and delivering it to the user. (A more detailed analysis of the *product designing* process is provided in Section 2.2.1. The reader will notably find an illustration of the relationships between product development, prodct designing, and product manufacturing in Figure 2.2 on page 34.)

In this research, we focus on the *product designing* process. This process indeed plays a critical role in the success of a new product — notably as it greatly impacts its final cost (Ulrich and Pearson, 1998; Ullman, 2010). Quickly developing products that meet customers' needs at low cost is the key for the economic success of most firms (Ulrich and Eppinger, 2012). In addition, we note that designing is an activity that has an effect on nearly every sphere of human life (Pahl et al., 2007a). Improving the product designing process appears thus important for more efficiently developing products that better address our needs.

1.1.2 A science of design

Separating product designing from product manufacturing enabled a global industrialization via the automation of the latter. Industrializing manufacturing enabled to lower the cost of produced goods, notably via production outsourcing, standardization, and production runs. However, the manufacturing process has no influence on the accuracy of the solution proposed to meet users' needs. Improving the product designing process is thus a key to develop better and more relevant products (Ullman et al., 1988).

The need to rationalize product designing with the view to optimize industrial processes led researchers and practitioners to use a scientific approach in order to study and improve the designing process. Even if the object of study of this science remains fuzzy (Horváth, 2004), how one designs has been widely studied, notably since the 1950s (Heymann, 2005; Pahl et al., 2007a). Several approaches aimed at improving the designing process (Cross, 2007), arguing about the scientific nature of design (Table 1.1). We consider that — regardless of the nature of design itself — product design can be an object of science. Or in other word, that one can scientifically study product designing in order to improve it.

We thus acknowledge that "design science studies the creation of artifacts and their embedding in our physical, psychological, economic, social and virtual environments" (Papalambros, 2015, p. 1). It is rooted in many scientific disciplines, and completes other fields of science — such as Management

Table 1.1
Four approaches on how to combine *design* and *science* (Cross, 2001).

Approach	**Scientific design**	**Science of design**	**Design as discipline**	**Design science**
Nature of the design process	scientific (objective and rational)	not prejudged (could be scientific or artistic)	implicit and intuitive	a scientific method
How should the design process be studied?	n/a	scientifically (i. e., with the tools and methods of science)	in a reflexive approach, by practitioners and without scientific tools	scientifically, aiming to rationalize, objectivize, and systematize design activities

science and Business economics (Hatchuel, 2012), or History of techniques. They share the same subject of study, but with different perspectives: the science of design focuses on the designing process and related activities — i.e. focusing on designers work (Warfield, 1994; Braha and Maimon, 1997) — when management and economics rather focus on organizations and social systems (S. L. Brown and Eisenhardt, 1995).

Contributions of the science of design are multiple (Papalambros, 2015). One can notably distinguish the understanding of the designing process through "the formulation and validation of models and theories about the phenomenon of design with all its facets"; and the improvement of design in practice through "the development and validation of support founded on these models and theories" (Blessing and Chakrabarti, 2009, p. 5).

One should note that the generation of knowledge about design precedes the generation of support for design. Our role as researcher in design is hence to better understand how one designs, in order to enable later improvements of this process (see Figure 2.6 on page 39).

1.1.3 Multiple models of designing

Numerous models of designing are reported in the literature. Indeed, due to the intrinsic nature of the designing process (see Section 2.2.1 on page 33), "there is no 'silver bullet' method which can be universally applied to achieve process improvement" (Wynn and Clarkson, 2005, p. 35). We here detail main differences among these models and reasons why multiple models are necessary.

i There are multiple specific models of designing

Multiple models of these practices exist with different perspective on the designing process and are used for various purposes (ibid.). Each model simplifies the complexity of the reality to make it more easily graspable, and thus serve a particular purpose (Jockisch and Rosendahl, 2009). They are used for understanding current practices, as well as easing and improving them in the industry (Töllner et al., 2009). They appear yet to "show separate development strands for each discipline" (Gericke and Blessing, 2011, p. 393), and for each type of product developed (tangible artifact, software, service, architecture, etc.). Models differ on their detailed level, even if they share similar abstract levels (ibid.). Howard et al. (2008) compared majors models of designing and underlined this recurrent typical sets of phases among most models.

ii These models are required to cope with different designing contexts

Modeling the designing process enables "to raise the quality of the designed products and improve the efficiency of the designers" (Ullman et al., 1988, p. 33). One focus of the science of design is thus to produce "design theories and methodologies" that are "a rich collection of findings and understandings resulting from studies on how we design (rather than what we design)" (Tomiyama, Gu, et al., 2009, p. 544). These understandings (notably via their materialization through models) are later used to develop dedicated tools to make the most of specific approaches of design.

Concrete (or procedural) models focuses on a particular approach to design or aspect of design. At the opposite of abstract models which are "relevant to a broad range of situations, but does not offer specific guidance useful for process improvement" (Wynn and Clarkson, 2005, p. 37), procedural models are "less general [...] but more relevant to practical situations". We see here that there is a trade-off between the breadth of the area of applicability of a model, and its relevance for the practitioner.

As detailed in Chapter 2.3 on page 43, we observe different models of designing that were developed to cope with distinctive features of to the type of product designed — tangible material, tangible digital, and service (Figure 2.4 on page 37). This, in order to develop dedicated tools and methods for dealing with different contexts of design.

As we aim at making the most of a new approach to design (that is open-design) by developing relevant tools and methods therefor, a specific model is required. Indeed, not taking specific features into consideration make developed tools and method less likely to make the most of particular approaches.

Chapter 1.2
The open approach

The second pillar on which our research rest is the so-called open approach. This approach is rooted in the Free and Open-Source Software (F/LOSS) movements. It later democratized and impacted various sectors outside the software industry.

1.2.1 Free and Open-Source Software: the roots of the open approach

Initially, we here recall how the open approach appear — first through the free-software, and the through the open-source movements.

i Origins of the Free Software movement

At the beginning of Information Technology (IT), sharing software's source-code[1] was common among programmers — even from companies to researchers or end-users (Lerner and Tirole, 2002; Stallman and Williams, 2010).

In the 1970s–1980s however, the structure of the IT market evolved, notably due to changes in the US anti-trust legislation.[2] It shifted from a vertically structured industry — the same company was selling hardware and software — to a modular and horizontally structured one — e.g. a company selling software for various brands of computers (Ong, 2004). Moreover, some companies claimed Intellectual Property (IP) on software (and thus did not allow source-code sharing anymore) — a noteworthy example is the

[1]The *source-code* is a text file containing all instructions to be performed by the computer executing it. It is like the 'recipe' that the computer has to follow, and thus where all the value of the software lies in. This file can either be a binary code (i.e. in machine-language, that is not understandable by the programmer) or written in a programming language (i.e. human understandable — e.g. in C++, Java, etc.).

[2]See the "*USA v. IBM*" case, juged by the United State District Court of the South New-York district on January 17th, 1969.

company AT&T claiming rights on UNIX. To protect software IP (i.e. restraining software copying, keeping secret a competitive advantage, etc.) and *de facto* to retain users, the release of only a binary version of the source-code of sold software became the norm (Stallman and Williams, 2010).

Reacting against this 'liberty privation' — as it was not possible anymore, legally or technically, for users to modify software and to adapt them to their needs — the free-software[3] movement was launched, notably through the publication of *The GNU manifesto* by Stallman (1985). This "political movement" (Stallman, 2008) is now structured within the Free Software Fundation (FSF). Its outcomes mainly relies on the GNU project and the General Public License (GPL) (FSF, 2007).

This movement promotes four liberties for the user of a software (FSF, 2014; Weber, 2004). They can be summed up as following:

1. to run the software without any restriction;
2. to be able to study and modify its functioning;
3. to have the right to redistribute original copies of the software;
4. to have the right to redistribute modified copies of the software.

ii Towards Open-Source Software: the shift from a political to a pragmatical approach

Practical consequences of FSF's political program democratized under a more pragmatical approach.

The free-software movement is now widely spread within the IT sector: e.g. the GNU/Linux operating system, as well as most actual programming languages. However, the whole software community did not share the same vision about how to spread this model. It is the reason why a pragmatical off-shoot of the free-software movement appeared in 1998 with the Open-Source Initiative (OSI). This initiative focuses on the practical consequences of the open-source principles, rather than on related values (Open Source Initiative, 2006).

Free-software (responding to the four previously enumerated liberties) can be thus considered as a subset of open-source software (meeting the ten criteria of OSI's definition (OSI15b) — that is itself a subset of software with an open source-code (Figure 1.1 on the next page). We acknowledge

[3]The word *free* is equivocal, meaning both "with freedom" and "at no cost". Moreover, the context of its use is ambiguous: numerous free-software are distributed at no cost (*freeware*) — cf. Figure 1.1. Following sentence is broadly used to disambiguate the meaning of *free* in *free-software*: "free as in *free speech*, and not as in *free beer*" (FSF, 2014).

Warger's definition of open-source software, which he describes as "an approach to software development and IP in which program code is available to all participants and can be modified by any of them" (Warger, 2002, p. 18).

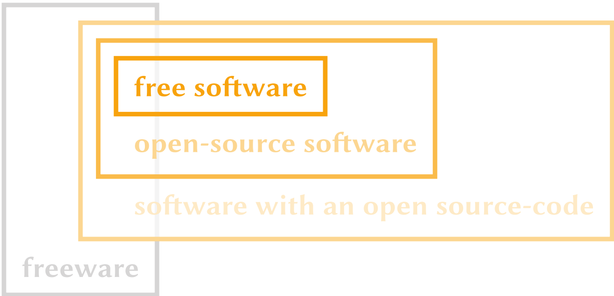


FIGURE 1.1
Disambiguation of free-software, open-source software, software with an open source-code, and freeware (software free of charge)

This shift from a political to a 'technical' movement is what enabled the rise of Free/Libre Open-Source Software (F/LOSS), as well as, later, of the open approach — see below.

1.2.2 Specific models of designing for Free/Libre Open-Source Software

The spread of F/LOSS led to new designing practices in the software industry.

Indeed, allowing anyone to study and modify the mechanism of a software makes that some users actually modify it and broadcast modified versions of the product. Hence the arrival of end-users into the designing process of such software. This raises three challenges: First, end-users-designers address their own particular needs. Second, some of these end-users-designers are amateurs who are not necessarily trained for design. Third, the public broadcast of software sources lead to asynchronous and non-coordinated collaborations (Kogut and Metiu, 2001).

These challenges are addressed by existing approaches to design. First, user innovation (Hippel, 1998) that argue in favor of the development of new product by those who benefit from these solutions. Second, amateur design — that is design not done by professionals (Beegan and Atkinson, 2008) — or "Do-It Yourself" (Atkinson, 2006), which does not necessarily imply 'less professional' work (R. Brown, 2008; Turner-Rahman, 2008). Lastly the 'bazaar' (as opposed to the 'cathedral' structure of orthodox development projects) described by Raymond (2000b).

Reis and de Mattos Fortes (2002) show the impact on the designing model through changes in the roles of developers, tools and boundary objects used, as well as activities undertaken. Similarly, Schaachi (2002, 2004) identifies differences in software processes between F/LOSS development and traditional software engineering in terms of requirements and designing process. Lastly, the null-cost of source-code duplication also lead to the development of multiple 'chunks' or software modules that are later used and combined to create more complex systems by the mean of well-defined interfaces (Mockus et al., 2000; MacCormack et al., 2006). This modularization of developed systems is necessary to enable contribution of external parties (Torvalds, 1999).

We thus see how a specific feature of F/LOSS (the free access to the source code) led to new practices in software designing.

1.2.3 The open approach: open beyond software

In Warger's definition of open-source software (see on page 13), we observe that what is opened in open-source software is the process ("software development") and related rights ("intellectual property") — not the software itself. This enables us to consider this approach outside of the field of IT.

Since the beginning of the 1990s, the concept of 'open' has indeed spread over various sectors. This trend is correlated to their digitalization, the development of digital techniques (Atzori et al., 2010; Berry, 2008), as well as the democratization of affordable and high-speed internet (ITU, 2013; OECD, 2012). This digitalization is the context enabling the spread of the open-approach. However, these necessary conditions are not sufficient. Two motivations can be distinguished in order to explain how do stakeholders get involved in open projects: ideology, and opportunity. Raymond (2001) highlights the ideological motivation (even "zelotery") of some participants. However Lakhani and Hippel (2003) have shown that this is not the only motivation since the direct or indirect benefits earned by participants are also important. This is reinforced by Lerner and Tirole (2002) in their neo-classical micro-economical analysis of open-source. Benefiting from a favorable context, and with various motivations, the open approach spread over numerous sectors. The open approach — or the so-called "open-x" (Avital, 2011; Omhover, 2015) — gathers together open-data, open-access, open-science, etc. They are the 'openized' version of these sector; or in other words, the implementation of open principles of open in this sector (Benyayer, 2014).

Beyond software, we can notably note:

OPEN-DATA: where data of all types (but mostly raw data) are put at everyone's disposal by companies[4] or public entities[5] (Bonnet and Lalanne, 2014);

OPEN-ART AND CULTURE: where the outcome of an artist or an author is in open-access, while being protected (notably via e.g. Creative Commons licensing) (Maurel, 2014);

OPEN-EDUCATION: with MOOC and P2P knowledge sharing;

OPEN-SCIENCE: an equivocal notion, which refers both to the modern way of practicing science (Dasgupta and David, 1994; Merton, 1973), as well as to a renewal of its practice in a more ethical way (open peer-reviewing, pre-publication of protocols, open-access journals, etc.) (Gruson-Daniel, 2014);

OPEN-LICENSES: for protecting both IP, and the open nature of someone's work — cf. eg. the GNU-GPL (FSF, 2007), the Creative Commons licenses (cf. creativecommons.org/licenses), etc.

All these practices are gathered under the concept of the so-called open approach. We will now see that design is no exception and is impacted by the open approach as well.

[4]Such as the Parisian railway service (`data.ratp.fr`) or Google (via the API `developers.google.com/maps`).

[5]See `data.gov` or `etalab.gouv.fr` for governments of the USA and France, respectively.

Chapter 1.3
Open-Design

The third theme of our research is open-design. We first present this new approach to product designing and its background. We then highlight its potential. Lastly, we underline the need for a modeling of the open-design process.

1.3.1 The rise of open-design: what is it and how did it appear?

In a first phase, we consider that open-design lies where product design and the open approach meet — i.e. "design whose makers allowed its free distribution and permitted modification and derivations of it" (van Abel, Evers, and Klaassen, 2011, p. 10). We will further detail this concept in Part 2, and notably coin a new definition of open-design (see on page 62).

Open-design arose because of the spread of the open approach (as detailed above), but also due to the democratization of designing itself. Designing democratization was caused by three factors: the democratization of manufacturing, the digitalization of the product designing process, and the emerging of new structures for designing.

i Democratization of manufacturing

At first sight, it might appear surprising that the democratization of product design occurred via a change in product manufacturing. However, manufacturing impacts the plan (or design) of a product: a mechanical part will not have the same design if it is made by sand-casting, by machining, or by forging. So the democratization of manufacturing (via its digitization) boosted the democratization of design (Phillips, Baurley, et al., 2014).

Manufacturing is becoming more and more democratized (G. Bull and Groves, 2009), notably via the rise of digital manufacturing (Anderson, 2014). It is due to the emerging of low-cost manufacturing solutions (additive manufacturing or '3D printing' (Gibson et al., 2015b), but also laser-cutting, etc.[1]). They reduce the cost obstacle, just like new facilities for locally manufacturing (e.g. Fabrication Laboratory (fab lab), makerspaces, etc. — see below) and Manufacturing as a Service (MaaS) companies[2] that enable the production of single prototypes or limited series artifacts for private individuals.

Digital manufacturing impacts the designing process in several ways. First, it is no longer necessary to master craftsmanship skills to produce things. The correct definition of an object makes it manufacturable by any machine. This is especially true with additive manufacturing where the *a priori* knowledge of specific rules is not required: not angle of draft as in molding, most geometries are "printable", entire functional units with moving parts can be produced in one go, etc. (Gibson et al., 2015a). It is then not necessary to be a craftsman anymore to design and produce new objects by yourself.

Then, using CNC-machining also enables to outsource the manufacturing. One can only focus on the design of an object, and send the numeric file to be produced. So objects can be produced without tinkering out, because high-precision tools can be used to this intent.

Lastly, using digital files and at-home machining (e.g. laser cutting, additive manufacturing) enables both a low-cost and a try-and-fail approach, such as adapting already existing designs. This makes the gap to cross over for adapting already existing solutions smaller. These changes in the manufacturing process lead to new forms of production, as listed by Yip et al. (2011): "open manufacturing" (Heyer and Seliger, 2012), "open production" (Wulfsberg et al., 2011), "crowd manufacturing" (Send et al., 2014), "peer-production" (Benkler and Nissenbaum, 2006; Kostakis and Papachristou, 2014), as well as MaaS (Tao et al., 2011).

ii Digitalization of the designing process

The second factor facilitating the democratization of design is the digitalization of almost all steps of the designing process — via Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Computer-Aided Engineering (CAE), and also via the Product Life-cycle Management (PLM). It makes easy to exchange boundary objects at various stages of the development, and thus to outsource one or more steps of this process. This

[1] See for example the Open-Source Ecology (OSE) project that provides open-source plans for 3D printer, Laser Cutter, Computer numerical control (CNC) torch, Trencher, etc. (OSE, 2016)

[2] Such as Shapeways (`www.shapeways.com`) and i.materialise (`i.materialise.com`).

digitization occurred upstream, starting from the manufacturing (see above), and then reaching early phases of the designing process.

Manufacturing tools have been automatized for a long time, starting in 1725 with a loom using a punched ribbon (Ligonnière, 1987), preceding automatized machines with CNC. However, the machining sequence only was automatized.

Through progresses of complex geometries modeling (notably via Bézier's curves), CAD[3] appeared, shifting from drawing board to digital parametrized volumes. It was then possible to define the to-be-produced objects, what enables inference checking, automatic generation of bill of materials, etc. But the greatest advantage was the consequent development of CAM, i.e. digitally connecting product definition with its manufacturing. Later improvement of CAD no longer focused only on 3D-definition of the to-be-produced object, but also included decision-making tools (integrating stress analysis, structural calculation, strength of materials, kinematics, etc.). This global digitization is also referred to as CAE (Lee, 1999).

This automation focused on the late phases of the designing process, that is detailed design. However, recent studies address the automation of its early phases: for example, the project TRends ENabler for Design Specifications (TRENDS) (Bouchard, Omhover, et al., 2008) aims to compute the inspirational phase (Bouchard, J. Kim, et al., 2010) and developed a creativity support tools for designers (J. Kim et al., 2012). At the same time, the project GENeration Innovation User-centred System (GENIUS) aims to help designers with automatic shape generation (Omhover et al., 2010).

The digitalization of all steps of the product designing process enables the spread of computing tools for design. These tools enable the computation of some steps of the designing process, and thus lessen the need specialized skills. As a consequence, it favored design democratization.

iii New structures for designing

Lastly, design democratization is also rooted in alternative structures for designing: fab labs, makerspaces, hackerspaces, and techshops (Cavalcanti, 2013). If fab labs (Gershenfeld, 2005), and hackerspaces emerged from the open-movement and the movement of the makers (Anderson, 2014), all of these initiatives are not fully new. Indeed, maker spaces and collaborative development stemmed from industrial collaborative ecosystems in the 19th

[3] Note that in the context of Computer-Aided Design, the word *design* should be understood in a narrower meaning that the definition coined above, i.e. as the 'plan' (see Figure 2.2 on page 34) that is the unequivocal representation of the product.

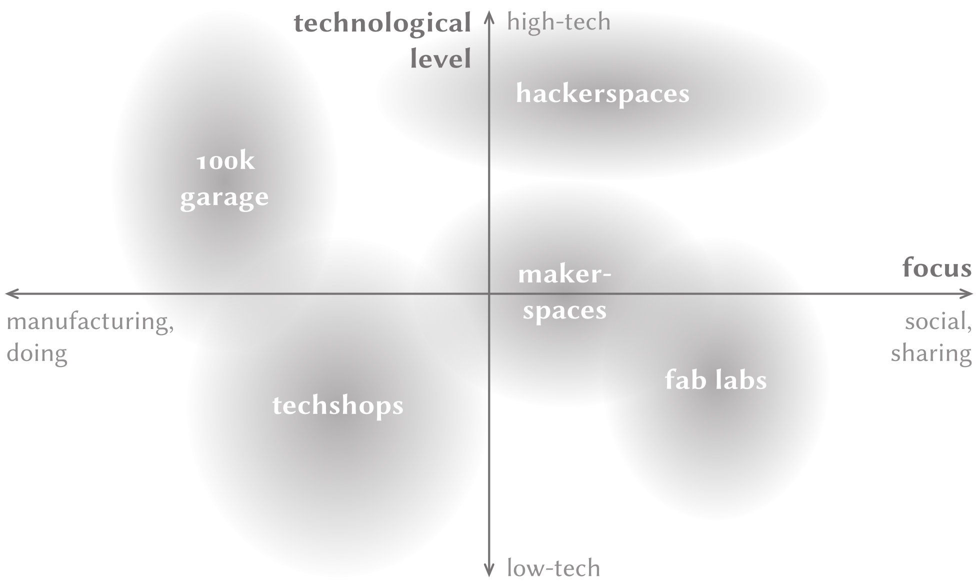


Figure 1.2
The alternative structures for designing, *adapted from Troxler (2011, p. 92)*

century.

Fab labs, techshops and hackerspaces are workshops dedicated to personal digital fabrication. They differ in terms of subject of production (low vs. high-tech products) and focus (how do people spend their time in these structures?) — see Figure 1.2. Their origins are also different: fab labs were coined in at Massachusetts Institute of Technology (MIT) in the early 2000s — originally for developing Information and Communication Technologies (ICT) in network, with personal manufacturing machines and at an affordable price (Mikhak et al., 2002). It then grew into a network that nowadays represents more than 1000 different laboratories[4] sharing four common principles[5].

Techshops follow the same purpose as fab labs — Cavalcanti (2013) argues that both are "makerspaces franchises". They enable personal (digital) manufacturing in an open and collective workshop. However, even if *techshop* is now used as a generic noun, it comes from the TechShop company that started in 2006 in Menlo Park, CA. This company is a chain of for-profit open-access public workshop, that includes facilities and design services. Where fab labs have no, or limited, fees for participating but requires personal implication and/or open-source project documentation, techshops are

[4]The Fab Foundation (www.fablabs.io/labs) listed 1163 fab labs in 106 different countries on 2017-07-14.

[5]As listed by the Fab Foundation (2016), these principles are: public access; subscription to the fab lab charter (CBA, 2012); sharing tools and processes; and taking part into the fab lab network.

personal manufacturing provider as a service, and thus have higher fees.

100k garages share same principles as techshops, but rather focus on the making. Like subcontractor's workshop for digital fabrication, they are, however, dedicated to amateurs.

At the same time, hackerspaces (originally underground networks) grew in popularity — cf. NYC Resistor and Noisebridge, two famous US hackerspaces, respectively created in 2007 and 2008; or the Berliner one c-Base that opened in 1997 and which is considered as the first hackerspace. They were originally defined as "a collection of programmers (i.e. the traditional use of the term *hacker*) sharing a physical space" (ibid.). Focused on programming, they then expanded to electronics and mechatronics. They are rooted in and influenced by the free-software movement.

However, these places for collaborative design and development are not totally new but recalls preexisting practices. Nuvolari and Rullani (2007) highlight how "collective inventions" (Allen, 1983) existed since the industrial revolution. See Hunter (1949), Foray and Perez (2006), and Nuvolari (2004) for case studies on that topic. Makerspaces and other manufacturing spaces with pooled means are very similar to what we previously presented, as they share the same purpose. However, if they have been recently created, they look like older structures such as artists workshops and studios of the 19th century, where knowledge, know-how and tools were put in common. These new structures enabled open access to the making process, which in turn led to the design democratization by making the design phase closer to the consumer, but also by changing the general perception of industry and making it closer to end users (Rumpala, 2014).

We observe through the semantic of this phenomenon ('movement of the *makers*', '*fabrication* laboratories') that this new approach to design occurred upstream, i.e. is correlated to a change in the manufacturing of objects. Moreover, this approach is very much product or outcome oriented. It means that design is taken on relatively to the manufacturing and not *per se*.

It is in this context of the product design realm that open-design emerged when product design met the open approach.

1.3.2 Why does open-design appear promising?

Benefits of F/LOSS have been acknowledged for a long time in the industry. This type of software is characterized by permission being granted to anyone to use, study, modify, and distribute their source-code for any purpose. These liberties enable the following benefits respectively: flexibility and freedom (open standards are used for easier integration in or with other systems; easy customization), auditability and reliability (anyone can detect and correct a bug or a malicious feature), support and accountability (development of upgrades is supported by the whole community; contributions are tracked and monitored), stability and maintenance (software development can continue even if original editor closes down). These benefits have led to great industrial successes: For example, GNU's not UNIX (GNU)/Linux that is an operating system on which two thirds of web servers in 2017 were run (W3Techs, 2017). It is sold by Red Hat (among others) — a company that generated more that $2 billion of revenue in 2016 (Business Wire, 2016). Further, the Apache HTTP Server powers one half of web servers worldwide; Docker Inc. has been valued at one billion dollars in 2015; etc. Specific features of F/LOSS also brought about new practices: iterated and decentralized development, asynchronous bottom-up contributions, flat-hierarchy project structuring, and active involvement of end-user in the development, etc. (Raymond, 2001).

This phenomenon has long been limited to the software industry. However, due to global digitization and the spread of efficient and low-cost communications, it has spread to other industrial fields (see Section 1.2.3 on page 14). Design is no longer an exception: the term open-design has been used since the late 1990s. Van Abel, Evers, and Klaassen (2011, p. 10) define open-design as "design whose makers allowed its free distribution and permitted modification and derivations of it". Open-design uses two levers: the power of the crowds (summing single contributions lead to great progresses) and 'standing on the shoulders of giants' (efforts are only spent on improving existing solutions, and not reinventing the wheel). Noteworthy examples of open-design include: RepRap, an amateur-designed 3D printing machine whose documentation is freely available on Internet (CAD files, assembly instructions, versions records). This has served as a basis for 400+ customized derivatives (Gilloz, 2014). Arduino, an open-source micro-controller, and related Integrated Development Environment (IDE), which makes it easy for the user to build and control electronic systems and has interfaces for external 'shields' (sub-modules that enable a specific function, e.g. a Radio Frequency IDentification (RFID) reader). And also the solar photovoltaic sector where several companies shared their IP in order to boost the development of new techniques (Buitenhuis and Pearce, 2012).

1.3.3 Why is it important to model open-design?

We presented the new paradigm we study. We now detail motivations for addressing the issue we investigate: the modeling of the open-design process.

i Specific characteristics of open-design projects

Reports on open-design show that this approach has specific characteristics. It is rooted into both open-source software design and traditional design.

Open-design projects indeed share characteristics with open-source software projects (Raasch, 2011): access to sources of design, development of a modular product, the use of external volunteers in the co-development of products. However, all characteristics of open-source software do not apply to open-design: most project open only part of their sources (Raasch, Herstatt, and Balka, 2009; Balka et al., 2010), the breadth of required knowledge is indeed more important in the development of physical artifacts, the tools needed are also more complex to master and require greater investments (in terms of time and money), and lastly, the rival nature of atoms (compared to bits) implies higher costs and logistic issues in the production.

This thus requires distinct stakeholders, notably in the production and distribution phases — as it is the case for traditional design (Abdelkafi et al., 2009; Hippel and Krogh, 2003). The manufacturing might indeed be outsourced to conventional companies (Raasch, Herstatt, and Balka, 2009) — what differs from the production of Open-Source Software (OSS).

This makes that if open-design is rooted in both the open-approach and traditional design, it possesses specific features that prevent to boil it down to one of these categories only.

ii Existing models do not take into consideration specific features of open-design

We have highlighted specific characteristics of open-design. If we look at existing models of designing, we observe that they do not fully take these specific characteristics into consideration.

Raasch (2011) states that, “subject to certain contingencies, open design processes can be organized to resemble OSS development processes to a considerable degree”. We also know that OSS designing processes differ from designing for tangible artifacts (see Section 1.2.2). We can thus consider that there is a difference between open-design model and traditional ones.

However, Raasch also states that “physicality matters for [open-design] processes”. Indeed, dynamic design models combined with contributions of both agile and crowed-sourced approaches do not explain how does stakeholders collaborate when each of them do not have access to a prototype. The intrinsic differences between software and hardware (zero versus non-null marginal cost; non-rival versus rival goods) makes direct transposition of knowledge about F/LOSS into the design of tangible artifacts difficult (Abdelkafi et al., 2009). Moreover, 'sources' of tangible artifacts must be detailed. This argue in favor of differences between open-design and OSS designing processes too.

Hence the gap between existing models of designing (either for physical or for digital designing processes) and open-design practices, due to specific features of the latter. Yet, as detailed above, making the most of a specific approach to design requires adequate (and thus specific) models of the designing process for supporting the development of relevant tools and methods for practitioners. It is thus crucial to model the open-design process.

Synthesis

Product designing is the first part of a more global process that is product development. The latter aims at providing end-users with an object that meets some of their identified needs in a better way than the already existing available solutions. The former focuses on conceiving and defining the solution to this need. It is then followed by the manufacturing of the defined solution. Improving the designing process is critical to better address our needs in a more efficient manner. This has an impact on economic success of goods producing companies. Understanding current designing practices as well as developing methods and supports to improve them is the objective of the science of design.

To improve designing processes, numerous models of designing have been developed. They differ notably to cope with characteristics of developed products: one does not design cars the same way one designs chairs. Similarly, we observe different models (or practices) for designing hardware compared to those used for designing software. This, because it appears important to develop specific tools and methods according to the type of product in order to make the most of it.

At the same time, a movement originally coming from the software industry arose: the so-called *open approach*. This movement, still active today, aims at giving more freedom to users, notably in the use and broadcast of information relative to their products. In the context of software it means enabling the user to study, modify, and share the source-code of the software. Such approach induced new practices in the designing of open-source software (e.g. Peer-to-peer (P2P) collaboration, decentralized and asynchronous development, as well as crowd-sourcing). It also impacted other sectors: open-data, open-government, open-hardware, open-licensing, etc.

Design is no exception and is impacted by this open approach too. Open-design is then where the open approach and product design meet. Specific features of the open approach led to industrial successes in the software industry. We could claim that companies developing tangible products might also benefit from it. However, intrinsic differences between hardware and software (notably the zero marginal cost of software production) make difficult to directly transpose best practices in the development of tangible products, and to know to which extent open-source software development practices apply to hardware.

The objective of our research is hence to gather data about this emerging, yet promising phenomenon that is open-design. Modeling the open-design process should help us better understand it. This study would then be a basis for future researchers and practitioners aiming to develop specific tools and methods for making the most of open-design in the development of tangible products.

2

Literature review

In the previous part, we identified a research area that appears interesting and relevant for further investigation: the open-design process and its modeling. In this part, we review scientific literature on the topic in order to cover previous studies investigating this area, to clarify existing knowledge and its limits, as well as to define major terms and methods that will be used later.
First, we expound our scientific positioning. Then, we summarize actual state of the art on designing processes modeling and present major types of models. The next chapter details specific features of openness. Lastly, we report the first insights on the emerging topic that is open-design.
The description of the already completed research on the topic will serve as a basis for planning our study, as detailed in Part 3.

Part 2 Literature review

Chapter 2.1
Scientific positioning

Prior to summarizing current findings on open-design, we feel necessary to clarify our scientific positioning. First, we set our research paradigm out — i.e. the 'scientific rules we play by'. Then, we clarify disciplines in which our research is rooted and the field to which our study aim to contribute. Lastly, we position our work regarding our local environment and the international scientific communities.

2.1.1 Research paradigm and chosen methodology

A research paradigm is made of "examples of actual scientific practice — examples which include law, theory, application, and instrumentation together — [that] provide models from which spring particular coherent traditions of scientific research" (Kuhn, 1970, p. 10). In other word, paradigms are a "a set of beliefs, values, and assumptions that a community of researchers has in common regarding the nature and conduct of research" (B. R. Johnson et al., 2007, p. 129 sq.). They are characterized by their ontology (the "nature of 'reality'"), their epistemology (the "nature of the relationship between the knower […] and the known"), and their methodology (the way to "find out knowledge") (Guba, 1990, p. 18).

We fell necessary at the beginning of this research to clarify how we will address the research gap previously defined. Methodological choices will indeed be impacted by the research paradigm in which we place our study.

As we consider our research as *scientific*, it falls within the positivist framework. More precisely, we acknowledge limits of a pure positivism and thus place ourselves in the *post-positivism* paradigm. The latter shares the *realist* ontology — things exists 'out there' and their underlying principles can be summarized in context-free generalizations — yet with a critical distance — reality can never be fully apprehended (Sider, 2009). The related epistemology is the *modified objectivist* (Guba, 1990) or representational epistemology: one can know this reality and use symbols to describe and explain it, yet reality can only be approximated even if "objectivity remains a 'regulatory ideal'" (Guba and Lincoln, 1994, p. 110).

For what regards methodology, we use the *modified manipulative* one. This methodology uses "more qualitative methods", and notably "depend[s] more on grounded theory" (Guba, 1990, p. 23) than the original manipulative methodology that belongs to the positivist paradim. Using qualitative methods is indeed compatible with the post-positivist paradigm (Bryman, 2004). Combining qualitative and quantitative methods raises several issues, that can be addressed when separating methods from their often associated constructivist paradigm (Morgan, 2007). We thus found appropriate to adopt mixed methods research approach (B. R. Johnson et al., 2007), and notably use constructivist qualitative methodologies for our exploratory research (Angen, 2000).

2.1.2 Areas of relevance and contribution

Once this meta-scientific scene set, we now detail disciplines influencing our research, and the one to which our research contributes to.

Our research is driven by two major topics: product design and the open approach. This makes our research be influenced by numerous disciplines. They chiefly come from two main fields of science: sciences of artificial — i.e. sciences that study non-natural (or man-made) objects and phenomena (Simon, 1996) — and social sciences — i.e. sciences that studies human beings and their interactions. This encompass multiple disciplines such as:

Design science: See below.

Computer science: "The study of the phenomena surrounding computers" (Newell and Simon, 1976, p. 113), i.e. the study of the design and use of computers. Better understanding the nature of computers and software help us assess how this impacts the way they are designed.

Economics: The study of the production, distribution, and consumption of goods. We try to understand motivations for a company to broadcast its ip at no cost.

History of techniques: The study of the evolution of techniques over time. We aim at defining what is characteristics of open-design and what comes under older forms of collaboration.

Management: The study of business activities' organization and coordination towards defined objectives. How is a business organized might impact the way a company develops a product.

Sociology: The study of social behaviors. We study how different people can collaborate, notably without financial incentives.

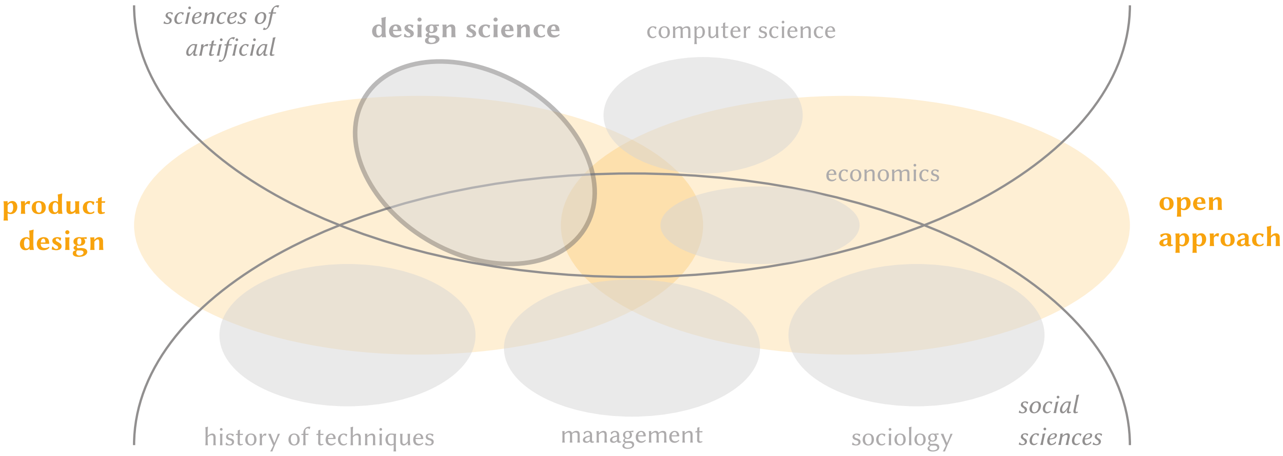


Figure 2.1
Areas of relevance and contribution diagram: our research fall within the framework of the design science.
Orange areas represent the two main topics of our research. Gray ones are for the different disciplines influencing our research. They belong to one or the other of both fields of sciences outlined in gray. Finally, we highlighted design science *— the discipline our study contributes to.*

We have observed that our work is rooted in multiple scientific fields. Our intended contribution is, however, narrowed to one topic only: the designing process. As evoked in Section 1.1.2, a specific scientific field studies this process. Our research hence falls within the framework of the *design science*. The latter "is about observing existing and created design practices, about formulating design theories and models for describing and improving design practices, and about evaluating these design theories and models" (Vermaas, 2014, p. 47).

We sum up these various fields and disciplines with their relationships and subjects related to them in Figure 2.1.

2.1.3 Research environment

This PhD study was conducted in the Product Design and Innovation Laboratory (or LCPI, standing for Laboratoire Conception de Produits et Innovation) of Arts et Métiers ParisTech, in Paris, France. Research conducted in this laboratory focuses on the optimization of the product designing process. Three main approaches are used for that. First, enriching the designing process through the integration of new professions. Second, the modeling of individual and collective processes occurring during the various steps of design. Third, supporting these processes through the development of new methods and technologies. Our research fall within the second approach, as it aims to model the designing process in the specific context of the open approach.

Our research is also related to works carried out by other researchers across the world. Numerous academics studies in the field of design science.

They are notably gathered in the 'Design Society'. Some of them more specifically study open-design or related concepts. Without pretending to be exhaustive, one can notably list:

- A 'German School' consisting in the work carried out by Raasch at the School of Management of the Technical University of Munich, and Herstatt at the Technische Universität Hamburg — notably in the early 2010s during the PhD of Balka.
- An 'American School' consisting of research on user-innovation lead by Hippel at the Sloan School of Management of the MIT, collaboration with Lakhani of the Harvard Business School. To this group adds Krogh of the Department of Management, Technology and Economics at the Eidgenössische Technische Hochschule (ETH) Zürich. This group is linked to the German school, notably through Spaeth who collaborated with Krogh at the ETH Zürich and now works as the Technische Universität Hamburg. Works of both of these schools are close from our research. However, one should note that they rather fall within the framework of management or business science.
- A 'Brazilian School' with Rozenfeld and Macul from the Departamento de Engenharia de Produção of the Universidade de São Paulo who notably studied the OSE community.
- A 'Dutch School' with van Abel, Klaasen, Evers, and Troxler. These forerunners of open-design notably published *Open Design Now* in 2011, which is a compilation of articles and case studies on open-design. Note that this school is mostly constituted of practitioners.
- A 'Franco-German School' with notably Boujut, Bonvoisin, and Mies. This group is constituted of researchers of French laboratories G-SCOP and CERAG in Grenoble, and of the Technische Universität of Berlin, Germany. They study and develop new tools and methods for supporting the open-design of innovative products. Their research is supported by a tree-years research program that started in 2016 and which also gathers private firms using open-design processes (Raidlight) and two open-design platforms (P2PLab and OSE).

Chapter 2.2
Designing processes modeling

In the previous chapter, we defined how we intend to address the question of the open-design modeling. We now review current scientific literature on topics investigated. In this chapter, we start with the designing process and its modeling. First, we define what is product designing. Then we detail the difference between the 'design process' and 'designing processes'. We continue with listing the different parameters used to describe product designing processes. Finally, we report how and why one models designing processes.

2.2.1 What is product designing?

In Chapter 1.1, we outlined differences between product development, product designing, and product manufacturing. We here go in depth into the definition of product designing. First, we disambiguate the difference between *design* and *designing*.

i Design versus designing

The term *design* is polysemous, hence sometimes ambiguous. It is used in English both as a verb and as a noun, with slight nuances in the meaning thereof. Deriving from its Latin root "*designare*" (meaning to define, to describe, or to mark out), design "is above all determination through representation" (van den Boom, 1994, translated in Bürdek, 2005, p. 13).

As a verb, *to design* is used to describe the activity of conceiving and defining an object that meets identified needs. We will use the gerund *designing* to emphasis the aspect of a process being carried out through a succession of activities (e.g. 'models of designing processes'). This process has yet specific characteristics that makes it different from other activities such as science or art (see Section 2.2.2). We will then use the infinitive *design* to refer to the singular mental process called on during these activities (e.g. "*the* design process", as detailed on page 36).

As a noun, *a design* is used to refer to the representation of a product definition that still has to be realized. It is precisely this unambiguous description of the conceived object that is the output of the designing process, and the input of the manufacturing one (Cross, 2001). To avoid ambiguity, we will then use the noun *plan* (see below) as a synonym of design in this context.

Lastly, in the expression *open-design*, the noun *design* refers to the designing process with both its in and outputs together.

ii Product designing: a definition

As introduced in Section 1.1.1, product development is "the transformation of a market opportunity into a product available for sale" (Krishnan and Ulrich, 2001, p. 1), i.e. going from a gap to a product. Product designing is a sub-process of product development. It admits a *gap* as input, and delivers a *plan* as output (Figure 2.2).

The *gap* (sometimes called 'need' or 'market opportunity') is the difference between current situation and a preferred one (Simon, 1996). Or in other words, the difference between what users expect to be and what actually is. The perception of this gap by the user itself or by observers (the gap can indeed be conscious or not) is the prerequisite of the designing process (Ulrich, 2011).

The output of the designing process is the so-called *plan*. This "final description of the [designed] artifact" (Cross, 2000, p. 4) is usually constituted of drawings. In addition, one frequently adds other specifications such as bill of materials, dimensions, building instructions, and other codified documentation (ibid.). These instructions are nowadays digitized.

Product designing is thus the process of devising and then unambiguously defining a product that would meet a targeted gap. We call a *design project* an instance of the product designing process.

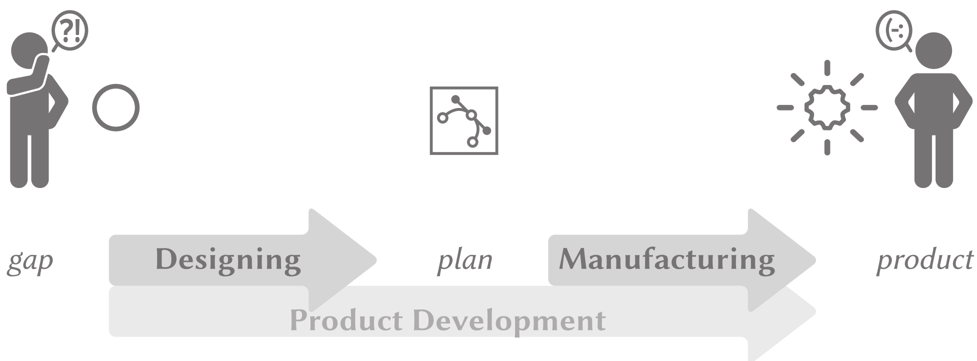


Figure 2.2
Product development and its two sub-processes: designing and manufacturing, *adapted from Ulrich (2011, Exhibit 1-9, p. 6)*

Product designing is obviously about products. We distinguish tangible products — which include both physical (e.g. chairs) and digital objects (e.g. software) — from intangible products (e.g. services). Service design (Shostack, 1982; Mager, 2008) is the "overall process of developing new service offerings" (S. P. Johnson et al., 2000, p. 5) or "the work of specifying an idea about a new service in drawings and specifications" (Cho and S. Kim, 2013, p. 9). It is a notable example of using a designing process outside the development of objects. One can also co-produce services (Parker and Heapy, 2006). Designing services has then become a growing and major topic (Meroni and Sangiorgi, 2011). However, it is not covered by the scope of this study that focuses on the open-design of *tangible* products only. Similarly, we will not detail the designing of hybrid products such as product-service systems.

iii The nature of the designing process

Designing is a complex process. It means that this process is hardly computable, because of the amount of contingencies, the range of issues that must be addressed, as well as the variety of influencing factors and their related interactions.

Designing is indeed an instance of "wicked problem" (Rittel and Webber, 1973) solving (Cross, 1982; Willem, 1990; Buchanan, 1992). This means that the initial gap is usually ill-defined, sometimes with contradictory expectations (Jansen, 1990). Each instance of designing is contingent, unique, and thus not reproducible. This is because the problem itself evolves, and also because the process of solving it can never be duplicated (there are not the same person to solve it, or they don't have the same constraints nor resources, etc.). Even if one would have to solve the same problem twice in the same conditions, one would be more experienced the second time. In addition, there is no definitive formulation of the problem (here the design gap). Indeed, "the information needed to *understand* the problem depends upond one's idea for *solving* it" (Rittel and Webber, 1973, p. 161). This makes that there is no definitive solution that can be found as gaps are contingent and evolve over time, and because solution's evaluation criteria are relative to the solution developed. Chosen solution is then a compromise balanced by designers (Matthews et al., 2002).

All this, plus the fact that most variables are subject to the observer's effect, makes that the study of the designing process is not an exact science. This does not prevent science to study designing (Cross, 2007; Farrell and Hooker, 2013), as we present in this thesis. However, it explains intrinsic limitations of findings about designing processes.

2.2.2 One design process and multiple models of designing

The mental process called on by designers during the process of conceiving and defining an object that meets identified needs is singular. This "designerly way of knowing, thinking, and acting" (Cross, 2001, p. 54) intrinsically differs from the scientific (Stolterman, 2008) and the artistic process (Cross, 1982).

This mental process is the transition from a "problem space" to a "solution space" (Newell and Simon, 1972, cited in Richard, 2004) that are co-evoluting (Maher et al., 1996; Dorst and Cross, 2001). The process is constituted of two main abductive phases (Tomiyama, Takeda, et al., 2003; Kroll and Koskela, 2015): the generation of possible solutions to the problem, and the selection of the most appropriate one (Figure 2.3[1]). J. C. Jones (1984) prepends a preliminary phase to these two major ones that is the analysis. It is a refining of the problem (notably through translating the problem from the user or marketing point of view into a designer point of view). Bouchard (2010) details a fourth phase appended to the three major ones: the materialization that is the formalization of the selected solution.

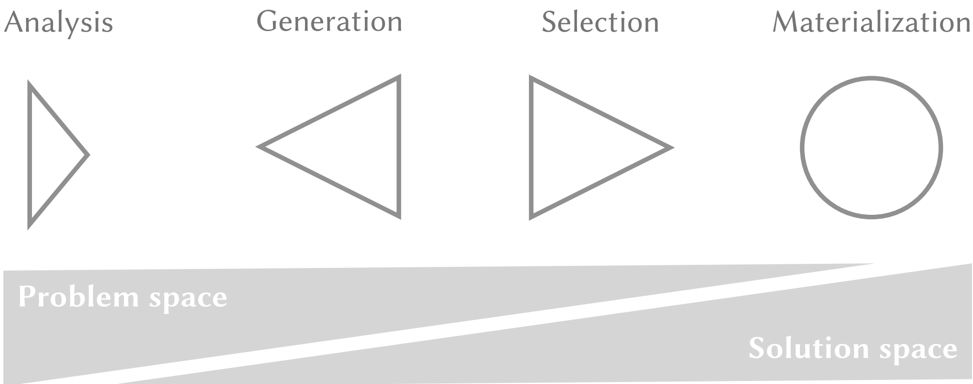


Figure 2.3
The *design process* is the transition from a problem to a design space via four major phases.

These phases overcome the various models of designing: they are what constitutes the act of designing and makes its singularity — whatever the method or steps followed. What differs among models though, are the

[1] This figure imitates the model of Bouchard (2010, Fig. 12, p. 27). The terminology is yet not exactly the same: in the original model, the four phases are named *information*, *generation*, *evaluation*, and *materialization*, respectively.

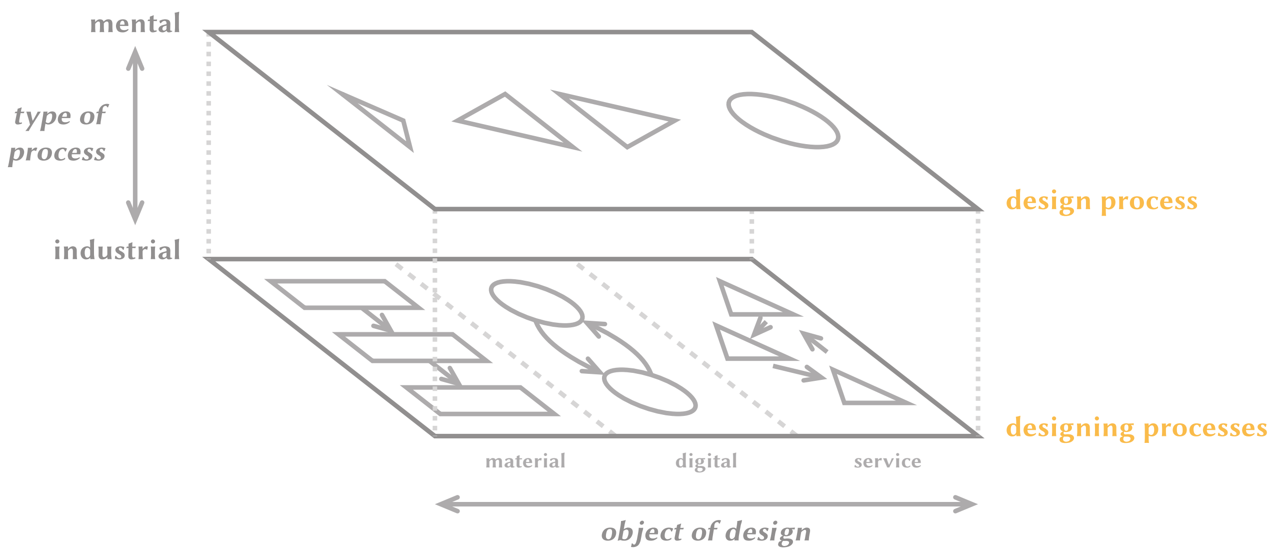


FIGURE 2.4
Multiple *designing processes* exist to cope with different contexts of design — notably the type of product developed.

different activities and how they are organized, stakeholders who are taking part in them, and the nature of information they exchange.

Indeed, as detailed in Chapter 2.3 on page 43, numerous models of designing have been described in the literature (Tomiyama, Gu, et al., 2009; Howard et al., 2008). They notably aim to cope with distinctive features of the type of product designed — physical, digital, and service (Figure 2.4). Other models aims at optimizing a specific step of the designing process or at increasing a virtue of the to-be-produced artifact (Holt and Barnes, 2010), such as *Design for x* models — where *x* stands for manufacturing, assembly, additive manufacturing, etc. (Kuo et al., 2001). Finally, another set of models aim at emphasizing a specific objective of the designing process: making end-users the of design (user-centered design — Norman and Draper, 1986; Abras et al., 2004), or even integrating them into the designing process (participatory design — Kensing and Blomberg, 1998; Schuler and Namioka, 1993; Spinuzzy, 2005). For what regards this study, we aim to construct a model that highlights distinctive feature of one type of designing processes: the open-design.

2.2.3 How to describe product designing processes

As presented above, the designing models of designing processes developed in the literature can notably be classified according to their intent (prescriptive, descriptive, etc.), to their form (linear, iterative, sequential, parallel, etc.), and their scope (chosen boundaries, industrial sector-specific, etc.) (Wynn and Clarkson, 2005). This classification enables to distinguish one *model* from another.

To describe designing *processes*, however, we use different parameters (Figure 2.5). As previously mentioned, designing is a process that has input (the gap) and output (the plan). The *gap* and the *plan* are thus the first two parameters we will use. As for the 'black box' that is the designing process, it can be further detailed. We describe it through its three main factors. First, the phases or *activities* carried out during this process (i.e. sub-processes). Second, the *stakeholders* involved in these activities (i.e. who is doing the job). Stakeholders are notably described through their skills. Indeed, various specialists are listed in the literature: engineers, designers, ergonomists, etc. Each specialist has its own representation of the problem, and solves it in a specific way. Third, *boundary objects*, which are formalized media for exchanging knowledge and information during and between activities — i.e. inputs and outputs of the sub-processes (Carlile, 2002).

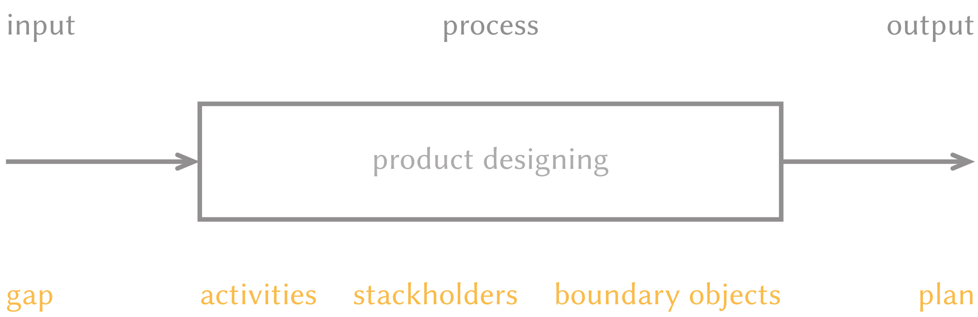


Figure 2.5
The five parameters used to describe designing processes

2.2.4 Constructing models of designing processes

We consider models as "a simplified and therefore to a certain extent a fictional or idealised representation" of the process (Maier et al., 2014, p. 133). They notably consist of "descriptions" and "set-theoretical structures" — i.e. a set of entities and relations between them (Vermaas, 2014, p. 51). In this section, we address the reasons and methods for creating models of the designing process.

i Why creating models?

Modeling the designing process enables "to raise the quality of the designed products and improve the efficiency of the designers" (Ullman et al., 1988,

p. 33). One focus of the science of design is indeed to produce "design theories and methodologies" (DTM) that are "a rich collection of findings and understandings resulting from studies on how we design (rather than what we design)" (Tomiyama, Gu, et al., 2009, p. 544). These DTM are generally represented through models. They can serve different purposes: describing design practices (descriptive theories), defining which practices fall under the term of design (demarcating theories), or "singling out particular types of design practices and positing favourable properties about these practices" (prescriptive theories) (Vermaas, 2014, p. 49).

The first and last purposes highlight the two movements of the science of design (see Figure 2.6), which is an applied science — meaning that its aim is to improve designing in practice.

The first movement is the bottom-up *explanation* (or synthesis). In this praxeologial approach, researchers identify hypotheses for general patterns in designing practices by gathering data on them. Once these hypotheses are tested, laws that rule the designing process can be defined. Combining and generalizing these laws leads to design theories. These descriptions help to explain or predict practitioners' activities.

The second movement is the top-down implication (or integration). In this prescriptive approach, a set of general theories are admitted. Researchers infer from them processes to be followed and activities to be carried out during a design project. These prescriptions help to improve practitioners' activities.

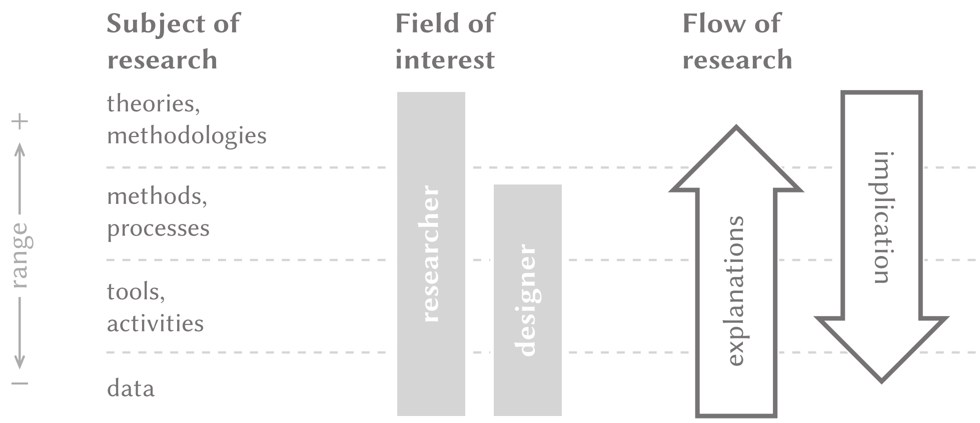


FIGURE 2.6
The two movements in the science of design, *adapted from Lahonde (2010, Fig. 10, p. 39)*

Models are thus media used to convey a certain understanding on design practices (how they are, or how they should be). They are tools that help to summarize and broadcast findings. Creating models about specific aspects of designing practices is thus an integral part of the science of design — used during both explanation and integration phases. So "there is no reason to believe that the existing models are sufficient" (Smith and Morrow, 1999, p. 259): developing new models is necessary to help us understand new practices such as open-design.

However, we must acknowledge limitations of providing models (Lane, 1992). These "limitations arise from the modeler's need to reduce the complex situation to a more structured form in order to have it fit in the modeling framework, the lack of quantitative modeling approach, the obviousness of findings that arise from a model, the difficulty of capturing process steps that are often intuitive, and the lack of the ability of the model to be updated as the organizational situation changes" (Smith and Morrow, 1999, p. 241).

It then appears relevant for us to create a model of the open-design process in order to explain this new phenomenon and to be a basis for future research on the topic.

ii How to create models?

Morris argues that modeling is an "art", where "the process by which the experienced [...] scientist arrives at a model of the phenomenon he is studying is probably best described as intuitive" (Morris, 1967, p. 707). We acknowledge that inferences or abductions occur during the generalization of an observed phenomenon. However, we don't find satisfactory to rely on intuition solely for creating a scientific model.

We then found various approaches to model human processes, notably in the context of business processes and workflows (Kettinger et al., 1997; Aguilar-Savén, 2004; Giaglis, 2001). Some of them are dedicated to the modeling of product designing processes (Smith and Morrow, 1999). They differ in terms of purpose and what they explain. Amigo et al. (2013) develop a extensive literature review of existing modeling methods. They notably list the different purposes a model could have (e.g. calculate slack/float time, define/show activities/sequences, show flow of data or information, etc.). We must observe, however, that these tools and techniques detail different representations of the designing models (i.e. sets of elements and conventions to use for modeling the process), rather than methods for creating these models (i.e. how to summarize the actual practices into a model).

Considering that open-design is an emerging practice with little findings reported in the scientific literature (see Section 2.4.5 on page 63), and that our objective is to model it for better understanding it and then being a basis for future researchers and practitioners aiming to develop specific tools and methods for making the most of open-design, we are looking at modeling techniques relevant for following purposes (ibid., p. 175):

- Define/show activities/sequences: process or project activities linear ordering, sequencing;
- Identify constraints that can interfere in the product development process;
- Show flow of data or information: show how information enters and leaves the process (process or activities inputs/outputs);
- Show process milestones/deliverables: highlight important process or project events;
- Shows activities' effects on deliverables/flow of information: connect activities with deliverables and indicate cause and effect relations;
- Visualize/understand design process: provide concise representation; communicate, explain process.

Nonetheless, no technique listed by Amigo et al. (ibid.) meet our requirements. We thus looked at other techniques for gathering data on socio-technical systems.

One of them is the grounded theory. It is a method for experience-based qualitative research (Strauss and Corbin, 1998), falling within the constructivist paradigm. It aims at constructing a new theory or model regarding social phenomena through the analysis of raw data, via a rigorous systematic step-by-step formalization and abstraction of these data. This whole process occurs iteratively, and enables to unveil valid models of implicit social constructs such as designing processes (Lingard et al., 2008). It can also serve to model a series of activities and relations between them. Indeed, "it is appropriate when the study of social interactions or experiences aims to explain a process, not to test or verify an existing theory" (ibid., p. 459). Its purpose is thus to develop new understanding on human phenomena and can be used either for phenomena that have not been modeled yet (cf. Laperrière, 1997; Schreiber, 2001), or for providing new perspective on already modeled phenomena (Guillemette, 2006).

The approach of the grounded theory appears then as a relevant method to generate a model that fits practices when little information about the phenomenon is available — which is the case when modeling the open-design process.

iii How to assess a model?

"A model [...] of designing should be able to describe or explain characteristics of one or more facets of design and designing" (Ranjan et al., 2014, p. 306). For that, Smith and Morrow (1999) detail criteria a model of the designing process must meet:

- addressing an important managerial issue,

- enabling to make decision based on information that is available and accurate,
- reasonable assumptions and simplifications of the model,
- and being computationally tractable.

However, the most notable point is the need for both “academic- and practitioner-oriented components” in these models (Smith and Morrow, 1999, p. 261).

To these global criteria, Lindemann (2014) add three characteristics of models: the reduction (i.e. a model simplify the complexity of the original situation), the transformation (i.e. elements of the models are added compared to the original situation), and the pragmatism (i.e. the model address a purpose and is dedicated to a defined set of users). From these characteristics derive six requirements (Kohn et al., 2013) — as described by Chakrabarti and Blessing (2014b, p. 21):

- the accuracy (i.e. the correspondence between the model and the original),
- the clarity (i.e. how clear the purpose and limits are to the user),
- the comparability (i.e. can it be compared with original or with other models),
- the profitability (i.e. what are the benefits of using the model),
- and the systematic settings (i.e. how to set up the model for using it).

“For a model to produce reliable predictions of living systems such as companies, markets, national economies, etc., it is necessary that such a model 1) is indeed complete; 2) is a precise representation of reality” (de Geus, 1992, p. 3). There is thus a “tension between ‘type 1 error’, believing a model’s results when the model is wrong, and ‘type 2 error’, not believing that what a model indicates is correct when in fact it is” (Smith and Morrow, 1999, p. 214). Or in other words, a tension between the validity and the credibility of the model.

We can also assess the *scientific* validity of a designing models. For this purpose, a combination of understanding, explanation and prediction is required as stated by Vermaas (2014, p. 49): “If a descriptive design theory binds together our knowledge of these regular design practices, and arrives at understanding, explanation and prediction of and about them, it is a scientific theory by the given definition.”

Chapter 2.3
Existing models of designing processes

We noted above that multiple models of designing processes are reported in the scientific literature. These models notably differ regarding the type of product designed. We here give an overview of such models and summarize differences between groups of models. We do not intend to give a comprehensive list of existing models — this point has already been addressed in various publications (Tomiyama, Gu, et al., 2009; Howard et al., 2008; Cross and Roozenburg, 1992; Finger and Dixon, 1989a,b). We rather aim at highlighting why these models differ, what are these differences, and how would a model of open-design be related to the ones presented in the scientific literature.

2.3.1 Categorization of designing models

Blessing (1994) (cited by Wynn and Clarkson, 2005, p. 36) details two major organization for designing models: linear stage-based models and cyclic activity based ones. These major approaches can be combined either in repetitive cycles, or in converging ones.

Another distinction is the focus or strategy of the process: either problem-oriented (the emphasis is put on refining and abstracting the design problem before producing solutions), or solution-oriented (the emphasis is here on refining proposed solution through its analysis and iteration with updated solution proposal). These strategies tend to be correlated with the model organization: linear models use more problem-oriented strategies when cyclic models use solution-based ones (ibid.).

One can also distinguish models according to their abstraction level: they are either abstract or concrete. (Tomiyama, Gu, et al. (2009) further distinguish between the generalization level of the model, and the abstraction of models constituting elements.) Abstract models gives an understanding of a broad range of design projects, but provides little specific guidance for practitioners. At the opposite, concrete (or “procedural”) approaches details designing processes in specific contexts. Note that Wynn and Clarkson (2005) also list analytical approaches. Such approaches describe particular instances of design projects (and thus are concrete) but uses tools and procedures to abstract the model.

The distinctions listed above focus on the form of the model. However, other approaches exist. One can categorize models according to their purposes — descriptive or prescriptive (cf. Section 2.2.4). One can also distinguish models according to the type of product designed (that is, the ‘object of design’) — physical, digital, and service (cf. Section 1.1.3) — as well as the openization of the process — traditional or open approach. We present in Figure 2.7 a mapping of the different types of design (according to both characteristics we just detailed), which we present in the following section. We grayed models of intangible product design as this goes beyond the scope of this study. In remaining entries, we show via a check mark if models of the given type are already reported in the literature.

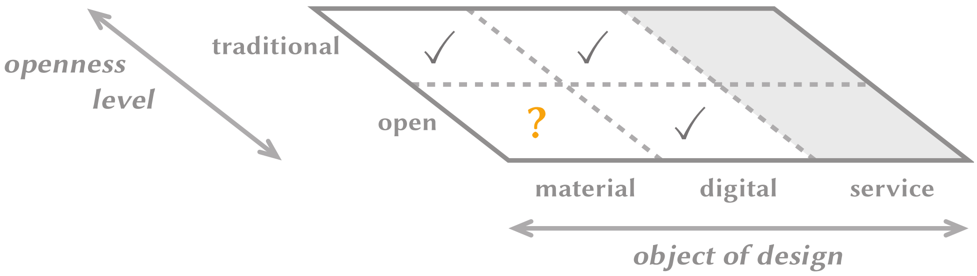
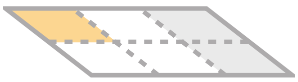


Figure 2.7
The different types of models of designing.

2.3.2 Comparing models of designing process according to the type of product

It is this section, we use the interpretive framework presented in Figure 2.7 for highlighting existing findings on open-design and differences between models for open-design and other ones.

i Traditional and physical: Traditional models of product designing processes



First, we consider traditional designing processes, i.e. designing for physical systems. Physical systems indeed predate other systems. First reported models hence describe the designing of such systems (e.g. Archer, 1984; Pahl et al., 2007a; French, 1999).

The specific characteristics of mechanical systems are the following. First, realizing (i.e. manufacturing) a prototype of the system takes time and money. Moreover, prototypes are often approximation of the final product, since some manufacturing processes (e.g. forging) have extremely high cost for unitarian or limited series production (Pahl et al., 2007c). This leads to rather linear and thus problem-oriented designing models (Wynn and Clarkson, 2005). A gap is defined at the beginning and the process goes through all activities leading to the validation of the plan through a prototype (Pahl et al., 2007e). In order to avoid major iterations — which would cost time and resources — activities are well defined and boundary objects are specified at the end of each of them. Stakeholders' role are also well defined and their assignment to one activity or the other might lead to silo organization (Anand and Daft, 2007).

Note that this tend to change with computer-based simulation, what allows testing virtual prototypes and reduce the cost of prototyping.

ii Traditional and digital: Software designing models

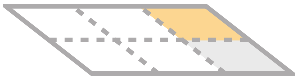
The specific characteristic of digital systems is the quasi-zero marginal cost of software manufacturing: producing a software costs almost nothing to produce (i.e. compile or execute) given the source-code.

This impacted designing as following: since producing a prototype take no time and no cost, prototypes (or 'beta-versions') are frequently and quickly developed and tested (Jacobson et al., 1998). It hence leads to more solution-oriented development processes, constituted of multiple iterations or cycles (Wynn and Clarkson, 2005).

Software designing processes are also impacted by the *agile* framework, which is a global product development approach (Beck et al., 2001; Collier, 2011). It consists of numerous iteration where a product definition is quickly defined, and incrementally refined by comparison with the targeted need. The objective here is to shift from the carefully targeting of an optimal solution to a responsive delivering of an acceptable solution (Nerur and Balijepally, 2007). The priority is hence to develop a new prototype (or improve previous one) and plan a new iteration based on the test of this prototype.

We thus observe the emerging of dedicated designing models, such as eXtrem programming (Beck, 1999), Incremental build model (Pressman and Maxim, 2014), Iterative and Incremental development (Larman and Basili, 2003; DOD, 1985), or the model developed by Cooper et al. (2007).

iii Traditional and intangible: Services designing models

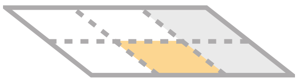


The designing of services differs from above processes because of the nature of service: “unlike a product, service components are often not physical entities, but rather are a combination of processes, people skills, and materials that must be appropriately integrated to result in the ‘planned’ or ‘designed’ service” (Meyer-Goldstein et al., 2002, p. 121).

New service development is the “overall process of developing new service offerings” (S. P. Johnson et al., 2000, p. 5). This definition can be detailed with the one of service design, which is itself “the concretization of the service concept in drawings, flowcharts” (Gummesson, 1991).

Specific characteristics of service induce following features in service designing processes: a prominent part of testing, the involvement of multidisciplinary experts (Saco and Goncalves, 2008) — this, even if models resemble traditional processes (Morelli, 2002). As each instance of the service is unique and impacted by numerous external factors, a key requirement in the designing of services is then the robustness of the design. Service designing is also intrinsically user-oriented (Polaine et al., 2013).

iv Open and digital: Free/Libre Open-Source Software designing models



The specific characteristic of F/LOSS systems is the free access to the source-code of project that is granted to anyone (cf. Section 1.2.1). To this feature add the ones of digital systems (see above).

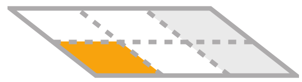
These characteristics impacted designing as following. First, the free access in practice requires a centralized platform for hosting the source code. It also imply a web-based tool. Indeed, “the key to a successful open design framework is having a robust web portal where engineers ‘meet’ to collaborate on projects” (M. Koch and Tumer, 2009, p. 103). These platforms are called *forge*. We could cite GitHub, SourceForge, GNU Savannah, etc.

Second, hosting on the web source-code of software made easy for numerous people to collaborate over distance and time. Stakeholders are indeed no longer required to be at the same location or even to belong to the same organization (Bonaccorsi and Rossi, 2003). This impact organization with a shift from a “cathedral” — a well structured hierarchical organization — to a “bazaar” — a flat organization where power is meritocratically earned (Raymond, 2000b). Moreover, this collaboration can be asynchronous (Mockus et al., 2002).

Third, since anyone can contribute to the project, there is no fixed design team (Howison et al., 2006; Lerner and Tirole, 2002). Instead, there is rather a structure made of several layers — from the core to the periphery (Crowston, Wei, et al., 2006). The objective can thus vary over time.

Just like software development has been impacted by the agile approach, the open-source development is strongly rooted in the crowd-sourcing approach (Krogh et al., 2003). The latter is a problem-solving and production approach "that is so radically distributed beyond the boundaries of professionalism" (Brabham, 2008, p. 75). This imply to consider the crowd (with the notable presence of non-experts, or amateurs) in the design team — even if a clear distinction between them might remain. One must note that crowd-sourcing is no prerogative of the open approach: both approaches are intrinsically correlated yet distinct (ibid.). Mau et al. (2004, p. 17) summarize this approach as following. "[Crowd-sourced designing] is dominated by three ideas: distributed, plural, collaborative. It is no longer about one designer, one client, one solution, one place. Problems are taken up everywhere, solutions are developed and tested and contributed to the global commons, and those ideas are tested against other solutions."

v Open and physical: open-design



This topic is the core subject of our study. We thus dedicate the entire Chapter 2.4 to the study of this approach to design.

2.3.3 Comparison between designing approaches

In the preceding section, we presented how different types of products implied different designing processes. These designing processes fall within the framework of one or more designing approaches. These various designing approaches are the reason for differences in designing processes. Hence, we now detail the differences among these approaches according to parameters of a designing process (see Figure 2.5 on page 38).

i Designing approaches and types of product

Previous overview of models of designing processes shows that these models are impacted by the type of product designed.

These differences are explained by different designing approaches that are used according to the product. These approaches are either different structures of the designing process (linear and cyclic — see Wynn and Clarkson, 2005), or more global development paradigms (agile and crowd-sourcing). Differences between these designing approaches relatively to the describing parameters of the designing process (see Section 2.2.3) are presented in Table 2.1 on the facing page.

As stated by Wynn and Clarkson (2005), designing processes for physical goods rather follow a linear approach. Quite the opposite, the design of digital goods tend to follow a cyclic approach — sometimes also impacted by agile methodologies. (These archetypes of design only give a general trend; there are also physical goods designed using cyclic approaches and software developed linearly.) The most distinctive practice is the development of open goods that deeply rely on the crow-sourcing approach. Again, this does not imply that crowd-sourcing based approaches are kept for open goods designing only. Approaches like user innovation or participatory design (cf. Section 2.4.3 on page 56) — which integrate end-users in the designing process, i.e. a form of crowd-sourcing — are indeed used outside the context of open goods' development.

ii The gap

In linear and cyclic approaches, the gap is scoped at the beginning of the project. Of course, the proper definition of the gap or the refining thereof (that is the analysis of the gap — see Section 2.2.2) is the first activity carried out in multiple models: "task" and "clarification of the task" in Pahl et al. (2007e), "Recognition" and "investigation of need" in Andreasen and Hein (2000) (cited by Gerwin and Barrowman, 2002), "Identify needs" in Ullman (2010). However, it is this preliminary scoping of the gap that triggers the designing process. It is defined at the beginning of the design project and is commonly not related to design team stakeholders.

In the context of cyclic approach, the gap can be slightly redefined after each iteration. As for agile methodologies, a global gap is defined at the beginning of the project, but only some parts of it are addressed during designing 'sprints'. In the scrum method — an instance of agile methodology — the 'product owner' is the one who defines the 'product backlog' and the tasks to be carried out during one sprint (Schwaber, 1995). At the end of each sprint, the gap is challenged and a new iteration starts with a new objective (Schwaber and Beedle, 2001).

Lastly, for crowd-sourced — and hence open-source — projects, the gap evolves over time according to user feedback and designing team members priorities. We might note that stakeholders of crowd-sourced projects often have an interest in the need addressed when these stakeholders are voluntary (Lerner and Tirole, 2002).

TABLE 2.1
Comparison of designing approaches

Approach	**Linear**	**Cyclic**	**Agile**	**Crowd-sourced**
Used for designing	Physical goods	Physical and digital goods	Digital goods	Open goods
Gap	The gap is scoped at the beginning of the project. It is chiefly not related to design teams' stakeholders.	The gap is scoped at the beginning of the project. It is chiefly not related to design teams' stakeholders.	The gap is scoped at the beginning of the project but might be redefined after each iteration.	Evolves according to team members (and their priorities).
Activities	Linear stage-gate based.	Iterative accomplishment of a set of activities.	Frequent iterations of design sprints, aiming to incrementally improve the product definition.	Some activities only can be crowd-sourced.
Stakeholders	Specialized and organized as silos.	Multidisciplinary teams with frequent informal interactions.	Multidisciplinary teams with frequent informal interactions.	A narrow core team, assisted by numerous external stakeholders for some activities.
Boundary objects	Formalized after each activity.	Informal during the designing process.	Formalized at the end of design sprints.	Fully digitized, hosted on remote repositories.
Plan	Formalized at the end of the process.	Formalized at the end of the process.	Functionalities and quality increase after each iteration or design sprint.	Fully digitized and continuously evolving.

iii Activities

Activities ordering in the linear approach is mainly stage-gate based: an activity starts when the previous one has finished (Pahl et al., 2007a). (One must, however, note the possible existence of feedback loops between activities — e.g. French, 1999.) However, the approach of concurrent engineering lead to conduct overlapping activities — what aims at decreasing the total designing time (Horváth, 2004).

At the opposite, the cyclic approach operates with repetition of a line of activities. Note that cyclic processes tend to be 'combined' with a linear approach, where the repetition of activities evolve through multiple stages, possibly when converging towards the solution (Blessing, 1994; Wynn and Clarkson, 2005). Agile approaches are close to the cyclic ones — the difference is that activities carried out in a design sprint differ from one iteration to the other, according to the sprint's objective (Schwaber and Beedle, 2001). Moreover, a prototype is delivered at the end of each sprint (even if it only addresses part of the gap); when it is not necessarily the case for cyclic approaches.

As for crowd-sourced approach, it usually resembles agile methodologies even if crowd-sourcing can also be integrated into linear development processes for example via crowd-sourcing contests (Zheng et al., 2011).

iv Stakeholders

Separating each activity in linear approaches tend to call for stakeholders who are specialized in a specific tasks. The risk is then to lead to silo-organization with only a loose coordination between activities (Anand and Daft, 2007).

This is the issue addressed in the cyclic approach where teams tend to be multidisciplinary and stakeholders go over multiple activity. The same is in the case of agile organization (Dybå et al., 2014). The specificity of agile teams is the self-management (Moe et al., 2010).

As for crowd-sourcing, the stakeholders' organization is obviously the differentiating point regarding previous approaches. As detailed below, we observe a distinction between a couple of projects leaders, assisted by a few members of a so-called 'core team' (Crowston, Wei, et al., 2006; Kazman and Chen, 2009). This core team then coordinate and aggregate contributions from a multiple of other participants.

v Boundary objects

Boundary objects are the materialization of the design team knowledge during and more especially between designing activities (Carlile, 2002). Because of the high formalization of activities, linear approaches require formalized data and knowledge exchange between each activity (cf. Pahl et al., 2007b; VDI, 1993). We there see detailed list of requirements, principle solution, preliminary layout, etc. The need for strictly defined boundary objects is lessened in cyclic approach.

In agile methodologies, there is a call for "working software over comprehensive documentation" (Beck et al., 2001). The formalization is thus not an objective *per se*. The main boundary object is thus the "potentially releasable increment" delivered at the end of each sprint (Schwaber and Beedle, 2001).

The specific characteristic of boundary objects in crowd-sourced approach is that they are chiefly digitized in order to enable collaboration over the Internet (Bonvoisin and Boujut, 2015).

vi The plan

The plan is the output of the designing process and serves to unambiguously define of the to-be-manufactured product.

In linear approaches, the plan is the last boundary object to be formalized (Pahl et al., 2007d). It is the outcome of all preceding activities. Similarly, the plan is formalized at the end of the global process in cyclic approaches (and more notably in hybrid approaches where cyclic activities are combined with progress through a number of successive phases (Larman and Basili, 2003).

The difference between cyclic and agile approaches is the incremental framework of the latter. Indeed, the objective of agile methodologies is to tackle parts of the designing problem one after another until reaching a satisfactory partial solution, and then aggregate these partial solutions (Schwaber and Beedle, 2001). Thus, the plan evolve after each design sprint, with the addition of a "potentially releasable increment" to the previous plan (Petersen and Wohlin, 2009).

As for crowd-sourced approaches, their specifics lies in the form of the plan. In order to be accessible by a decentralized crowd, the plan is fully digitized. Moreover, since contributions in crowd-sourced projects are asynchronous, the design project is continuously evolving such as the released plan then (Kazman and Chen, 2009).

This review of existing approaches to design and related models of the designing process enabled to perceive the diversity of practices. This will serve as a basis for now presenting the open-design process and highlights its singularity, as well as its similarity with existing approaches.

Chapter 2.4
Open-design

We highlighted the importance of the designing process in the development of new products, and the necessity of models reporting the singularity of each different approach to design, in order to make the most of them. Then, we presented the different existing models of designing reported in the literature and how one relate to one another. We identified how is open-design related to other approaches to design. We now detail what is open-design, how it impacts the designing process, and how it is related to other forms of designing.

2.4.1 What does *open* in open-design mean?

In Section 1.2.3, we showed how a political movement, initially concerning software only, spread and democratized across multiple fields. This new approach shook up established practice especially by bringing end-users into the designing process. The latter then evolved to cope with these new practices. We identified multiple instances of 'open-x': open-data, open-education, open-hardware, etc. These heterogeneous practices have a common denominator: the so-called *open approach*. We consider open-design as another of these instances.

Under *open*, we refer to open-source principles (and not only the technical feature of an open source-code) with an apolitical approach. The Open Knowledge Fundation (OKF) coined the following definition: "Open means anyone can freely access, use, modify, and share for any purpose (subject, at most, to requirements that preserve provenance and openness)" (OKF, 2015). The fundamental principles of *open* are thus:

- the free[1] access (technically and legally) to anyone, without any discrimination;
- the free use (and then the right to modify and redistribute — even for profit);

[1] *Free* referring to freedom, and not necessarily at no cost.

- a potential limitation, in order to preserve the original work and its open characteristics.

These principles induce two other aspects of the open approach:

- the digital form of contents: to ensure the free access in practice, content must not be physically localized somewhere. It must thus be somehow digital. If hardware cannot be digital, its blueprint, electrical diagram, etc. can be so;
- peer-to-peer collaboration: since every one can access and (re-)use the content, a fostered consequence is that people (who are now peers) tends to join their efforts.

2.4.2 When open meets products: open-source hardware

Open-Source Hardware (OSH) — or open-hardware — is the open approach applied to tangible products, or in other words: "the sharing [of] the original design files for an object in a way that allows it to be modified or reproduced by others, including for commercial use" (Mellis and Buechley, 2012, p. 1175). We consider it as a preliminary form of open-design.

i Sharing design data

The OSH implies that the design files of developed products are openly accessible. However, a fundamental difference remains between open-source software and hardware: the matter (i.e. shifting from bits to atoms), which implies a non-zero marginal cost for duplicating an object. In the case of OSH, sources are not source-code — that is, to some extent, directly runable on a computer — there are plans (technical drawing), digital files (such as a 3D model file, e.g. the `.stl` files; or a vector graphic enabling laser cutting), and/or mounting instructions (Tincq and Benichou, 2014; Macul and Rozenfeld, 2015) of an object — that still need to be actually manufactured.

Lapeyre (2014) shows that sharing design information is not completely new, using the example of the industrial cooperation within the silk industrial community in Lyon (France) at the 19th century. However, only the current context of openness, as well as the democratization of design and production, enabled the rise of open-hardware (Atkinson, 2011).

The OSH now represents a wide variety of products: micro-controllers (Arduino†[2]), manufacturing machine tools (RepRap (R. Jones et al., 2011),

[2]Websites of projects indicated with a dagger (†) are respectively: `arduino.cc`;

Open-Source Ecology (OSE)†), cars (Tabby†, Wikispeed†), smartphones (Open-Moko†), satellites (Ardusat†), as well as furniture†, knickknacks, non-technical objects†, etc.

ii Fixing, improving, re-designing: first steps towards open-design

As products are becoming open, their designing process also tend to be 'openized'.

As noticed with open-source software, the attribute of being open enables anyone to influence the designing process: bug reporting or debugging, feature request, add-on development, etc. We can then observe that users colonize and take action in the designing process upstream. As the source of a product are open, it becomes easier to repair it along the same lines as the Do-It Yourself (DIY) (Stikker, 2011). New organizations can facilitate that, such as "Repair Cafés" (Charter and Keiller, 2014).

Thus, empowered users can now 'hack' their objects by changing their original purpose, or by improving them via the development of 'tangible add-on'. If this phenomenon is not new, nor directly related to OSH, opening objects sources stimulates this behavior, as well as recently created digital platforms for sharing DIY-projects (Phillips, Baurley, et al., 2014)[3].

opensourceecology.org; osvehicle.com; wikispeed.org; wiki.openmoko.org; ardusat.com; opendesk.cc; and thingiverse.com.

[3] See e.g. www.instructables.com

Table 2.2
Principle of open, and its impact on software and hardware.

Principles of open	**Free access**	**Free (re)use**	**Potential limitation**
Consequences on software	– sources available online – new business models (the value is not in the software itself)	– sources released in human-readable language – spread of forks and hacked versions (sometimes more used than the original one) – taking part of end-user in the development process	– use of specific licenses (Apache, GPL, etc.)
Consequences on open-x	– digitization of the sources (sometimes, redefinition of the sources of an object)	– development of derivative works – end-users as benevolent designers – new development processes	– apparition of new legal frameworks (e.g. Creative Commons licenses)

Principles of open stem from free software, but have been applied in broader contexts (Table 2.2 on page 55). Finally, opening sources enables a re-design of products by "forking" them, what is the first step into open-design.

2.4.3 Open-design compared to other forms of designing

Open-design lies where the *open approach* meets *product design*. However, this unique term is more or less closely related to multiple already existing sets of practices. So to define open-design, we must first be able to assess the openness of a design project. This will enable us to map this notion relatively to already existing forms of designing.

i Assessing openness

If we refer to previously quoted definition of open (see on page 53), almost no real design project fully meets this definition. There are always some parts of a project that are open, some other not — deliberately, or not (e.g. lacking of documentation about intermediary stages of the designing process). Thus, openness appears as a continuum, rather than a discrete or binary criteria. It means that a project is not *open* or *not open*,[4] but rather *more or less open*.

Product designing is constituted of three main components: the input, the process itself, and its output (see Figure 2.3 on page 36). The input is the *gap*, and the output, the *plan*. However, the gap is contingent, and independent of the design project. Thus, the two controllable parts of a design project are its process, and its output. So for assessing the global openness level of a project, we should distinguish two independent dimensions, as coined by Huizingh (2011) for open-innovation: the process, and its output.

Openness of product design will thus be assessed using two continuous scales (from *not open* to *open*) over two axes (*process* and *output*).

ii Forms of designing related to open-design

Numerous different practices, or forms of designing, are observed and reported in the literature. They are open in some part. We found necessary to

[4] We chose to use *not open* (instead of *close*) as the opposite of *open*, because 'openizing' the process or its output is a deliberate choice, when not opening it can be due either to a volunteer move (that is *closed* design), or simply to a passive lack of broadcast.

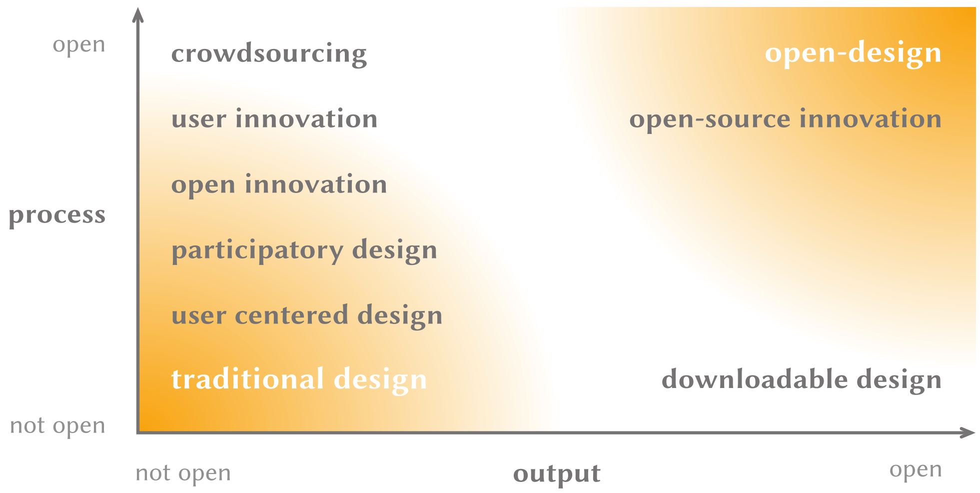


Figure 2.8
Open-design and related forms of designing

define them and to disambiguate their link with the concept of open-design. Figure 2.8 sums up these notions and maps them according to previously identified axes. *Traditional* (or conventional) *design* is when neither the process, nor the output are open.

A design project might have an open process without presuming the openness of its output (see *crowd-sourcing*); and at the opposite, an open output might be the result of a close (or traditional) process (see *downloadable design*). *Open-design* can in a first approach be considered as a design project, in which both variables are open.

Considering the first variable that is the process only, various shades of openness can be observed. We will now present concepts that do not necessarily have an open output, from the least to the most open regarding their process.

User-centered design

This approach, popularized by Norman and Draper (1986), tends to focus on the end-user's needs and context at each phase of the designing process, that is, to design *for* the end-user. Even if a wide range of methods and practices implements this approach (Abras et al., 2004), we will limit this definition to its narrow and original form (see the formalization in norm ISO 9241-210 for interactive systems), since more evolved forms fall within the scope of following concepts.

Hearing users' voices during the designing process is a preliminary yet limited step into the openization thereof.

Participatory design

Participatory design is an adaptation of the product designing process "in which people destined to *use* the [*product*[5]] play a critical role in *designing it*" (Schuler and Namioka, 1993, p. xi). This approach pioneered during the 1970s in order to assist the implementation of computer-based systems into workplaces — notably in Scandinavia where it was supported by cultural leanings for equality and democratic collaboration, such as homogeneous and highly educated workforce (Ehn, 1993). We can refer to Kensing and Blomberg (1998) for details on the reasons for deploying participatory design, the nature of end-user participation, as well as methods and tools used.

This approach differs from *user-centered design*, because it explicitly involves the participation of end-users during the process. Nevertheless, end-users — even taking part in the designing of the product — remain end-users and no co-designers.

Open innovation

Coined by Chesbrough (2003a), this form of innovation promotes information exchange across enterprise boundaries. Open-innovation does not belong to the open approach, since knowledge transfers are usually limited to a contractual framework and subject to Non-disclosure Agreements (NDA) (Marais and Schutte, 2009).

This approach is nonetheless a step further into the openization of the designing process as it fosters the extension of the design team outside of the boundaries of the enterprise. Note that, unlike the two previous approaches that focused on end-users involvement (i.e. focused on stakeholders), the open innovation framework focuses on knowledge.

User innovation

This model coined by Hippel (2005, 2014) considers users as a source of innovations (Füller et al., 2007; Bogers and West, 2010). User innovation is defined as "open, voluntary, and collaborative efforts of users" (Shah, 2005, p. 1). However, if innovation comes from users, sharing knowledge and open-access are not granted in user-innovation.
Within the same concept, we gather the related notion of *co-design*, or *co-creation*, that refers — beyond their literal meaning of designing or creating in a group — to "the creativity of designers and people not trained in design

[5]This approach was originally coined for computer system designs. We extended this definition to our context by replacing the word *system* by *product* in the original citation.

working together in the design development process" (Sanders and Stappers, 2008, p. 6).

Crowd-sourcing

(or crowd-sourced design) is using "the crowd" — often end-users, but also normal persons not specifically related to the project — in order to solve design problems (Brabham, 2008; Nickerson et al., 2011). We use following definition: "Simply defined, crowd-sourcing represents the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call. This can take the form of peer-production (when the job is performed collaboratively), but is also often undertaken by sole individuals. The crucial prerequisite is the use of the open call format and the large network of potential laborers" (Howe, 2006). The openness rate relies on the public-ness of crowd-sourced results, and the influence participants have on the design.

Crowd-sourcing can be also used in non-open designing process (Nickerson et al., 2011). The openness level of crowd-sourcing can thus vary, and in some cases might be less open than as depicted in Figure 2.8.

We have seen how designing processes could have various levels of openness, without necessarely implying an open output. Now we present concepts leading to open outputs, starting with those having the least open process.

Downloadable design

This notion refers to a product which sources can be downloaded (Atkinson, 2011). A later personal manufacturing (e.g. via 3D printing or laser cutting) is expected — at home of in a fab lab.

If sources might be open, the designing process is, however, not necessarily open: 2D models of furniture are for example freely downloadable on Opendesk[6] under a Creative Commons license, but designing of this furniture occurred traditionally (i.e. by professional designers without collaboration with end-users). Motivation for it are various, from gaining in exposure to ideology (Baytiyeh and Pfaffman, 2010; Hertel et al., 2003; Oreg and Nov, 2008).

[6] www.opendesk.cc

Open-Source Innovation (or open-source model)

The concept of open-source model might be the closest one to open-design. It refers to a collective development process (Gläser, 2007) used in free-software context (i.e. via dematerialized contributions). The question is to know if this model can be extended outside of the software industry (Raasch, Herstatt, Blecker, et al., 2008; Raasch, Herstatt, and Balka, 2009).

According to Raasch, Herstatt, and Balka, open-design is an instance of open-source innovation applied to physical objects. We argue that we consider open-source innovation and open-design (see our definition below) as similar, yet different. Indeed, as a "a collective innovation process and model" (Blanc, 2011, p. 23) open-source innovation appears as a more general process that goes beyond the scope of product design.

2.4.4 Definition proposal for open-design

All approaches presented above are at least partly open on one or both of dimensions on which the openness of a design project is assessed. In Figure 2.8, we mapped *open-design* in the upper right corner of the graph, i.e. where both the process and its outcome are open. We now detail how this notion is defined in the literature. We show that these definitions are various, but do not succeed in reporting the dual nature of the openness in open-design; hence the need for a new definition we coin over a second phase.

i Existing definitions

Indeed, "open design has become an umbrella term for a wide range of approaches to design and creativity where professional design is challenged" (Cruickshank and Atkinson, 2014, p. 361). It "covers an extensive area and its contours are not yet clearly defined, making it difficult for designers to come to grips with" (van Abel, 2011, p. 236).

One of the earliest definition proposal for open-design is reported in Vallance et al. (2001). Authors define open-design as the compliance of the IP licensing of a project towards the *Open Design Definition* (ODF, 2000). The latter, derived from the *Open Definition* (OKF, 2015), notably focuses on the existence of design documentation and its licensing. This definition, however, do not take the designing process into account.

Conversely, Raasch, Herstatt, and Balka (2009) focus on the process in their definition of open-design. Indeed, the authors first define the Open Source

Innovation model as the generalization of the F/LOSS development model outside the software industry. They characterize this model by the "free revealing of information on a new design with the intention of collaborative development of a single design or a limited number of related designs for market or non-market exploitation" (ibid., p. 383). Then, they define open-design as "*physical* objects being developed in accordance with the [Open Source Innovation] model" (ibid., p. 384).

A more global approach to open-design if presented by Aitamurto et al. (2013), who detail three "layers" of open-design. They define the latter as "[a] process [that] provides public access to participation in the design process and to the product resulting from that process, as well as the data created in the design process, whether that is technical details or other data and content gathered or generated during the process" (ibid., p. 182). The three layers, "Listen into", "Interact and create with", and "Share with", are related to increasing collaboration between a company and a customer. In our opinion, however, these layers could be mapped in Figure 2.8, close to participatory design, co-design (i.e. user innovation), and downloadable design, respectively. These practices are necessary aspects of open-design, yet we do not consider them as sufficient to define a design project as falling within the framework of open-design. Moreover, this definition assumes that the designing process is coordinated by a company, what do not take into consideration community- or peers-driven projects.

Van der Beek (2012, p. 423) "considers open design as a philosophical position that relates to broader cultural developments and puts the way we deal with design in the perspective from our attitude to identity which can be described as a performance". That is, a "state of mind" (ibid., p. 424) for a reflection by designers on their relation to design and products. This new paradigm (and induced practices) are defined as "rhizomatic", i.e. as an acentric non-hierarchical anti-system. Through a reflexive approach, the author aims to go beyond the opposition between idealistic and skeptical description of open-design. Considering this issue as "a matter of survival" (cf. Thackara, 2011) for designers, the author then presents open-design as a holistic shift in the consideration of products, designers, and design. Unlike previous definition, van der Beek thus takes the designing process in the definition of open-design.

Tooze et al. make the dual nature of open-design (in the sens that it regards both the designing process and its outcome) even more clear. Indeed, the authors define open-design both as "a type of design process that allows for (is open to) the participation of anybody (novice or professional) in the collaborative development of something" and as "the distribution and unrestricted use of design blueprints and documentation for the use by others" (Tooze et al., 2014, p. 538). They also distinguish between partially and completely open design projects — fully open design project being project where "the development of a design solution [is] created by the input of open design contributions and results in an open design solution" (ibid., p. 543). However, this definition evaluates the openness level of a designing process according to its inputs and outputs only. We argue (see below) that the openness of the processing itself should be considered for defining open-design projects.

ii A new definition of open-design

As highlighted in the preceding subsection, existing definitions of open-design cover multiple aspects of this new and atypical emerging paradigm of design. However, these definitions fail to report the dual nature of openness open-design (regarding the designing process and its outcomes at the same time), as mapped in Figure 2.8 on page 57. Therefor, based on previous definitions of open-design and related designing approaches, we propose following definition:

> *Open-design is the state for a design project where both the process and the sources of its outputs are accessible and (re)usable, by anyone and for any purpose.*

This definition covers following aspects :

- Open-design is about both the process and its outputs;
- Pure open-design is an abstraction, since we do not think that full openness could be achieved in practice;
- Openness in open-design can be summarized as "accessible and (re)usable, by anyone and for any purpose". This has to be understood as a rephrasing of the *Open Definition* (OKF, 2015) only;
- "the sources of its outputs": what matters is not the product itself that cannot be accessible or share by anyone, but its sources that enable its later manufacturing;
- The definition applies to a design project (i.e. an instance of the product designing process), because a process cannot be open *per se*. Similarly, if two processes follow the same steps, one can be open when the other not;
- "A process that is usable by anyone" means that anyone could take part in it or have an input on it (even if not necessarily considered by the design team).

2.4.5 First insights on open-design

Once open-design defined, we now detail insights about open-design found in current literature. We first detail the link between open-design and F/LOSS. Then we detail specifics of open-design according to the five parameters of the designing process (see Figure 2.5 on page 38).

i How is open-design related to F/LOSS?

As highlighted through the history of open-design (see Section 1.3.1 on page 17), and underlined in the concept of Open Source Innovation (Raasch, Herstatt, and Balka, 2009), open-design is rooted in F/LOSS development approach. However, physicality matters — notably in terms of skill requirements, needed tools, intellectual property rights and later production (Raasch, 2011), or lifetime, modularity, supply chain, replication and cost structure (Abdelkafi et al., 2009). Indeed "'free hardware' is not software — it's not like anything we knew before. The mindsets, the methods and the outcome are different. Many tools and licensing are borrowed from the software world, but you can't patch a silicon die and you can't 'execute' an etching mask." (Guidon, in Weber Morales, 2004). Stakeholders supporting the project have then a large influence on the success: with more resources, projects initiated by commercial companies can overcome issue inherent to the physicality of open-design more easily (Abdelkafi et al., 2009). Moreover, norms and regulations might also restrain open-design projects in specific sectors, such as the car industry (Müller-Seitz and Reger, 2010).

The reason for the spread of the F/LOSS approach outside the software industry is due to stakeholders' motivations — intrinsic (such as psychological or social) and extrinsic ones (career, self interest, paid contribution, etc.) (Lakhani and Wolf, 2005). Like in F/LOSS projects, various balances between firms, users, and developers can be successfully implemented (Nuvolari and Rullani, 2007).

As a 'fork' of F/LOSS development process, open-design originally uses tools and methods coming from its original field. However, it must yet evolve and develop singular solutions to cope with atom-specific issues.

ii Specific of open-design

The gap

Open-design is not reported as specifically impacting a given sector or type of product. Raasch, Herstatt, and Balka report the implementation of open-design "in a substantial variety of projects with different organisational and institutional structures" (Raasch, Herstatt, and Balka, 2009, p. 382). However, as noted by Shirky (2005, p. 488) "Open Source methods[7] [...] are not pixie dust to be sprinkled on random processes". Indeed, just like "Open Source software [is] written to scratch a developer's particular itch; Open Source methods work less well for the kinds of things that people wouldn't make for themselves" (ibid., p. 485).

Open-design appears thus more relevant to address 'itching' needs, i.e. gaps conscientized by end-users.

Activities

In accordance with our definition of openness understood as a continuum rather than a binary variable, Balka et al. (2010) note that, in practice, the openness level of the designing process can vary for the different part of the designed system.

However, only a few models of open-design process activities are detailed in the literature. Fjeldsted et al. (2012) presents a high-level, model of the Open-Source Development process. This model is yet not detailed and rather falls in the framework of business science. Another designing process model is presented by Macul and Rozenfeld (2015). Based on a study of the OSE community, they detail 6 stages in the designing process of this community:

1. Research and Initial design,
2. First pass design review,
3. Design refinement,
4. Design review,
5. Build and documentation,
6. and Project review.

This model resemble F/LOSS development models (see above) — with still some differences such as the build at the very end. This is underline by Balka et al. (2009), who noted that "tangible objects can be developed in very similar fashion to software." Indeed, "subject to certain contingencies, open design processes can be organized to resemble [F/LOSS] development processes to a considerable degree. Some practices are established specifically to uphold [open-source] principles in the open design context, while others starkly differ from those found in [F/LOSS] development" (Raasch, 2011, p. 557).

However, actual supporting tools and methods available to practitioners are dedicated to traditional development approaches for physical objects or

[7] In the context of cited work, "open source methods" refer to principles of open-source applied to the design of tangible objects — that is quite what we defined as open-design.

for F/LOSS. Practitioners in open-design thus lack of supporting tools and methods to make the most of this approach (Bonvoisin and Boujut, 2015). They notably face difficulties to manage product data, or to collaborate as even traditional design methods are not widespread within open-design teams (Macul and Rozenfeld, 2015). This makes currently difficult for open-design projects to tackle large and complex problems. The opinion that open-source principles must be adapted to other contexts beyond software is summarized as following by Shirky (2005, p. 488): “Instead of assuming that Open Source methods are broadly applicable to the rest of the world, we can instead assume that that they are narrowly applicable, but so valuable that it is worth transforming other kinds of work, in order to take advantage of the tools and techniques pioneered here.”

Stakeholders

Open-design is characterized through a bottom-up self organized approach, where end-users (or the community) plays a considerable role (Panchal and Fathianathan, 2008). This disrupt traditional design teams. Thus, professional designers first appear reluctant to adopt open-design principles in their practice because of the current lack of sustainable open business model (Almeida Meroz and Griffin, 2012), and because it deeply redefines their role and relation to design (van der Beek, 2012). Open-design communities gather both amateur and professional contributors. Their size vary from one to several hundred stakeholders (Balka et al., 2009). These communities are organized in different “layers” with a small and very involved core team and masses of contributors at the periphery of the project (Kazman and Chen, 2009).

Stakeholders are moved by various motivations (Lakhani and Wolf, 2005): the pleasure of taking part in such project (Lindenberg, 2001), their identification to a project and the personal benefits they get from it (Hertel et al., 2003), the reciprocity induced in the hacker culture (Rayood), because of career concerns (Lerner and Tirole, 2002), orfor their own use of the product (Hippel and Krogh, 2003). However, these stakeholders must possess strong and specialized skills such as engineering or informatics (Raasch, Herstatt, and Balka, 2009). Although a prior experience in open-source development is not required; stakeholders must yet concur with this new paradigm of intellectual property (ibid.).

This “community-based model” puts end-users at the center of the process. Such user communities are currently not well integrated into processes that involve commercial firms. The critical issue is in the freedom that the latter should guarantee to community members so that they can continue to innovate (Shah, 2005). When successful, the cooperation between a community and a company is nonetheless a win-win situation that boosts the development process (Tamminen and Moilanen, 2016).

Boundary objects

Studying also the OSE community, Affonso and Amaral (2015) show a low usage of boundary objects in open-design projects. This is due to their complexity, although they are acknowledged by stakeholders as essential for collaboration. Bonvoisin and Boujut (2015) highlight the lack of dedicated tools available to communities for managing and broadcasting boundary objects in open-design projects. Indeed, as shown in the early example of the Lyonnaise silk industry in the 19th century, opening access to inventions enables to boost innovation, yet the effective broadcast of these inventions is critical (Foray and Perez, 2006). The difficulty in managing product data is a hurdle to effective collaboration, what induce a lower quality in products designed (Macul and Rozenfeld, 2015).

To solve this issue, Raasch (2011) promotes modularity, and a better sequencing of on- and off-line activities. Tailored IP architecture appear necessary to handle this new paradigm (ibid.) This significance of IP and information sharing in open-design is indeed underlined in the open-design definition coined by Vallance et al. (2001).

The plan

A wide variety of fields and type of products are developed in open-design (Balka et al., 2009). However, beyond a certain complexity, developed products are highly modular, and their development divided into smaller chunks (Kostakis and Papachristou, 2014; Raasch, Herstatt, and Balka, 2009).

Cruickshank and Atkinson (2014) show that products impacted by open-design polarize between low complexity casual design (such as cups, T-shirts) and very complex critical systems (such as medical equipment and smartphones). The former leveraging the personalization and the latter the distribution of tasks or crowdsourcing enabled by open-design. This phenomenon is also highlighted by Phillips, Baurley, et al. (2014) that shows that simple objects were first developed, and then kits for constructing and customizing more complex objects. However, delivered products also vary in quality. Tamminen and Moilanen (2016, p. 63) claim that "designs shared among the open design community are not standardized in the way commercial companies legitimate their products. Designs are tested, commented on and discussed by open design community members; only 'the fittest survive'. The lack of official standardizations requires end-users to be more responsible and careful when utilizing open design products, especially if the safety of people or the environment is at stake."

For what regards semi-openized projects, the openness can either concern certain submodules of the system ("open parts"), or some information (which enables full collaboration) only, that are revealed when some others are not disclosed (Raasch, Herstatt, and Balka, 2009). Raasch (2011) also detail how the production (done by community members themselves, by the company driving the open-design process, or outsourced) impacts the required information delivered at the end of the designing process.

Synthesis

Designing is the process of devising and then unambiguously defining a product to would meet a targeted gap. (The latter is a difference between what a user expect to be and what actually is.) The mental reason involved during this process is singular, and notably different from what happens in scientific or artistic processes. It is indeed a complex process, as it aims to solve ill-defined problems through abductive reasoning.

There is thus no 'silver bullet' method for designing. Quite the reverse, multiple methods for designing (and hence models of the designing process) are described in the scientific literature. They serve at better understanding actual practices; for later providing practitioners with more efficient tools and methods.

Reported models notably differ according to the type of product being designed: is the product physical, digital, or intangible? Each type of product imply a different designing process: indeed, one does not design chairs (physical) the same way as software (digital), or a train ticket booking system (service).

At the same time, the open approach was long limited to the software industry. (This approach — induced by the Free Software movement in the late 1970s — aims at guaranteeing freedoms to the end-users of a product.) What was once particular to the software industry, has now impacted numerous fields such as data, education, science, etc. The common denominator of these various situations is: the free access (technically and legally) to anyone, without any discrimination; the free use (and then the right to modify and redistribute — even for profit); with a potential limitation, in order to preserve the original work, and its open characteristics.

Physical goods are no exception as they are also impacted by the open approach. First restricted to the use and making of objects (open-hardware), the open approach spread the product development process upstream up to the early design phases. This new phenomenon is called open-design.

As stated above, models for designing differ according to the type of product. Similarly, specific features of openness led to new forms of designing: F/LOSS (digital and open) are not quite designed as traditional software (digital and traditional). The scientific literature then reports models of open-design dedicated to the designing of open digital goods (F/LOSS). However, little findings are available on the open-design of material goods.

So it appears needed to model the open-design process in order to later develop dedicated and relevant tools and methods. This would help practitioners to make the most of open-design. The question is how to model a designing process when there is little already formalized knowledge about it.

As a piece of scientific research, our study presented hereinafter falls within the post-positivist paradigm. This does not, however, prevent us from using qualitative and 'grounded' methods. Our research contributes to the design science by formalizing new knowledge on as a specific designing process: the open-design process. It is yet rooted in much more fields belonging to the sciences of artificial or the social sciences.

3

Research positioning

The literature review highlighted the relevance and the singularity of open-design, as well as the lack of reported findings about designing processes in this context. It also pointed out the need for models of designing processes in order to develop later relevant tools and methods for practitioners. These tensions are the object of our investigation. We now need to define the particular question that will be addressed in our study. This part aims thus at introducing this research question, as well as related hypotheses. The latter will then be tested through experiments, as detailed in Part 4.

Part 3 Research positioning

Chapter 3.1
Analysis of the literature review

The literature review we have just drawn enabled us to develop a global understanding on open-design and of concepts related to it. These concepts were presented thematically. We here remind major statements that depict this global picture.

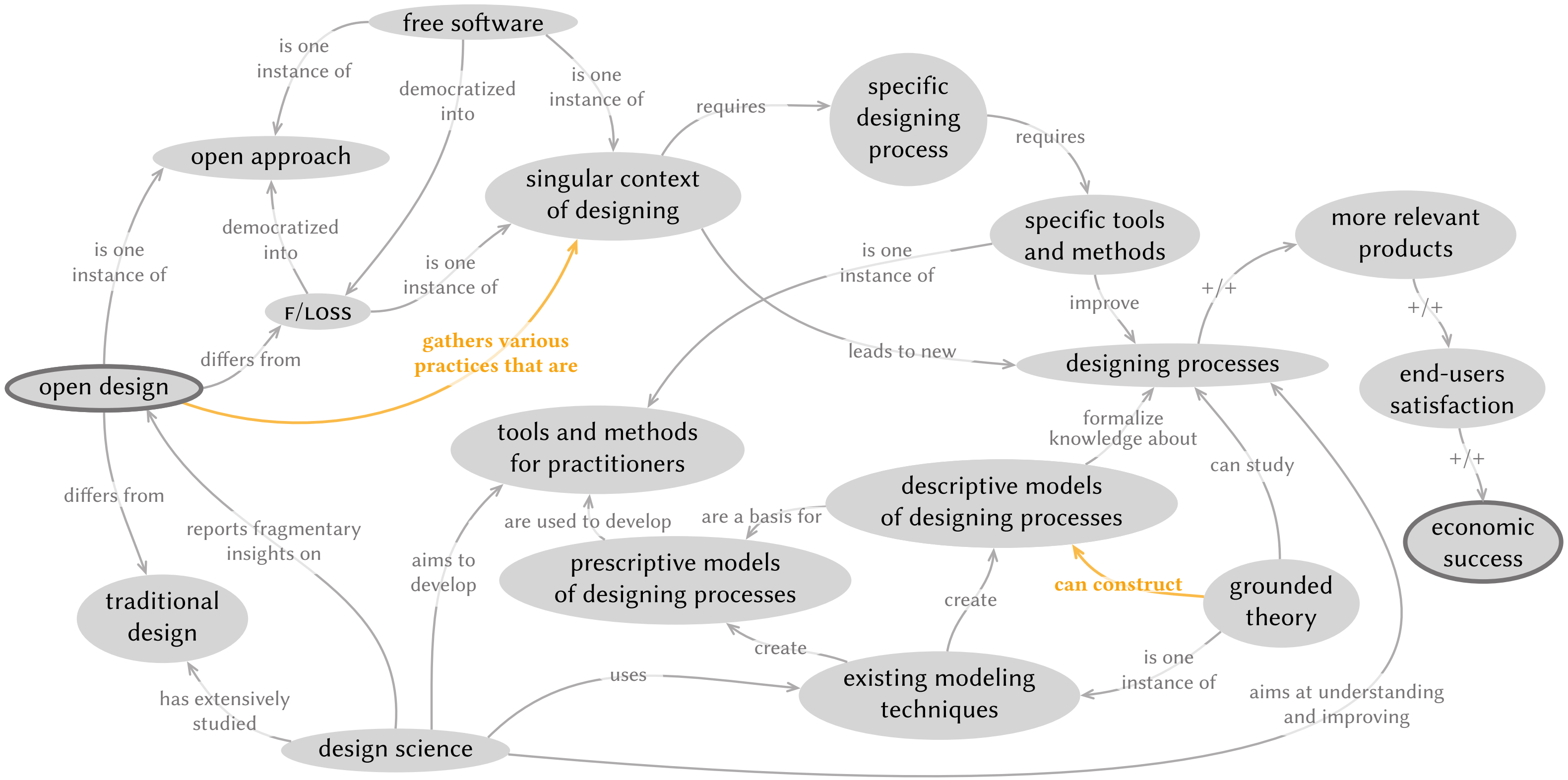
1. The science of design, which is the science aiming at understanding and improving designing processes through the development of tools and methods for practitioners, has extensively studied traditional design.
2. Improving designing processes is important, because it helps to create more relevant products that should better meet end-users expectations. Ultimately, this positively impacts a company's economic success.
3. To improve designing processes, science of design formalizes actual designing processes into descriptive models of designing. Some existing techniques are used for it.
4. Based on these descriptive processes, prescriptive ones are created. They serve as a basis for developing new dedicated tools and methods for practitioners.
5. The grounded theory appears to be a valid approach for producing descriptive model of designing processes. As such models are grounded into actual practices, they tend to be less prone to bias due to preconceptions. However, it is not considered as one of the typically used modeling techniques.
6. Singular contexts of designing require specific designing process. In order to make the most of them, dedicated tools and methods are necessary, in order to improve these designing processes.
7. Free software (just like F/LOSS) is a singular context of designing. Indeed, specific features of Free Software impacted the process of designing them.
8. Free software democratized into F/LOSS. The latter itself democratized and led to the open approach. Open-design is one instance of the open approach.
9. Open-design differs from F/LOSS designing, because of the intrinsic

differences between bits and atoms; this makes duplicating F/LOSS designing best practices in tangible products development not direct.

10. Open-design also differs from traditional design. Indeed, the openness of products impacts the designing process thereof (as seen for software).
11. However, the science of design reports fragmentary findings on open-design only. They tend to demonstrate that open-design gathers multiple practices, which seem to be singular.

This global picture is depicted in the Impact model to find in Figure 3.1 on the next page. Open-design appears as the core thematic of our study, whose final purpose is to increase economic success of companies in a delimited context. However, two assumptions were previously put forward (Item 5 and 11). In the impact model, they are depicted via highlighted arrows. As detailed hereinafter, these hypotheses are the subject of experiments we conducted.

Figure 3.1
Impact model based on our literature review



Chapter 3.2
Research question formulation

We have seen that specific models of the designing process are needed to develop dedicated tools and methods in order to make the most of a particular approach to design. Specific features of open-design are yet not taken into consideration in models currently reported in the literature.

A model of open-design appear thus needed. However, no global overview on open-design exists and results reported in the literature are fragmentary.

The research question we chose to address in this thesis is then:

> *How to model the open-design process, in the development of tangible products?*

To solve this question, we propose two hypotheses based on our literature review and detailed hereinafter. They have been tested through experiments presented in the next part.

Chapter 3.3
Hypotheses

We present below both hypotheses ("explanations that [are] suggested by knowledge or observation but has not, yet, been proved or disproved" (Macleod Clark and Hockey, 1989, p. 27)) we propose as answers to our research question. They are rooted in the literature review detailed in Part 2, and will be tested in experiments detailed in Part 4.

3.3.1 Hypotheses formulation and overview

To answer the research question we address in our study, we put two hypotheses forward:

H1: A systematic search and review of scientific literature enables the formalization of a typology of open-design practices.

H2: Using a grounded theory-based approach enables the construction of models of the designing process for a given type of open-design practices.

To answer the research question, we indeed first consider that it is necessary to better understand which practices are gathered under the umbrella-term of open-design. Once these clarified, we will then aim at modeling one of these practices (see Figure 3.2 on the following page).

3.3.2 H1: First hypothesis

i Context

The literature review enabled us to grasp the big picture. It shows that open-design encompasses a wide variety of practices. For our model to be accurate, we yet want to represent a homogeneous type of practices. For that, we need to explicit major types of practices gathered under the umbrella term of open-design.

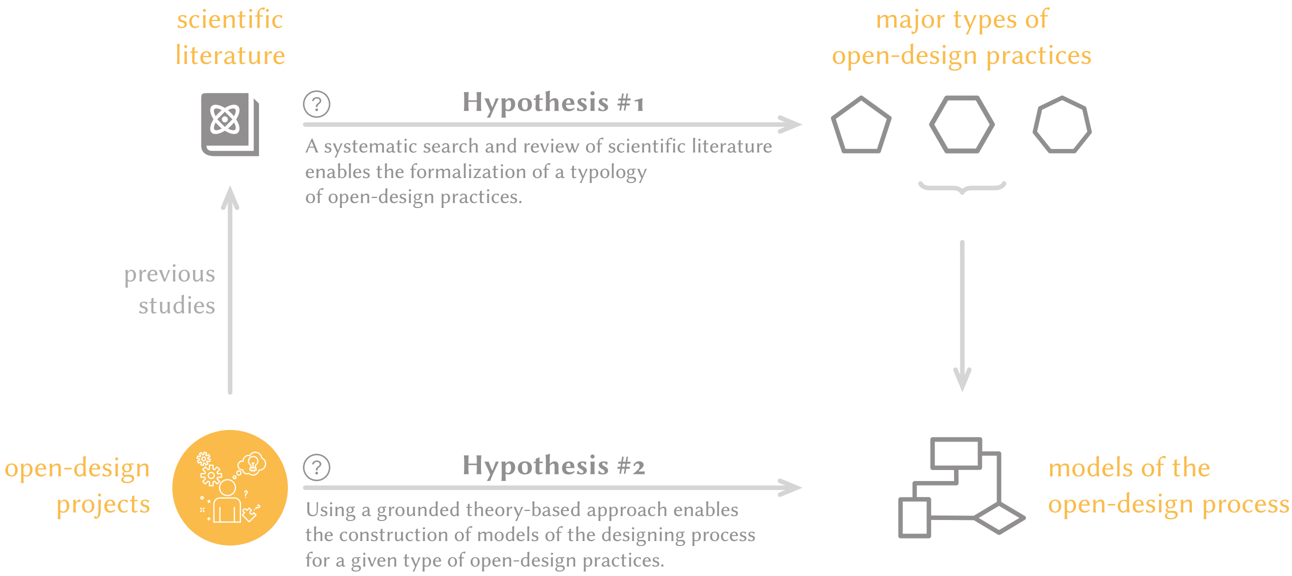


Figure 3.2
Hypotheses overview: Modeling the open-design process.

A systematic search and review is a type of literature review that "combines the strengths of a critical review with a comprehensive search process" (Grant and Booth, 2009, p. 102). It "typically [...] addresses broad questions" (ibid.). It is defined by going through a comprehensive set of publications, incorporating multiple study types. These publications are then critically analyzed by investigators.

It appears as a relevant method to detail major types of open-design.

ii Statement

The first hypothesis (H1) we put forward is then:

> *A systematic search and review of scientific literature enables the formalization of a typology of open-design practices.*

iii Objective

The systematic search and review should thus enable us to take an inventory of existing practices. This would enable is to later group them into coherent sets of open-design practices; hence a typology of open-design. We could then select one of these sets to model it, as detailed in the next hypothesis.

3.3.3 H2: Second hypothesis

i Context

Once major families of open-design described through a typology of practices, we select one of these types and aim at modeling its designing process. We, however, saw that no method is explicitly dedicated to the modeling of emerging design practices.

At the same time, the grounded theory is a method for experience-based qualitative research (Strauss and Corbin, 1998). It aims at "the discovery of theory from data systematically obtained and analyzed in social research" (Glaser and Strauss, 1967, p. 1). It consists in constructing a new theory or model through the analysis of raw data, via a rigorous step-by-step formalization and abstraction of these data. These data are first divided into segments (chunks of data conveying a single meaning) that are coded and later grouped into concepts and categories. Based on these categories, a model is constructed without any a priori knowledge about existing theories (Paillé, 1994). This whole process occurs iteratively, and enables to unveil valid models of implicit social constructs (Lingard et al., 2008). Results produced by following the approach of the grounded theory appear thus credible, plausible, and trustworthy (Glaser and Strauss, 1967).

ii Statement

The second hypothesis (H2) we put forward is then:

> *Using a grounded theory-based approach enables the construction of models of the designing process for a given type of open-design practices.*

iii Objective

Choosing a grounded theory based approach appear as a relevant method to construct a model that fits practices when little information about the phenomenon is available. By observing and analyzing actual projects falling within a given type of open-design, we should be able to model the various facets of the designing process (activities carried out, stakeholders taking part in the process, information and boundary objects used) in such context. This should also enable us to avoid bias (e.g. more or less conscious projection of existing models on facts) but report the very singularity of open-design through a bottom-up approach, i.e. by grounding our model on facts.

4 Experiments

In the previous part, we detailed the research question addressed in this study that is: *How to model the open-design process, in the development of tangible products?* We also put forward two hypotheses to solve this question. These possible answers were identified through our literature review. They still have to be tested, in order to be proved or disproved. This part thus aims to present experiments we conducted in order to falsify the hypotheses. We detail the protocols we developed, as well as the results arising from their implementation. Then, we analyze these results in order to solve the veracity of tested hypotheses. The global contributions of these experiments will be summarized later, in Part 5.

Part 4 Experiments

Chapter 4.1
Plan of the experiments

Our study aims at answering the previously coined research question that is: *How to model the open-design process, in the development of tangible products?* To answer it, we put forward two related hypotheses (see Chapter 3.3). The experiments we conducted in our study and that are presented in this part aim to test these hypotheses in order to prove or disprove them.

As we presented both hypotheses, we noted that they are related, as shown in Figure 3.2 on page 80. Similarly, both experiments detailed in this part are related (Figure 4.1 on the following page). The first experiment is a systematic analysis of the scientific literature on open-design. It aims to test H1 (*A systematic search and review of scientific literature enables the formalization of a typology of open-design practices.*). In the second experiment, we implement a grounded theory based approach in order to construct models of the open-design process. The modeling is based on interviews of leaders of open-design projects. This second experiment aims to test H2 (*Using a grounded theory-based approach enables the construction of models of the designing process for a given type of open-design practices.*).

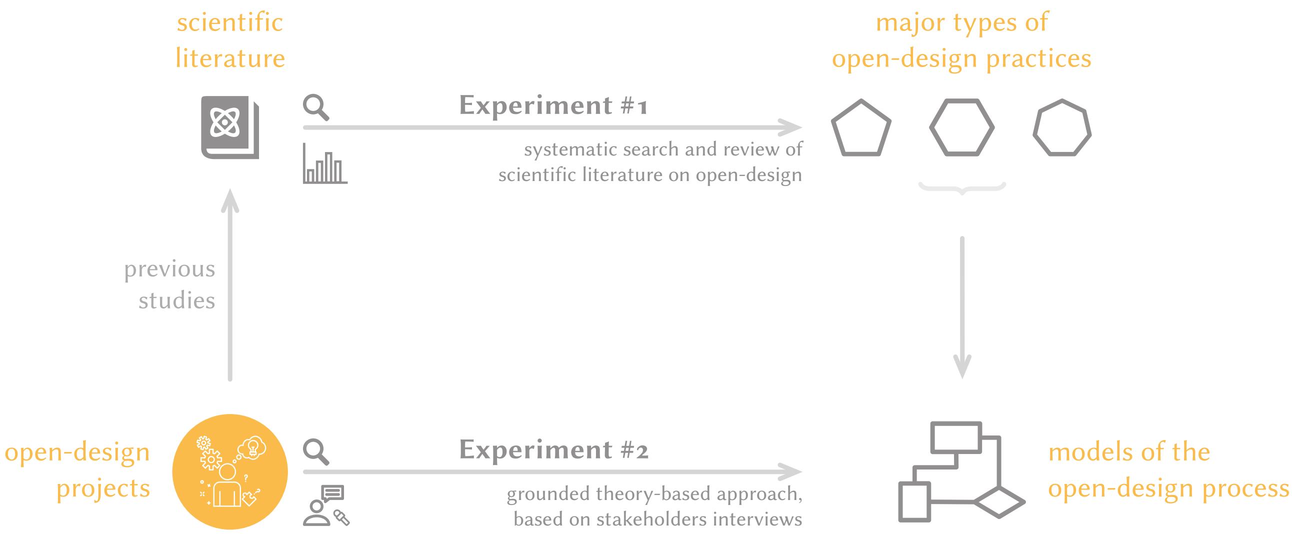


Figure 4.1
Experiments overview
Two coordinated hypotheses will be tested to address the research question

Chapter 4.2
Experiment 1: Systematic analysis of the scientific literature

Preliminary results on open-design appear to be fragmentary. We can, however, notice that a wide variety of practices seem to be gathered under this umbrella term.

At the same time, our objective is to model the open-design process. And to provide a relevant and accurate model, a coherent and homogeneous set of practice is required.

We highlighted above that a systematic search and review is a type of literature review that "combines the strengths of a critical review with a comprehensive search process" (Grant and Booth, 2009, p. 102). This technique seems to be able to categorize practices referred as open-design in the scientific literature.

We thus put forward following hypothesis (H1): *A systematic search and review of scientific literature enables the formalization of a typology of open-design practices.* The experiment reported in this chapter aims at testing this hypothesis.

First, we present the protocol we developed to test H1. Second, we report results of the study we conducted. They are then analyzed over a third phase. Results are reported and analyzed in two steps: we first give quantitative insights on literature about open-design, and then summarize results through a qualitative typology. Finally, we conclude regarding the validity of the hypothesis tested based on results' analysis.

4.2.1 Method

This experiment consists of a systematic search and review of the literature on open-design. First, we collected every paper matching the keyword `"open design"` in the *Scopus* database. We then removed false positives and

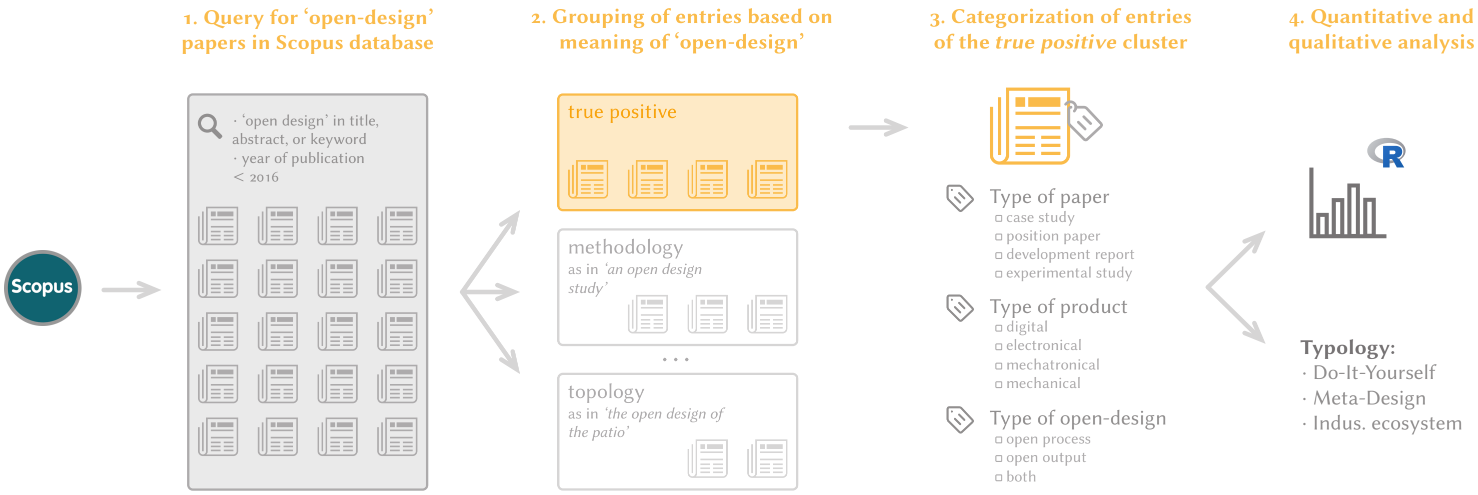


Figure 4.2
Protocol of the first experiment: A systematic search and review of literature about open-design.

manually categorized remaining papers according to the type of open-design their referred to. Finally, we conducted both a qualitative and a quantitative analysis of these results. These four steps, summed up in Figure 4.2, are detailed below.

i Query in the scientific literature

We have listed all references matching with the research term "`open design`", using the *Scopus*[1] database integrated research tool. We looked for this keyword in the fields title, abstract, and keywords (authors' and journal's ones). We did not set boundaries for subject areas. However, in order to make our research reproducible, we limited the results to the most exhaustive but complete corpus at the date of writing, that is publication prior 2016. So our query was `TITLE-ABS-KEY("open design") AND PUBYEAR < 2016`. We accepted all document types except patents.

We chose the *Scopus* database since it is one of the largest ones, and because it covers the majority of journals in engineering and design. The fact that the reference lists are only indexed consistently from 1996 onwards is not a major bias since open-design is a recent notion (see Figure 4.3 on page 91).

[1] `www.scopus.com`

ii Removing false positive

Then, we aimed at removing false positive entries. For this, we manually grouped the listed references into homogeneous categories according to the meaning of *open-design* in them. Indeed, open-design has different signification according to the context (see Table 4.2 on page 92). We used information contained in the title, abstract, and keywords of the paper to define to which category a paper belongs to. When we were not sure, we read the entire paper to resolve the ambiguity.

Entries in the same category share the same signification for open-design. Categories emerged during the processing: if one paper did not fit into one existing category, we created a new one. At the end of the processing, some categories that contained a few papers only were merged to other ones, in order to form bigger, but still homogeneous, clusters.

We were interested in entries fitting our previously coined definition of open-design. These entries are the so-called *true positives*, i.e. entries matching the query and to some extent our definition. (Among potential *true positives* we have neglected seven papers that were not categorizable because of the language. Five entries were written in Chinese and one in Italian. A last entry, written in 1990, was not accessible to us.)

In order to minimize bias due to the clustering, papers were affected to the *true positive* category by default. This category is thus constituted of all papers that are not radically different from the previously coined definition — that is, all entries in which we found no information would make it belong to another (or a new) category.

iii Categorization of remaining entries

At this point, we considered "true positive" papers only (i.e. entries matching the query and to some extent our definition.) We skimmed through these entries and tagged them according to three criteria:

Type of the entry: We categorized entries according to the type of scientific paper it is: does it report the development of a particular system (*development report*); does it analyze a system or its development (*case study*); does it report an original research survey where the author had an influence on development context (*experimental study*); or is it made up of author's analysis (*position paper*)?

Type of product: Entries refer to one or more products. Are these *digital*, *electronical*, *mechatronical*, or *mechanical* systems? We also considered the case where *multiple* types of systems were mentioned, and when the type of product was *not specified.*

Type of open-design: All entries are "true positives", so they refer to some extent to our definition of open-design. We tagged entries according to the part of the design openized in the paper: the *process*, the *outcome*, or *both* (cf. axes used in Figure 2.8 on page 57).

iv Analysis of remaining entries

Next, we ran descriptive statistics using the *R* language (R Core Team, 2015) to determine if correlations were present in the gathered data and produce trend analysis. Correlations were confirmed using the *Apriori* algorithm (Hahsler et al., 2005). This algorithm tests every directed association between two or more characteristics of an entry (e.g. $development.report \Rightarrow digital$) and weights these associations according to their veracity and representativeness (Agrawal, Srikant, et al., 1994).

After having quantitatively analyzed bibliometrics of the *true positive* corpus, we read and qualitatively analyzed listed entries in order to summarize their content. This synthesis enabled us to create a typology of open-design practices.

4.2.2 Result: Quantitative bibliometric analysis of scientific literature related to open-design

In this section and the next one, we first present and then analyze quantitative insights on the papers we studied, respectively. A qualitative summary (that supports the typology of open-design practices we develop) is presented over a second phase, as of Section 4.2.4 on page 97.

References were searched on April 19th, 2016. 624 entries matched the query.

We clustered them into 8 categories: 3 for noise (*irrelevant*, *n/a*, and *duplication*), and 5 for the different meanings of open-design— one is *true positive*, the others are *methodology*, *topology*, *problem*, and *structure*. Table 4.1 shows the spread of entries per categories: 106 match the category corresponding to our concept of open-design. These categories and their meaning are further detailed in Table 4.2 on page 92.

Table 4.1
Number of entries per categories

Category	#
methodology	240
topology	136
true positive	*106*
problem	51
structure	36
n/a	21
duplication	17
irrelevant	17
	624

Important: From now on, we will be considering entries in the true positive *category only.*

The number of entries-per-year depicts open-design as a topic that has expanded in the past decade (Figure 4.3 on the facing page).

Note that the decrease in the two last year is likely to be due to a partial

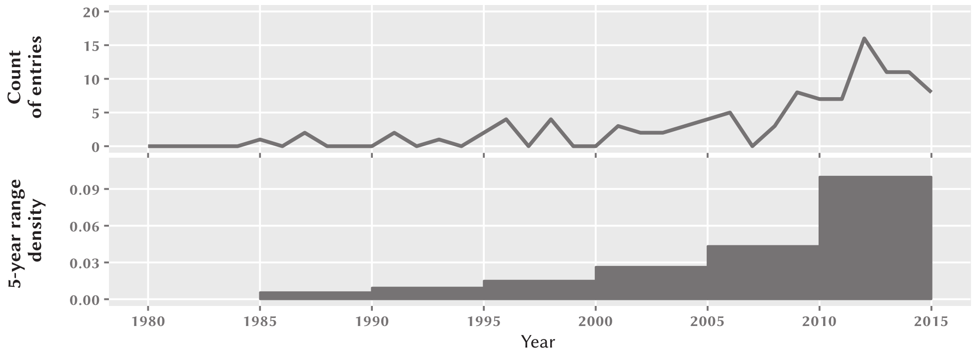


FIGURE 4.3
Number of relevant entries per year

referencing of the most recent entries by *Scopus* (i.e. in publication from 2014 and 2015). Indeed, a similar drop is observed in our database containing the 624 entries.

Among the 292 single authors referenced, only seven wrote more than three papers on the topic (Table A.1 on page 227). Note that these authors mostly wrote articles together (e.g. Raasch, Herstatt, and Balka; as well as Baurley, Phillips, and Silve).

Similarly, only two journals among the 91 listed (*Design Journal* and *Lecture Notes in Computer Science*) published more than five of the referenced entries (Table A.2 on page 227). We also analyzed keywords given by authors (Table A.4 on page 228), and journal's ones (Table A.3 on page 228). In addition to 'open' and 'design', most frequent keywords are related to the software industry ('computer software', 'source software', 'database', 'android', etc.) but also traditional design ('computer aided design', 'manufacturing', 'co-design', etc.).

The count of entries tagged according to their type, the type of product they refer to, as well as the type of open-design is to find in Figure 4.4 on page 93. We observe that most entries (71) are applied results (*case study* and *development report*) when only 22 are theory oriented. Similarly, most of the projects include a digital part, and process-only open-designs is rare.

The proportion of design projects including an open process increases as the product becomes less digital and more mechanical. Full open-design (with both the process and the output open) is mostly reported in case and experimental studies: they deal with real system development, but within the framework of research.

These results are confirmed by output of the *Apriori*-algorithm (see Table 4.3 on page 94). The support $S_{p \Rightarrow c}$ measures the breadth of the association

Table 4.2
Categories used in bibliometrics of open-design

Type	Tag	# papers	Meaning	Remark
meaning				
	methodology	240	Open-design refers here to the method used to lead a study. An open-design study is a survey, where neither the experimenter nor participants are aware if the latter belong to the control group or not. E.g., *"METHODS: The study was of randomized open design and was conducted at multiple centers in Europe."*	Most of these papers belongs to medicine studies
	topology	136	Design refers here to the shape of a product. Open-design is thus a product, which form is open (as in "the door is open"). E.g., *"The open design of most aquaculture systems allows the transmission of pathogens from the environment or from wild fish to the farmed fish." "The semi-open design of the domes moderates the problems of strong wind, humidity, and temperature gradients associated with OTCs."*	16 of these paper refers to the same system, that is a magnetic resonance imaging scanner.
	true positive	106	Open-design matching previously coined definition. E.g., *"They discard the 10-year-old IBM AT architecture in favor of more flexible, open designs." "Single design tools have to be integrated into an open design system ('Framework'), together with an integrated design data base and a common and comfortable user interface.""*	Papers belongs to this category « by default », i.e. if no information would make it belong to another (or a new) category.
	problem	51	Open refers here to an issue or a question that has no solution yet, or that might accept multiple solutions — and when this issue/question is about design E.g., *"As a work in progress, the new algorithm is presented with open design decisions." "considering as the input design space the open design variables associated to the subsystem descriptions"*	-
	structure	36	Open refers here to a system that has connection with the outside of a system. So a system that is not closed or isolated from the external environment. E.g., *"Security through obscurity has always been ineffective. Some open designs have also been proposed." "advanced metering infrastructure, open design and renewable energy connection and so on in distribution grid."*	-
noise				
	n/a	21	(1) When the result does not refer to a single work, (2) when the paper is in a language not spoken by authors, or (3) when the entry could not be accessed by authors (1) E.g., proceedings of a conference, referenced as one single paper; (2) Five papers written in Chinese and one in Italian; (3) One entry written in 1990.	-
	duplication	17	When the result refers to a publication have already been referenced.	The identification of duplication have been done manually.
	irrelevant	17	When the word *design* follows *open* by chance. E.g., *"two methods of endotracheal suctioning: closed vs. open. Design: A prospective, randomized, controlled study."*	Often the case for two following key-words.

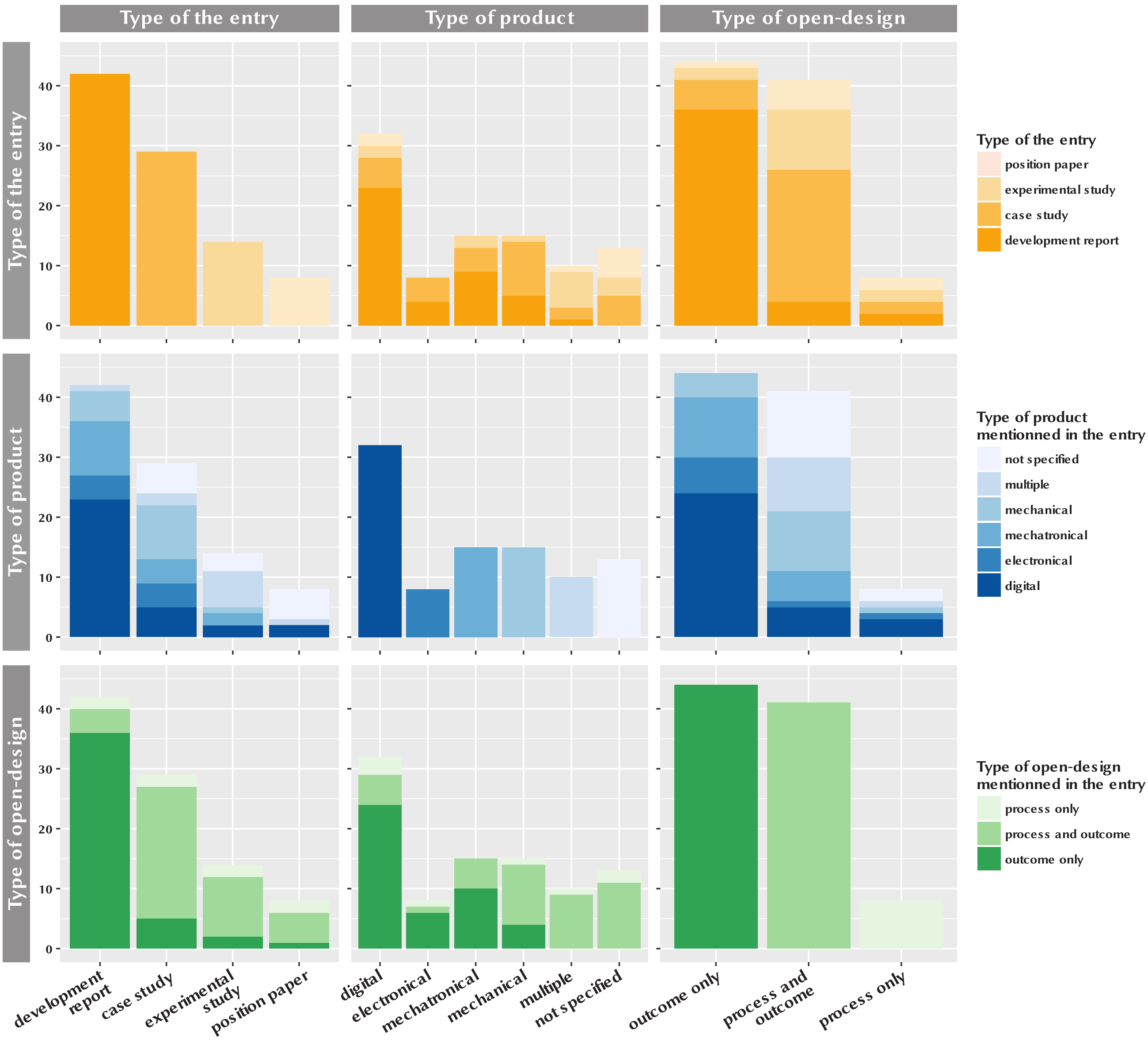


Figure 4.4
Count of entries, according to their type, the type of product they mentioned, and the subject of openness.
(Read top: the criteria used to spread entries into columns — see the label of each column at the bottom of the graph. Read left: the criteria used to spread entries, within a single column, using a color chart — see color chart at the end of the row.)

— 1 meaning that it concerns every single entry, and 0, none. It is defined as:

$$S_{p \Rightarrow c} = \frac{n_p}{\sum_i n_i}$$

where n_p is the number of entries that satisfy the premise p, and $\sum_i n_i$ the total number of entries. The confidence $C_{p \Rightarrow c}$ measures how correct is the association — 1 meaning that the association is always true, and 0, never. It is defined as:

$$C_{p \Rightarrow c} = \frac{n_{p \wedge c}}{n_p}$$

where $n_{p \wedge c}$ is the number of entries that satisfy p and c together.

4.2.3 Analysis of the quantitative results

We now analyze these quantitative results.

i Analysis of meta-data

This first section focuses on the analysis of the meta-data of the true positive papers.

The time-line (Figure 4.3) illustrates that open-design is a recent but growing phenomenon. The main rise of the concept started in the early 2000s (less than 15% of the references have been published prior to 2000), what corroborates our findings on the origin and the reasons for the rise of open-design.The number of published papers remains, however, limited. This advocates for a still restricted concept that has not spread over traditional design communities.

Table 4.3
Association results of the *Apriori* algorithm.

premise	**⇒ conclusion**	**support**	**confidence**
Type.of.entry=development.report	⇒ Type.of.openness=outcome.only	0.340	0.857
Type.of.openness=outcome.only	⇒ Type.of.entry=development.report	0.340	0.837
Type.of.entry=development.report, & Product.type=digital	⇒ Type.of.openness=outcome.only	0.179	0.826
Product.type=not.specified	⇒ Type.of.openness=process.and.outcome	0.104	0.846
Product.type=multiple	⇒ Type.of.openness=process.and.outcome	0.085	0.900
Type.of.entry=case.study, & Product.type=mechanical	⇒ Type.of.openness=process.and.outcome	0.085	1.000

The large distribution of authors referenced, as well as of journals, shows that, except a few research groups, there is no global community searching on this topic[2].

ii Entries content analysis

We now quantitatively analyze the content of the 'true positive' entries. This analysis is based on our tagging thereof (cf. stage 3 of the protocol depicted in Figure 4.2) and details the results summed up in Figure 4.4.

Type of product

Looking at entries listed, we observe that the typical entry in our database is the development report of a digital system in which the outcome only is open. These results are close to the situation of free-software in its early stages. A reason is that some funding agencies (e.g. in the European *Horizon 2020* framework program for research funding) explicitly ask for releasing research results in open-access (European Commision, 2016). Research groups tend thus to release their digital results with an open license, but without intrinsically aiming for collaboration.

As for mechanical products, most entries listed are case studies, in which both open process and output were adopted. This might be due to the fact that open-hardware is less common that open(-source)-software. This would imply that the ones who open their outcome are 'open-advocates' and thus more disposed to also adopt new practices during the development process.

Industrial sectors

Within entries referring to full open-design (i.e where both the process and its output are open), various industrial sectors are represented. Sectors can be grouped into families, according to the reasons explaining the penetration of open-design in them.

At the first place comes software. Of course, it is the most represented sector, as open-source has a longer background in software. Software dedicated to private individuals are as much represented as industrial software.

Then come objects that are used in an every-day life. They were the first to be impacted by the open approach via the 'hacking' of their objects by end-users. However, we noted that these objects are only low-tech products (e.g. wearable crafting, beehives). It can be explained by the fact that, in order to

[2]This statement should, however, be balanced for what regards the most recent years. See limitations detailed Section 4.2.6 for more details on this topic.

be hacked or reproduced by end-users, these objects must be manufacturable at home and at low cost. Reason for these re-design is either lowering cost of niche objects (e.g. beehives), or customization (e.g. clothing, furniture).

Literature also mentions technical products. In this case, open-source appears to be an asset for democratizing complicated systems, such as electronics ones. Using platform systems (e.g. micro-processing boards such as Arduino) makes it easy to the largest possible number to create their own system at lower cost. Opening sources also favors the spread of best practices, and p2p learning (via online documentation). It thus softens the learning curve and democratize these complex systems.

In the context of medium- to high-tech products, open-source has other assets, notably enabling the development of tailored niche-needs products – as for example in the medical sector. Joining efforts, and taking stock on existing systems reduces the investment (time, effort, money) needed to develop new specific systems.

However, everyday life objects are not the only ones impacted by open-design. Literature also refers to basic and generic systems that are 'openized'. These systems are mostly dedicated to energy production (wind turbine, solar cells). Motivation behind these initiatives are diverse. A notable example is the ideological framework of appropriate technologies (Hazeltine and C. Bull, 1998). The point is there to empower end-user and develop decentralized and locally controlled energy production units. Open-source is then an asset for enabling the decentralization of systems manufacturing, as well as for facilitating their appropriation by end-users. Another motivation is to join efforts in order to tackle a generic issue on a global level. This phenomenon can be seen in the photovoltaic industry.

iii Intermediary synthesis

These results argue for open-design to be recent yet growing phenomenon. No global research community investigating this topic is identified, even if a few groups of authors appeared constituted. They studied open-design on a small scale and not directly nor globally. The adoption of open-design in the industry remains limited. Literature dealing with both aspects of openness in open-design appear to be mainly theoretical considerations, rather than case studies of actual practices.

To measure this influence, we also aimed to run an exhaustive review of open-design projects from an industrial perspective. This would also have helped us to assess the relative penetration rate of openness too. However, we found no satisfactory corpus of projects that would permit a robust analysis. Databases we found were either too small, or too specific regarding a single sector — they would hence not have enabled to run robust statistics. The reader can find, however, a description and a categorization of typical open-design projects in Tooze et al. (2014).

We have dug into our database and highlighted major features of articles it includes. We will now draw a full synthesis of open-design in the case of product development, by summarizing these paper.

4.2.4 Result: Qualitative review of scientific literature on open-design

After having quantitatively analyzed our 'true positive' corpus, we now summarize current findings on open-design we found in the scientific literature. Our synthesis is based on the 'true positive' entries that we previously identified. Following analysis is summed up in Table 4.4 on the next page.

i What is new, and what is not

First, we must contextualize open-design, and recall that this approach is incorporated within the framework of established practices. Sharing knowledge and know-how, as well as collaborating during the design process are not prerogatives of open-design. Open-design is just an implementation of these practices, which have been developed independently. Moreover, despite noteworthy differences (physical production, IP protection, etc.) between the development of hardware and of software, "open design processes can be organized to resemble open-source software development processes to a considerable degree" (Raasch, 2011, p. 573)⋆.[3] However, issues remain, mainly because of the physical and rival nature of tangible goods.

Thus, we especially focused on entries reporting the development of mechanical systems, where both process and outcome were open. Indeed, as noted by Balka et al. (2009)⋆, if the field of open-source software has been widely studied, there are only a few studies on "open source development of tangible objects, so-called open design". The lack of successful empirical examples was a reason for that. However, this statement have been made eight years ago and might not be valid anymore.

We previously have listed the five parameters of a design project: the input, the process (which is itself described through the activities carried out during

[3] In this section, we indicate with an asterisk (⋆) references that were part of entries we extracted from the *Scopus* database.

Table 4.4
Synthesis of the impact of openness on design

Parameters of design	**Input**	**Process**			**Output**
	Gap	**Activities**	**Stakeholders**	**Boundary objects**	**Plan**
What does not change	– open-design problems do not radically differ from traditional design problems	– “no formally distinguishable patterns” (in open vs. traditional designing processes) found by Balka et al. (2009)	– no stakeholder disappear, even if they role evolves – compatible with professional product development	– no basic change (still use of hand drawings and sketches when designing) – high significance of boundary objects for asynchronous and decentralized collaboration	– embrace a wide variety of sectors
What changes with open-design	– new need appear: making the product and not only having it – bottom-up approach: need identified (and sometimes tackled) by end-user themselves	– highly iterative development with release of intermediary-state products – sequencing of online and offline activities	– role hybridization, and organization as a community – “bazaar” organization – benevolent user involvement, “moving progressively toward the front end of designing”, even if several levels of involvement exist – new skills are needed and a new role appear – meritocratic hierarchy of benevolent stakeholders	– use of digitized boundary objects only between activities – interface between members of the community via exchange platforms – new issues on intellectual property	– new outcome needed (mounting and assembly instructions) – focus on customization and adaptation of the outcome – a new type of output: meta-design

this process, the stakeholders involved in these activities, and boundary objects or information formalized and exchanged during the process), and the output (Figure 2.5 on page 38). So we divided our analysis based on these three parts, as well as a sixth one on motivations, benefits, and global consequences of open-design.

ii Input: the gap, or the open-design problem

The nature of design problems that open-design deals with is not specifically mentioned in the literature. The cause could be that open-design problems do not differ from traditional design problems — what Balka et al. (2010)⋆ report, saying that "open design projects tackle both incremental improvements and radically new designs". However, as presented by Bouchez (2012)⋆, the needs of some users is not *having* a product anymore, but rather *making* it. Because designers should not only design an artifact, but also the process of the user making of it, the need to be addressed by the output of the design process is thus changed.

Open-design is also sometimes presented as a bottom-up approach. We noticed that in most case-reports mentioned in the literature, the ones who took part in the solving of the design problem are the same as the ones for whom the need or gap is addressed. In other words, people who takes part in the design process are also the users of the solution: they are designing for themselves. This leads to this open-ended question: how can unexpressed or unconscious needs be taken into consideration by users-designers?

iii Phases and activities of the open-design process

The process of designing is the second and main part of a design project. Here, we analyzed the impact of openness in this process. This part is divided into the three components of the process: the phases and activities making up the process; the stakeholders contributing to the process and their involved skills; and the boundary objects used and the infrastructures used to manage them.

In current literature, it is hard to distinguish specific features of an open-design process, since most initiatives do not have sufficient perspectives for a reflexive study. In their quantitative study, Balka et al. (2009)⋆ "observe[d] different groups of actors being responsible for the creation of a product concept, the actual development work, and the final production, but [found] no formally distinguishable patterns". This might also be due to numerous and heterogeneous production models as explained by Troxler (2011)⋆. Indeed, we know that the chosen manufacturing process influences the design outcome and its process as well.

However, we can point out that new models for designing appeared in the software industry: some designers switched from a "cathedral" (vertical and hierarchical) to a "bazaar" (with horizontal organization, bottom-up streams, beta-versions, etc.) (Raymond, 2001). Benefits of this new organization have been validated scientifically (Feller and Fitzgerald, 2002; Fitzgerald, 2006)★ and industrially in the software industry. In these cases, "product development is organized as an evolutionary learning process that is driven by criticism and error correction and institutionalized as peer review" (Raasch, 2011, p. 559)★. But when it comes to hardware, corrections, updates, patches, improvements, etc. cannot be implemented "online": a circuit board cannot simply be "updated", nor a silicon joint be patched. Thus, a key point is the sequencing of online and offline activities (ibid.)★.

iv Stackeholders of the open-design process and their skills

Roles

In the open-design process, we observe a hybridization of roles, where a same stakeholder can wear many hats (Stappers et al., 2011★— see Figure 4.5 on the next page). Traditionally, users buy a product, i.e. trades money for an object they will use and live with. On the other side, the designer receives a brief that describes the general and strategic positioning of the to-be-developed object, and produces the plan of a product that meets defined criteria. In-between lies the product provider, who handles the whole product development process and cares for the manufacturing of the artifact. Of course, this linear representation is simplistic and does not reflect all current practices, but it illustrates that their relationships are standardized, well defined, and there is no direct interaction between designers and users — with exception of design activities, in which the designer decides to and defines how to interact with one or several users. In this case, the interaction is unidirectional and does not expect reciprocity.

Open-design however, reveals new forms of interactions between these stakeholders, and "user involvement is progressively moving toward the front end of designing" (ibid., p. 145)★. The user is considered an expert of his own experience; the interaction between product provider and the users go deeper and beyond a simple object-for-money trade (Stevens and Watson, 2008)★; and inputs for the design process are from many levels, such as design contributions.

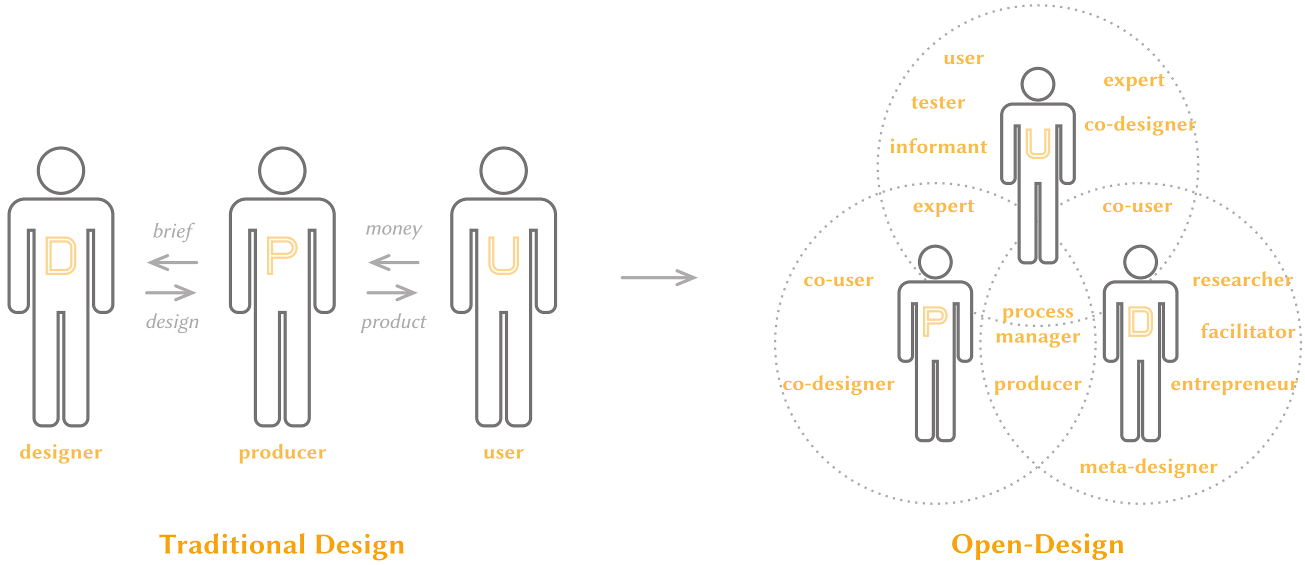


Figure 4.5
Blurring the roles of stakeholders, *adapted from Stappers et al. (2011)*

Community

To drive open-design projects, new skills are needed: Phillips, Ford, et al. (2013)⋆ highlight the role of *facilitators* between end-users and designers. This new role adds to the triad designers–user–fabricator (or client) highlighted by Stappers et al. (2011)⋆. However, in distributed co-development, having numerous users and contributors is a key point. Yet "only a few open design projects manage to attract a sufficiently high number of active contributors, both from private and commercial backgrounds, to build a developer community and to achieve progress in terms of project advancement" (Balka et al., 2009)⋆. The role of designer could also evolve as creator of design generators, i.e. meta-designer (Filson and Rohrbacher, 2011)⋆. Thus, open-design implies changes in the profession of designer (Atkinson, 2011): even if consequences and implications are not clear, the role of designer will evolve (de Mul, 2011) from creator to conductor.

Moreover, as previously mentioned (see Section 2.4.3), openness has to be assessed on a continuous scale (and not a binary one). Thus, various degree of openness can be observed — which is the case with end-user involvement in the design process. Aitamurto et al. (2013)⋆ distinguishes 3 steps in opening the design process to users: Layer 1: "Listen into" them; Layer 2: "Interact and create with" them; Layer 3: "Share with" them. We can then observe that open-design implies a special attention to the user, and suggest its integration during the design process. The role of users in open-design is also underlined by Stikker (2011) and Stappers et al. (2011)⋆, especially the one of novices (Rijken, 2011)⋆.

Hierarchy

However, even if new stakeholders appear in the design process, they do not have the same importance. As for open-source software, Raasch (2011)⋆ distinguishes two categories of stakeholders: the *core* development team, and the *periphery*. The former drives the development, when the latter provides "patches" and or tests development versions (Rullani, 2006)⋆. The access to the core-team is meritocratic, according to inputs given to the project and acknowledged skills (Roberts et al., 2006)⋆. Some teams also have a designated "benevolent dictator", often a project founder with major contribution in the project.

Incentive and motivations

In order to make horizontal user innovation work, three conditions are required according to Hippel (2007). The first one is that at least some users innovate in the field. The second is that these users need to have incentives to freely reveal their innovation. And lastly, that they can self-manufacture their innovations "cheaply". But these conditions focusing on end-users are not enough. Indeed, De Couvreur, Dejonghe, et al. (2013)⋆ underline how the role of the user's ecosystem impacts innovation.

v Boundary objects

Data and infrastructures

Boundary objects are critical in a collaborative design process, since they are used as a mean to share a common understanding of the aimed solution among the participants (Subrahmanian et al., 2013)⋆. This issue is also identified by stakeholders in open-design projects. However, as in immature or non-professional organizations their efficient use and management is limited. Affonso and Amaral (2015) reports that hand drawn sketches and prototypes are the only boundary objects used in the OSE community. One reason for that is the skills needed to master (create or exploit) more complex boundary objects (such as 3D modeling files, CAD and CAE systems, etc.).

To enable free sharing of information in practice (access without time nor geographical restriction) boundary objects must be digitized. However, in practice, verbal communication is identified as a key component of successful projects (Phillips, Baurley, et al., 2014; Filson and Rohrbacher, 2011)*, which underlines the need for alternating on and off-line phases (see *supra*).

To achieve this, Bonvoisin and Boujut (2015) claim that on-line collaborative platforms are needed to further foster the rise of open-design. These platforms must provide following features: community management (building and keeping the community active); convergence of the development process; knowledge and quality; and supporting co-creation. However, no existing tool currently offer such opportunity. Open standards appear as a solution for developing a shared language — a key issue elicited by Phillips, Baurley, et al. (2014) and Filson and Rohrbacher (2011)*— among stakeholders, especially in the industry (Carballo, 2005)*.

Intellectual property

Another issue, frequently raised when dealing with open-source, is the intellectual property, which is closely bound to boundary objects. Its fair valuation along the value chain are key point in successful and healthy industrial ecosystems (ibid.)*. Indeed, one common fear when dealing with open-design is 'how can I be paid for my work if everyone is allowed to use and copy it for free?' Various business models have been successfully developed in the software industry, even if intellectual property remains a crucial issue (Bertrand et al., 2014). Similar models can be also developed in the hardware industry (Buitenhuis and Pearce, 2012)*, which can be integrated into traditional value chain.

In the case of tangible artifacts, designers can benefit from open licensing (Katz, 2011)*. Thus, a fair valuation of intellectual property would help stakeholders to participate in an open-design process while ensuring them to capture enough value (Carballo, 2005)*. Regarding the licensing, "open design projects generally tend to make use of an open license, but licensing is less straightforward than for OSS" (Balka et al., 2009)*. Lastly, we can observe that this new form of designing will change infrastructures of the product development process. Due to the democratization of production means (Pettis, 2011)*, phenomena of micro-industrialization and distributed manufacturing will appear (Avital, 2011).

vi The open-design outcome

Open-design in mechanical products embraces a wide variety of sectors: energy production units, furniture, wear-craft, etc.

Considering the DIY approach, new types of outcome might be expected from the designer: they are product kits (with related manufacturing, mounting, or assembly instructions), but also design generators (or meta-designs). With the example of a line of furniture, Filson and Rohrbacher (2011)⋆ show that the outcome of the open-design process can be a platform that generates the design of an object based on input data given by the end-user (material thickness, desired dimensions, number of shelves, etc.). This is close to parametric or generative design (Avital, 2011), but the emphasis is here on how to open most variables to user's choice and creativity.

When it comes to outcomes in openness, modularity is a crucial issue. This enables sub-modules to be developed independently, and thus eases the customization or adaptation of one part of the design. Regarding the kind of outcomes of an open-design process, Balka et al. (2009)⋆ note that different level of complexity are reachable. A distinctive feature is the modularity and the digitization of the object.

Since openness promotes more frequent interaction between the product and the user(s), a key factor is that (more than in current industry) the outcome of the design process has to be considered all over the product life cycle (Gürtler et al., 2013)⋆.

vii Motivations, benefits, and consequences of open-design

People open their designing processes or outcomes because they have incentives for it. There are many reasons for this.

The first one is the adaptivity: adapting to subjective needs, tailoring to specific users or environments (production means, resource). But adaptivity is not an objective *per se.* Indeed, "local solutions are frequently more effective as they reflect the physical, emotional and cognitive needs of specific [users]" (De Couvreur and Goossens, 2011, p. 107)⋆. Open-design also helps to address niche needs (Phillips, Baurley, et al., 2014)⋆. Other strategic reasons exist as listed by Buitenhuis and Pearce (2012)⋆: increasing development speed and thus decreasing development cost, faster adoption of technology, and increasing the efficiency of design activities.

Open-design appears thus as a major change in design projects. It is driven by sociotechnical changes of our environment. For some, "[openness] is a matter of survival" (Thackara, 2011, p. 43). It is thus the responsibility of designers to consider openness and its impact. The fist step is thus to re-think the way design is taught and learned (Hummels, 2011; Zer-Aviv, 2011)⋆.

However, the added value of open-design is not limited to design itself (Laitio, 2011; Ratto, 2011)⋆: concepts involved in it, such as common goods (Hardin, 1968; Ostrom, 2008) would impact the whole society by changing

Types of open-design	**Do It Yourself**	**Meta-design**	**Industrial ecosystem**
Used by	private individuals	companies	companies
Dedicated to	private individuals	private individuals	companies
Description	bottom-up initiative, where end-users join efforts in order to develop products they care about	designers help end-users to design their own products by creating a favorable environment and providing designed units therefor (via platform, modules, parametric design, etc.)	private or corporate entities open up their product designs and process in order to develop an efficient and fair ecosystem; purest form of open innovation
Motivations	answer niche needs, tailor a product to specific constraints, lower product costs	increase potential customer base, product tailoring	share development costs and risks, increase process speed, transform solution into standard, reduce dependency to monopoly supplier
Related to	DIY, user innovation, co-design	mass customization, decentralized manufacturing	open standards, open (source) innovation
Examples	RepRap	Arduino	Thin Film Partnership Program, funded by the US National Renewable Energy Lab[4]

Table 4.5
Types of open-design for tangible products, and their characteristics

our relationship to goods and the status of the latter (Smiers, 2011). This can be related to a larger motivation for participants in open-design.

4.2.5 Analysis: a typology, or the three families of open-design practices

Previous results might appear heterogeneous, and do not make easy to grasp what open-design concretely is. We thus tried to define homogeneous families of open-designs, i.e. practices of the open-design approach that share similar distinctive features. Table 4.5 recapitulates these types.

[4] See Buitenhuis and Pearce (2012)

i Do-It-Yourself

The first and maybe most intuitive type is the Do-It Yourself open-design. It is an evolution and a structuring of initiatives from private individuals. These users share their design, either because they want to share their achievements, or because it enables joint-work with peers. As noted above, the digitalization of the design process enables experts to connect and work together on a shared project while enabling decentralization and asynchronous contributions. This approach is also encouraged in fab labs and other makerspaces networks. In this case, documenting and sharing projects enables to stack on ones work, and thus ease the achievement of more complex systems. As made plain in the term Do-It-*Yourself*, this approach is more oriented from private individuals towards private individuals.

Motivations are diverse. Some users open and document their projects only to share with others (cf. hobby blogging), and establish new connections with peers. For some others, the purpose is to join efforts of field experts, and or look for collaboration with others having complementary skills, in order to develop products answering very specific needs. Another motivation is the cost reduction of products: i.e. replicating functions of products, that are already available on the market, but at a lower cost (because home-made).

Success of user-generated products over designer generated ones has been proved in the industry (Nishikawa et al., 2013). Yet, this mostly concerns products of the every-day life, i.e. products that end-user have an expertise in.

However, DIY design is different form inclusive forms of design processes where end-users can take part in. Indeed, in the later, the users are mostly present during the idea generation phase only. The detailed design of the product is then done by expert-designers, supporting Ulrich who claims that firm's expert "have acquired skills and capabilities that allow them to perform most design tasks more effectively and at a higher level of quality" (Ulrich, 2011, p. 57). There is no expert-designer in the DIY design: end-users design and broadcast the product by themselves, possibly helped by peers. DIY-design is also different from 'user-design' (ibid.) or from odd jobs, because the broadcast of the formalization of the source that enables a manufacturing of multiple artifacts.

ii Meta-design

The second family is what we call *meta-design*.[5] Along the same lines of mass customization, users want to tailor the products they have — either to better address their personal needs, or simply to personalize them. One option to tackle this issue, is the open-design approach. Designers can thus develop systems that enable the user to set a certain number of parameters and generate adequate plan. This approach also enable a better integration of users inputs. However, their inputs are restricted to the fixed framework of the meta-system formerly defined by designers.

This approach is not restricted to open-design and can also be related to mass customization (Khalid and Helander, 2003). However, within the framework of open-design, this approach is used with a greater degree of freedom in user inputs (instead of simply selecting among a finite list of options). Parametric design that generates a new design according to a set of parameters (Monedero, 2000) is also related to meta-design, but again, if the choice might be here infinite, the end-user cannot go over possibilities enabled by parameters. It thus cannot create new functions.

Meta-design also includes systems that encourage and facilitate users to produce their own systems (designs), e.g. the Arduino micro-controller. According to this point of view, modules for modular systems or creation platforms — even if they can be considered as regular products *per se* — can be gathered under this family. Even if these modular systems can be considered as plateform for design, they do not fall within the framework of plateform design (Simpson, 2004) that is rather related to customization.

Finally, this family also include kits. Indeed, at the contrary of DIY open-design, DIY kits are developed by designers for users, giving the latter a broad degree of freedom in the making of the product. We thus chose to include this approach into the meta-design family. Even if this approach is not new (Resnick and Silverman, 2005), open-design toolkits focus on avoiding black-boxes, and empowering the user as much as possible by increasing the standardization, the compatibilities, and the possibilities of doable objects.

We can summarize that the specific feature of meta-design is enabling the end-user to somehow design by himself. That is, to support them and give degrees of freedom in the purpose and the form of the designed artifact.

[5] The term *meta-design* is also notably used in the design community by G. Fischer. He defines it as "a conceptual framework defining and creating social and technical infrastructures in which new forms of collaborative design can take place" (Fischer and Giaccardi, 2006, p. 428). If some consequences of Fischer's meta-design are also found in our 'meta-design' family (e.g. users becoming co-developers or co-designers), we do not refer here to the definition coined by these authors.

iii Industrial ecosystem

The last family of open-design we identified is the open *industrial ecosystem*.[6] In this approach, various stakeholders along the value chain and in the development process agree to open their processes and products. Because it concerns companies (most of them for-profit ones), this approach — at first glance counter-intuitive — is underpinned by rational strategic considerations. Indeed, opening the sources increases development speed. It also fosters the adoption of technology, which benefits the whole ecosystem.

We recognize here the principles of open-innovation. In practice, however, the latter can be one-directional (e.g. inbound, when a company acquires knowledge from the outside) and non-reciprocal. It can also be limited to cooperation between two companies and regulated by non-disclosure agreements — which makes it incompatible with open-design, as outlined by Chesbrough in his seminal work (2003). However, he later acknowledged this approach as the "purest form" of open innovation (Chesbrough and Appleyard, 2007, p. 60). We can, however, compare the open industrial ecosystem with what Allen (1983) calls "collective invention", encouraging a broad group of agents (mostly companies) to share information. This organization of innovation has proved to be able to generate rapid technical advances. In the case of tangible products, it was mostly limited to a co-localised group of agents, as the distance plays a critical role in the success of such collaborations (Cowan and Jonard, 2003).

We can also compare the open industrial ecosystem with the framework of free innovation, as defined by Hippel. In this case "innovations *[are]* developed and given away by consumers as a 'free good', with resulting improvements in social welfare" (Hippel, 2017, p. 1). In this context, developed products are *given away*, where they are rather *put at disposal* or *shared* in industrial ecosystems. The difference lies in the implicit expectation for synergies, where the designer benefits from its work — even if in a non-pecuniary nor regulated way. Moreover, free innovation is an evolution of user-innovation, which puts aside initiatives carried on by companies.

The two previous types of open-design are more dedicated to household sectors, because it involves end-users who are 'experts of their own life', the industrial ecosystem is dedicated to B2B exchanges in the context of technology development.

[6] One sometimes refers to the expression *industrial ecosystem* in the context of industrial ecology (Jelinski et al., 1992; Korhonen, 2001). If we fall within the same metaphor of natural systems, we here do not consider the ecological sustainability of the (eco)system, but rather its economical sustainability through sensible relationships and mutual dependence of economic agents.

4.2.6 Synthesis and discussion

Based on results of this experiment and on the analysis thereof, we now conclude regarding the first hypothesis we tested here.

i Major results of the study

This experiment aimed at testing our first hypothesis. This hypothesis states that *a systematic search and review of scientific literature enables the formalization of a typology of open-design practices.* We thus conducted a search and review study based on papers queried in the *Scopus* database. After having removed false positive entries, we categorized and then analyzed remaining ones.

Through the quantitative analysis, we were able to confirm that open-design is an emerging but growing topic and that research about it is fragmented. No global research community is constituted, even if some research groups have dug the topic. Moreover, the literature chiefly reports actual development projects, most of them about digital or electronic products. The proportion of designing projects including an open process increases as the product becomes less digital and more mechanical. Full open-design (with both the process and the output open) is mostly reported in case studies and experimental studies: they deal with real system development, but within the framework of research. These results are confirmed by output of the Apriori-algorithm. The current study of the open-design *per se*, in the context of mechanical products remains thus limited, as shown by the low number of papers in this category.

Through the qualitative analysis, we were able to identify the specific impact of openness on product design (see Table 4.4 on page 98). We detailed this impact according to the five parameters of the designing process (see Figure 2.5 on page 38). Moreover, we created a typology of open-design practices. Three families arose from this typology: *DIY*, *meta-design*, and *industrial ecosystem* (see Table 4.5 on page 105). These families can be summarized through the type of their project's stakeholders and end-users. These can be either private individuals or companies. DIY tallies with C2C relationships, i.e. from private individuals to private individuals with no or little pecuniary expectation. Meta-design is developed by professionals for end-users in order to help the latter to design their own products — this family can be compared with B2C approach. Lastly, the Industrial ecosystem type refers to B2B relationships where the openness is an economically attractive feature.

ii Limitations

Categorizing the meaning of *open*

During the tagging of entries in our database, we faced the following issue. How to distinguish between *open* as true positive, and *open* as in the case of a system that allows in- and outputs or interaction with the external environment?

For example, an abstract states: "Archangel98 uses the latest software design concepts allowing a very open design process, working with virtually all other applications" (Bilbija and Biezad, 1998, p. 3.226.1). "Open design process" here refers — as made explicit by the context of the paper — to a broad interoperability of the system with other ones. We could have said that it matches our previously coined definition of open, since this ability of the software enables others to use or implement this system with low technological barriers. However, this openness level of the outcome remains minor since there is no legal guarantee that the use, modification, and broadcast thereof is allowed. Moreover, the development process above-mentioned software is traditional. Such an issue is similarly found in Barrett et al. (2005, p. D562): "The database has a flexible and open design that allows the submission, storage and retrieval of many data types."

We thus categorized papers according to their contexts, notably considering if the openness of the structure was a sought asset of the developed system or not. However, we do agree that this categorization is somehow subjective — even if its impact on previous results is limited, since nine papers only of the *true positive* category are in this situation. We consider journal and author's keywords homogeneity (see Table A.3 and Table A.4, respectively) as a validation of our manual tagging.

Despite the contingent nature of evidence gleaned from the qualitative analysis of the literature, we did our best to provide an unbiased synthesis approved by a collegial consensus with our supervisors. Similarly, the typology we have created is contingent to entries referenced in result of our query to the *Scopus* database. One must note that we considered design of tangible products only, as detailed above. This does not allow us to generalize our results to product-service-systems. We also acknowledge that this typology is subjective, because it has been created based on our synthesis results. However, we checked that we were able to assign each entry to a type we defined. This argue in favor of the relevance of our typology.

Database exhaustiveness

This literature review aimed to be exhaustive. We used the largest database available for this purpose. We thus considered the entries referenced by *Scopus* only. Of course, it cannot be literally exhaustive.

Since the archiving and referencing of new papers is not immediate, some recent major papers on open-design have indeed not been found by our query. To nuance our analysis, we must then make a reference to *Open Source Innovation*, a collective book edited by Herstatt and Ehls (2015). It is not listed in our database, but gathers first results on “open source innovation”, that is a concept closely related to our definition of open-design (see Section 2.4.3 on page 56). The same phenomenon happened for an article written by Tooze et al. (2014) and cited earlier.

In our opinion, results presented above give, however, a valid and robust global snapshot of the current state of the art. This snapshot is intended to serve as a keystone for future research on open-design, but would have to be updated in the future, as the research field is maturing.

Consideration of synonyms

The previous limitation focuses on the breadth of the database we queried into. Another limitation regards the accuracy of our query. Indeed, as explained in our protocol (see Section 4.2.1), we looked for entries containing the keyword `"open design"` only.

We thus did not consider synonyms of this notion. This makes that close concepts such as open-hardware, open-source hardware, open-source development, open-innovation, open-source innovation, etc. were not taken into consideration in our query.

Reason for this was the lack of global overview of related syncepts at the beginning of the study. Moreover, this might have induced a bias in our analysis (especially the quantitative one) as certain concepts are used in specific contexts only. Finally, some of these synonyms are indeed used to refer to practices or projects that we consider falling within the framework of our definition of open-design. At the same time, we yet consider that these projects do not correspond to the concept — as we understand it — they are associated with, i.e. that they should be labeled as *open-design* rather than with their actual label

Nevertheless, we acknowledge that investigating concepts mapped in Figure 2.8 on page 57 and analyzing how these practices might overlap with the families we defined in our typology could help to clarify the positioning of open-design related to these concepts. This is then an idea for a future work.

iii Feedback on H1

The research question addressed in this study is *how to model the open-design process, in the development of tangible products?* The first hypothesis we put forward to solve it is: *A systematic search and review of scientific literature enables the formalization of a typology of open-design practices.*

As detailed in this chapter, our search and review of scientific literature we conducted, combined with both a qualitative and quantitative analysis thereof, enabled us to measure the reality of open-design as reported in previous studies. This lead us to develop our typology detailed in Section 4.2.5.

Therefore, *we consider our first hypothesis H1 as validated.*

Chapter 4.3

Experiment 2: Grounded theory based modeling of the open-design process

We aim at modeling the open-design process. Through the previous experiment, we were able to define distinctive yet homogeneous sets of practices gathered under the term *open-design.* Based on these sets, we develop a typology of open-design. By focusing on one of these types, we now want to model the open-design process in such context. However, no traditional modeling technique appear relevant to model these new and apparently singular practices (Amigo et al., 2013).

We are thus looking for a method to model the open-design process. The grounded theory appear to have required qualities (Lingard et al., 2008). However, we found no previous implementation of such a technique for modeling designing processes.

We have then proposed following hypothesis (H2): *Using a grounded theory-based approach enables the construction of models of the designing process for a given type of open-design practices.* The experiment reported here aims at testing this second hypothesis.

Thus, we first present the protocol we developed to model the open-design process using a grounded theory based approach. We then report results of this modeling and present the two models we constructed: the first depicts stakeholders and their interactions, when the second reports activities carried out in the open-design process and their arrangement. Once models constructed, we then present how we validated both the models and the modeling method using statistical analyses. Finally, we conclude regarding the validity of the hypothesis tested based on results' analysis.

4.3.1 Method: Modeling the open-design process

This experiment consists in constructing models of the designing process in the context of open-design. These models are constructed following a grounded theory based approach, and using interviews of open-design projects stakeholders. Two phases constitute the modeling method: the data collection and the data analysis. Then, in a third phase described separately, we aimed to validate both the modeling method and constructed models (see Section 4.3.4 on page 142 onwards).

During the data collection, we first selected a homogeneous set of open-design projects falling within a given type of open-design. We interviewed leaders of these projects and then transcribed their interviews.

As for data analysis, we first divided transcripts into semantically homogeneous segments. These segments were then coded according to their meaning, and then grouped into concepts that were used to define categories. We used these categories to construct models of the open-design process.

i Data collection

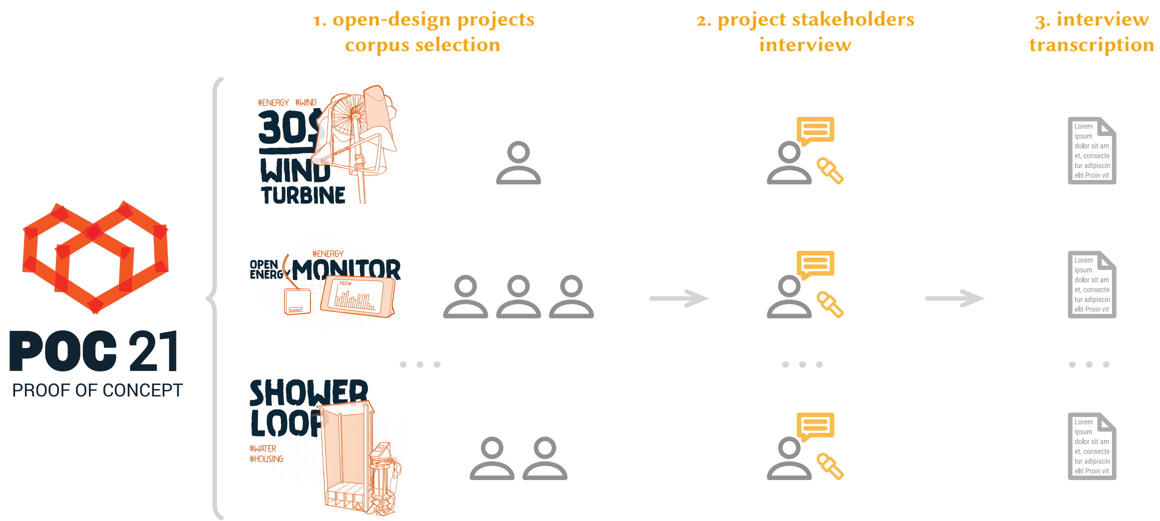


Figure 4.6
Protocol of the second experiment: Data collection through semi-directive interviews of project stakeholders.

As a corpus, we choose the 12 projects that took part in the *PoC21* event (Step 1 in Figure 4.6). PoC21 is an innovation camp, held in Paris area (France) in late summer 2015. Its name stands for an abbreviation of "Proof of Concept" and alludes to the CoP 21 — the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change that was held in Paris, France short after PoC21. This latter event "brought together

100+ makers, designers, engineers, scientists and geeks" during five full-time weeks, aiming to boost the development of 12 concrete solution to the global warming issue that were at the 'proof of concept' stage (OuiShare and OpenState, 2017). An overview of projects that took part in PoC21 is to find in Table 4.6 on page 119.

Once the corpus of projects was selected, we conducted 30 to 45-minutes interviews — each of them with one stakeholder of one project (Step 2). We asked semi-directive questions about the proceedings of the project based on the five parameters defining the designing process (see Figure 2.5 on page 38), except the gap[1]: activities undertaken; stakeholders involved in the project and their skills; data and information shared; as well as the outcome of the project. Interviews were audio recorded with the authorization from the interviewee.

Based on these recordings, we manually transcribed interviews using the *Sonal* software (Alber, 2016). This is the Step 3. We chose naturalized transcripts (Schegloff, 1997). However, involuntary vocalizations, pauses and non-verbals, as well as recurring language idiosyncrasies (e.g. "hum", "you know") were smoothed. Transcripts, however, still reflect the chaotic structure of oral verbalization: e.g. "well we're not so much… possibly we could… I mean, I've heard a bit, quite a bit about agile development and so on, and the elements of what we do are quite similar, we it is not something we're trying… we don't follow a process that closely." [OEM_38:52][2].

ii Data analysis

To analyze these interviews and construct models, we first divided transcripts into *segments* (Step 4 in Figure 4.7 on the following page), which are excerpts of verbatim in which one single idea only is expressed. Segments contains from a couple of words to a few sentences.

We then coded these segments according to their meaning (Step 5). *Codes* consists of a few words. They depict the idea expressed, or in other words, aim to answer the question 'What is this about? What is being referenced here?' (cf. Glaser and Strauss, 1967). We used multi-nominal codes (Dumez,

[1] Indeed, as detailed in Section 2.4.3, one assesses the openness of open-design projects based on their process and their ouput only.

[2] Such references indicated in square brackets point to a specific *segment* (see below) in the transcripts. The part before the underscore shows the interview from which the verbatim is dug out. The part after is the unique tag of the segment, which corresponds to the amount of time elapsed since the start of the interview at the beginning of the segment. So we here refer to a segment of the project OEM, which started at 38 minutes, 52 seconds after the beginning of our recording.

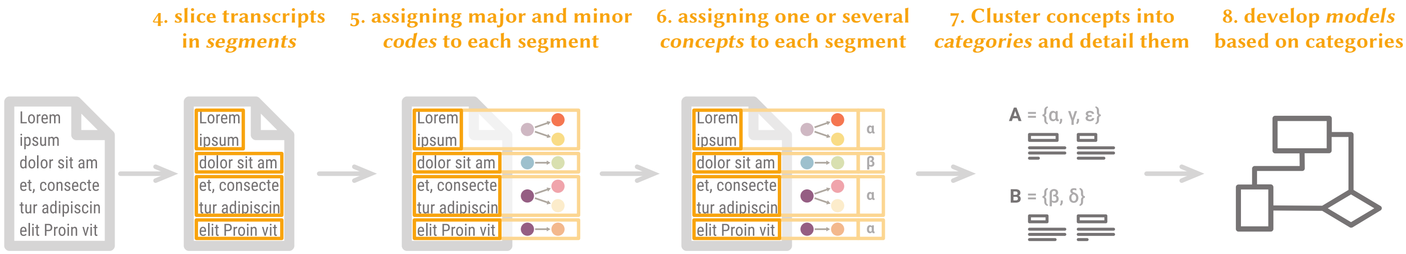


Figure 4.7
Protocol of the second experiment: Data analysis through a grounded theory based method.

2013): *major codes* describe the general idea expressed ('What is the generic idea referred to in this segment?'), when *minor codes* define the singularity of the verbatim regarding the major codes ('What makes the idea referred to in this segment distinctive to segments sharing the same major code?'). Each segment is tagged with one major code only, as well as with one or multiple minor codes. Both this step and the preceding one were done using the *Sonal* software and its integrated tools.[3]

Next, we clustered codes into *concepts* (Step 6). Concepts are more general and abstract ideas, under which several codes could be clustered. They have an internal consistency. Although codes were created without restriction (i.e. we looked at the segment's transcript, and created a code accordingly — most codes occurs thus only once), we tried to minimize the number of concepts. Therefore, we extracted a list each single major codes used. We used a self-written script that browsed through *Sonal*'s `.Rtr` files for that intent. Then, we assigned one or several concepts to each major codes. This concepts assignment was automatic. The same concept is indeed assigned to each code having been tagged with the same major code. In other words, the concept assignment is a surjective function from the set of the major codes to the set of concepts. For that, we created a 'major code-to-concept' assigning table, and assigned concepts to segments into *Sonal*'s `.Rtr` files through another self-written script.

Similarly, we clustered concepts into *categories* (Step 7). Categories are even more general ideas, under which several concepts can be clustered. The main difference with concepts is that we then characterized categories. For this, we looked at concepts belonging to a particular category (and transcripts of related segments) and abstracted recurrent specific features of these concepts.

Based on these categories, we built our *models* (Step 8). Models aim

[3]Slicing transcripts into segments and coding the latter was done manually. *Sonal* just served to handle data: it recorded our work and synchronized segments' with related part of the recording and excerpt of the transcript.

to summarize and transcribe common specific and iconic features of the different aspects of the designing process in the 12 projects. By extension, they aim at summarizing specific aspects of practices of the open-design type investigated. We constructed two models: a first one that depicts stakeholders taking part in the open-design process and their interactions (Figure 4.10 on page 124) and a second one that shows the different activities carried out during the designing process (Figure 4.11 on page 134).

All these stages, from data collection to model definition, were conducted concurrently and iteratively. Of course, we built categories only after having conducted interviews. However, we began to cluster codes after a few interviews only. Without changing the focus of next interviews, it narrowed down specific points to explicit. Similarly, looking at concepts within a category made us revise some major codes and their categorization.

4.3.2 Result of the modeling

In the previous section, we presented the method we used to construct models of the open-design process. We now detail results of the implementation thereof.

i Data collection

The first phase in the construction of models is the data collection. We thus introduce the corpus of open-design projects we studied, and then describe quantitatively data we collected.

Corpus of projects

As stated above, we choose the 12 projects that were selected to the PoC21 event. PoC21 is an innovation camp, held in Paris area (France) in late summer 2015. Projects that took part in this event had been selected according to 5 criteria (Open State and OuiShare, 2016):

1. proposing a concrete solution to the climate change issue,
2. developing a hardware product,
3. having already reached the prototyping phase,
4. being open-source,
5. and being able to take part in the innovation camp during the five weeks session.

Moreover, they were all supported by private individuals and dedicated to private individuals. They thus fall within the DIY open-design family, i.e.

one of the types of open-design we defined in the previous experiment.

These projects were selected after a call for participation launched in early 2015 (Open State and OuiShare, 2016). This way, the selection of projects has not been done by author but by PoC21's organizers. This minimizes selection bias. At the same time, these projects also cover a wide variety of applications. They include for example:

30$ wind turbine: This project developed a vertical-axis wind-turbine that is made up of scrap materials (offset printing plates, bike wheel, etc.). It can produce 1 kW in a 60 km/h wind. This wind-turbine can be manufactured by two people in four hours using a very limited set of tools (power drill, pop riveter, and utility knife). It was developed by D. Connell alone, based on a design freely available on the Internet. On the project website,[4] one can find technical drawings, a bill of tools and materials, detailed step-by-step manufacturing instructions, as well as a 3D animation detailing each phase of the manufacturing process.

Open Energy Monitor: The Open Energy Monitor project consists of a set of electronic devices used to monitor energy consumption and production. These modules are: a wireless room temperature and humidity sensor, a wired temperature monitoring device, a WiFi heat-pump monitor, an electricity consumption measuring device, etc. They interact through an open-source content management system also developed by project's initiators. These are two friends, G. Hudson and T. Lea, who initially documented their designs on their website. The project then gained traction, integrated external contributions, and successfully ran a £25k crowdfunding campaign. At the same time, plans, CAD-files, circuit plans, as well as build- and user-guides for each module and related software are shared on project's website.[5] There is also an online hardware shop where partially or fully assembled modules are sold.

Showerloop: This project aims at developing a real-time water filter system. It is then intended to be integrated into a more global approach constituted of various systems for reducing domestic water consumption. Showerloop consists in a loop (i.e. a plumbing connection) between the plughole and the shower head that reuses water while maintaining pressure and temperature, as well as while filtering and disinfecting water. It was developed by J. Selvarajan and E. Kobak, who were later helped by several graduate students. On their website,[6] one can find

[4] solarflower.org
[5] openenergymonitor.org
[6] showerloop.org

the bill of materials, building instructions, and research experiment results on water quality at the end of the loop.

A brief presentation of each projects attending the event is to find in Table 4.6.

Interviews and transcription

We decided to select only one stakeholder per project for practical reasons (availability of participants and duration of interviews post-processing) as well as for not over-weighting projects that have more stakeholders than the others. We thus conducted 11 interviews from stakeholders of 11 (out of 12) different project. Indeed, we failed in contacting one participant, who conducted his project alone. Each interviewee attended the PoC21 innovation camp.

Interviews were conducted between May and December 2016. Language talked was English, unless interviewee's mother tong was French. Two interviews were conducted physically, the others online through video-conference.

Recordings add up to 8 hours, 40 minutes, with an average of 47 minutes per interview. This corresponds to 67 012 transcribed words with an average of 6092 words per interview — see Figure A.1 on page 229. Note that non-relevant parts of the interviews (e.g. introductory and final greetings) were not fully transcribed.

TABLE 4.6
Presentation of the projects studied in the second experiment

Project name	Country	Description
30$ wind turbine	GBR	an easy-to-build wind turbine made of reclaimed materials
Aker	USA	modular kits for urban and non-industrial agriculture
Kitchen-B	FRA	kitchen modules for sustainable cooking
Bicitractor	FRA	a pedal-powered tractor for small- and mid-sized farm
Faircap	PER	a 1$ antibacterial 3D printed water filter
Nautiles	BEL	a bio-inspired energy efficient kettle
Open Energy Monitor	GBR	a household energy monitoring system
MyFood	FRA	a connected and low-maintenance home gardening system
Showerloop	FIN	a filtration system for real-time shower water looping
SolarOSE	FRA	a thermal energy producing solar concentrator
Sunzilla	DEU	a modular and portable solar-powered generator
VéloM2	BEL	a multimodular capsule system for standardized cargo bikes

ii Data analysis

We now present the analysis of our modeling. Major figures are summed up in Figure 4.8.

Transcripts were divided into a total of 1056 segments, with 96 segments per interview in average (Figure 4.9 on page 122). Segments corresponding to interviewee answers (represented by orange dots in Figure A.2) last from 1 to 154 seconds (29 in average). (Note that a few interviewer's sentences — corresponding to a demand for clarification, an agreement, or an interjection — can be contained in 'interviewee's answers'.) This corresponds from 1 to 580 words per segment (72 in average) — see Figure A.2 on page 243.

Each segment is coded with a major code and at least one minor code. 1069 single different codes were used. 347 of them are used as major code at least once. (In some rare cases, a single code was indeed used as both a major and a minor code.)

These major codes were grouped into 45 concepts. Each concept is constituted from 3 to 41 major codes (with 10 major codes in average). There are from 3 to 91 segments (28 in average) gathered into a single concept — we here neglect concepts of the *n/a* category, which were not used in the construction of the models.

Finally, these concepts were clustered into 8 categories. The concepts-to-categories conversion table, completed with the number of segments related to concepts and categories, is presented in Table 4.7 on the facing page.

One of these categories, called *n/a*, contains all segments that are not interviewee answers (notably interviewer's questions, and non-related discussions). Segments of this category were not taken in consideration in the construction of the models. Time lines showing the spread of segments per type as well as the count of relevant segment per project are to find in Figure 4.9 on page 122.

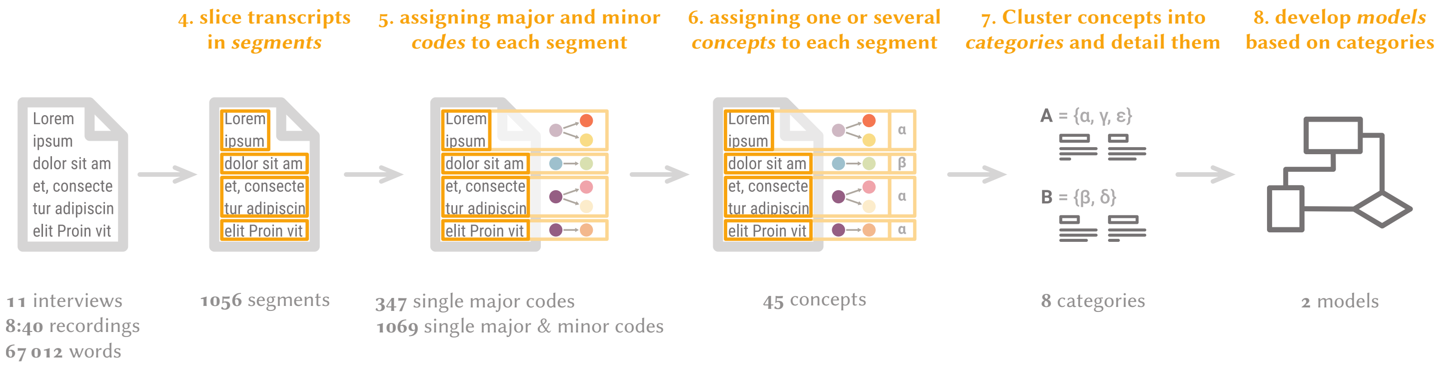


Figure 4.8
Results of the second experiment: From interviews to the model of the open-design process.
Quantitative results are indicated below each step of the model construction process.

Table 4.7
Categories, their related concepts, and number of segments

Category	# segments	Concepts (# segments)
Human	361	core team (91), contributors (81), skills (68), human interactions (66), management (26), collaboration (15), geographical location (6), project nebula (4), communication (4)
Process	294	development process (82), design process (63), start (39), design process phase (39), design (19), iteration (19), tools (14), development process phase (10), time (9)
Project	158	issues (40), project (37), objective (27), motivation (21), constraint (16), business (13), strategy (4)
Boundary objects	148	boundary objects (43), sources (27), 3D (22), contribution (17), prototyping (16), inputs (15), documenting (8)
Open	102	open (62), PoC (40)
Product	28	product (16), hardware (6), user (3), digital (3)
N/a	323	questions (165), introduction and closing (108), interruption (50)

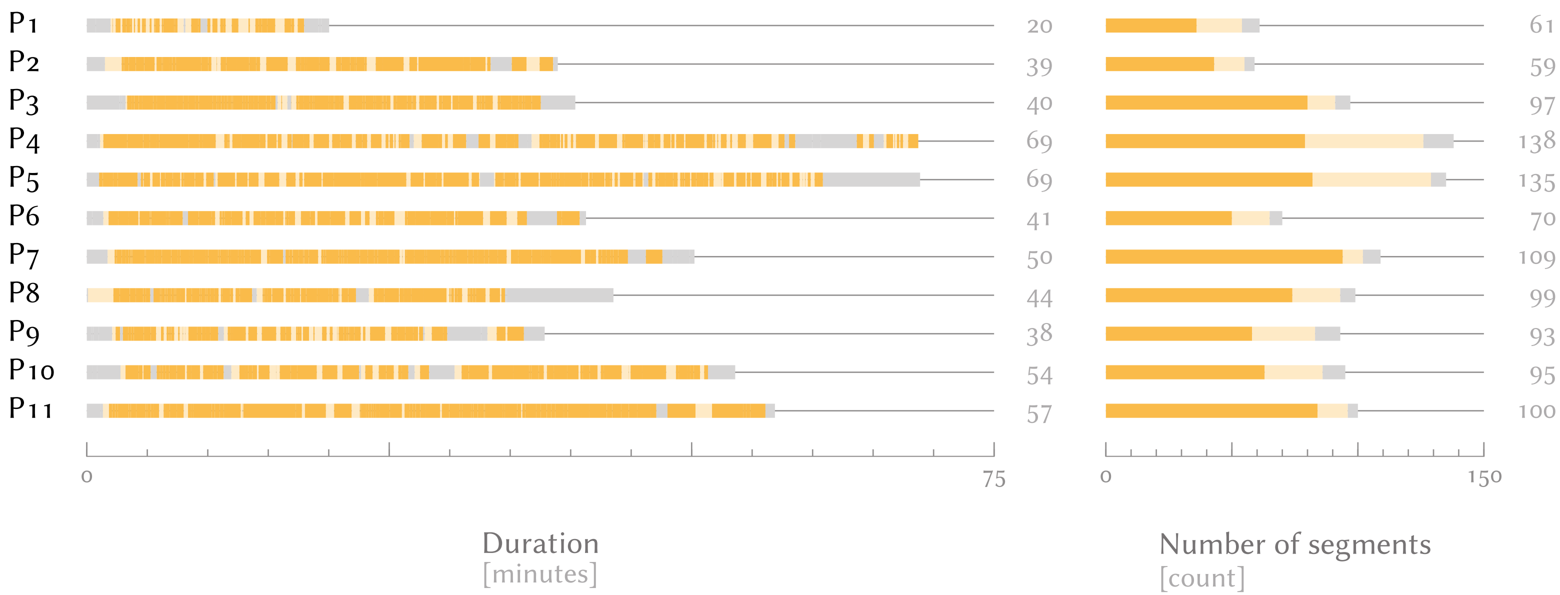


Figure 4.9
Spread of segments' type per project, in time and number.
The second column shows interviews' time line with segments colored according to their type. As in Figure A.2, orange segments correspond to interviewee answers, light orange ones to interviewer's questions, and gray ones to other non-relevant parts of the interview. (Note that most orange blocks correspond to multiple segments displayed side-by-side.) The fourth column shows the number of segments, again detailed according to their type.

4.3.3 Analysis: Two models of the open-design process

We now present an analysis of the results about which we just gave quantitative insights. We first review the type of projects studied and then present both models we constructed: the stakeholders model in the Section ii, and the activities model in Section iii on page 133 onwards. The description is based on our raw data, that are segments of the interviews. We indicate them via references in square brackets (e.g. [OEM_38:52]). Each reference points to a specific *segment* in the transcripts. The part before the underscore shows the interview from which the verbatim is dug out. The part after is the unique tag of the segment, which corresponds to the amount of time elapsed since the start of the interview at the beginning of the segment. So in our example, we refer to a segment of the project OEM, which started at 38 minutes, 52 seconds after the beginning of our recording.

i Corpus of projects

Most projects leaders come from western European countries (see Table 4.6 on page 119). This is most likely because PoC21 was organized in France and organizers did not support transportation costs. (Attending the event was otherwise free of charge, and participants were provided accommodation.) Moreover, PoC21 organizers were two western European associations (a French and a German one), what might have influenced people having heard about the event.

However, these projects correspond to our definition of DIY open-design and present a wide variety of products. Moreover, they fall within our definition of 'DIY open-design '. We thus consider this corpus as representative of this type.

ii Stakeholders model

The first model we constructed (Figure 4.10 on the next page) presents the stakeholders structure in open-design projects. It shows different layers of membership, along with interactions between these layers. These interactions are divided into three categories: membership (how does one get more or less involved in the project), social (the humans relationships between members of different layers), and material interactions (information exchanged between members of different layers).

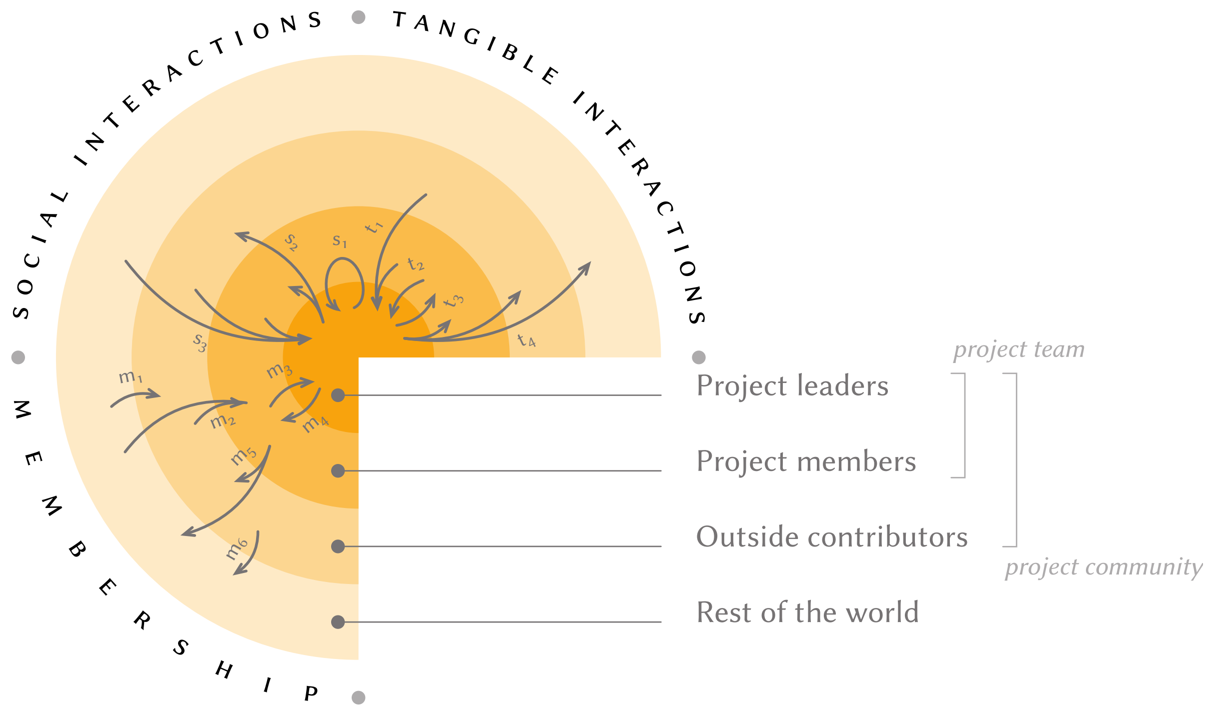


Figure 4.10
Stakeholders model — Four layers and two groups of stakeholders with three types of interactions

We first present elements constituting our model, and then detail interactions among these elements.

Model's elements: four layers and two groups

We here define each element, or *layer*, constituting the model ('project leaders', 'project members', 'outside contributors', and 'rest of the world'). Bringing multiple layers together, two *groups* are also defined (the 'project team', and the 'project community').

Project leaders

The core layer is constituted of *projects leaders*. We define the latter as the persons who initiated the project and are leading it. Their role is to carry on the project. They initiated the project and drive its development. The notion of being part of a "team" is pregnant among project leaders [Bicitr_34:11]. These stakeholders were those who attended the PoC21 event.

The composition of this layer is homogeneous. Project leaders teams are limited in size. They consist of a few people, usually between 1 and 5 members (see Table 4.8). Furthermore, we note that project leaders are chiefly men (87%), aged between 25 and 35 years old (cf. Open State and OuiShare, 2016). We should note though that the event format could have induced bias in projects leaders present to the event. Indeed, participants had to be present during the full five weeks of PoC21. This might have made difficult for hobbyist (i.e. people not working on the project on a full-time basis) to take part in the event — even if some participants were regular employee [VeloM2_24:45].

For what regards leaders profiles, most members have an engineering or scientific background [VeloM2_15:57, OEM_16:24, Shower_03:38, Biceps_20:38, SolarO_09:20, MyFood_16:35]. However, one team was exclusively constituted of product industrial designers [Biceps_02:53]. Other backgrounds are various: manual work [Bicitr_35:07], no university degree [Windtu_10:35], etc.

A previous experience of open-source is not a prerequisite [Biceps_21:47, SolarO_33:18, VeloM2_38:02]. However, most stakeholders were familiar with the open-source approach and had a previous experience in designing/producing systems, and or in a flied closely related to their project [Bicitr_03:55, Shower_26:26, OEM_02:35].

Their skills are similar though: We noted that a previous experience in open-design is not mandatory. The two most listed needed skills are self teaching [OEM_16:41, MyFood_17:00, Shower_43:18, Aker_04:44] and a problem solving approach [Shower_28:07, OEM_21:43]. One can see here a

TABLE 4.8
Spread of the number of project leaders per project

# participants	**# projects**
5	2
4	1
3	3
2	3
1	3

bottom-up approach, or amateur design — i.e. the DIY approach (Atkinson, 2006; Beegan and Atkinson, 2008; Jackson, 2010).

Involvement of leaders varies among projects. Some projects were done on spare-time [VeloM2_16:52, MyFood_05:48], besides another job. Some other leaders were full-time involved in the project [SolarO_19:14, Nautil_01:01].

Project members

Around project leaders gravitate *project members*. The distinction between project leaders and project members is not explicit, though. In a first approach, we can consider that they are distinguished through their involvement in the project.

Unlike for project leaders, we should first note that the number of project members varies a lot against projects: for some projects, there is no project members at all [Windtu_10:20], when for some others, there are up to 50 project members [SolarO_11:11, Nautil_13:23]. The rest of the project have up to a dozen of project members [OEM_11:12, OEM_26:18, MyFood_11:22]. An explanation is that, project members are benevolent. Projects must thus be attractive enough to motivate others to take part in them [Windtu_32:54, VeloM2_40:48].

We did not gather enough data to characterize these project members in terms of social characteristics. They are mostly private individuals giving some of their spare time to the project. A few projects also worked with organizations [Bicitr_14:29, Bicitr_25:21, SolarO_34:16, OEM_08:22]. These institutions bring financial supports, as well as expertise and workforce.

Individual project members share similarities with project leaders in terms of background [Shower_06:59, SolarO_09:20, SolarO_12:39] (i.e. scientific or design training), even if there are also members with backgrounds that are not related to either design or product development [Sunzil_06:36, SolarO_09:28]. Regarding organizations that projects collaborate with, there are non-profit associations in the case of projects interviewed.

Regarding project members participation to design activities, they take part in single tasks matching their expertise. They are integrated in the project team because of lacking skills among project leaders [Bicitr_30:14, Nautil_60:24], or to support them on specific activities [SolarO_06:50, OEM_11:09, OEM_11:25]. This makes that often, project members were asked by projects leaders to join the project [Nautil_39:04, MyFood_52:25, MyFood_53:49]. Project members also play a social role and their contribution can be non-working — for example just being there during meetings and creating a friendly atmosphere [SolarO_09:48, Windtu_45:31].

Compared to project leaders, project members implication is significantly lower (even if there is no general rule and they can work from a few hours to a few hundredth [Nautil_17:58]). Thus, interactions with project leaders occur at a lower frequency than among project leaders themselves [SolarO_31:41, Nautil_09:52].

First group: the Project team

For explanation purpose, we define the *project team* as the group made up of both project leaders and project members. It is not a layer *per se*, but a set of layers instead. The project teams thus consists of the stakeholder actively contributing to the development of the project. As detailed below, they also have access to more restricted information than other stakeholders.

Outside contributors

Outside contributors are individuals interacting with the project team, but who are not coordinated by project leaders. Some of them had no prior relations with the project [SolarO_32:03]. The others belong to private networks of project team's members [MyFood_11:40].

Outside contributors usually contribute on a 'one-shot' basis: they interact with the project team for giving an idea [SolarO_32:03] or a feedback [VeloM2_13:20], but do not involve in the project beyond this point. This makes difficult to analyze their background or motivation.

Since outside contributions are not monitored by project leaders, their inputs are less valuable for the project team as they are less accurate [MyFood_30:16, Sunzil_25:39].

Note that we also consider as part of the outside contributors layer, people who are interested in the project, yet who do not directly contribute to it [SolarO_11:05, Nautil_49:58, VeloM2_13:20].

Second group: the Project community

Similarly to the project team, we use the term *project community* to refer to all actors interacting with the project, that is the project team plus outside contributors. It is thus the group constituted of project leaders, project members, and outside contributors. It is not a layer *per se*.

Rest of the world

The *rest of the world* consists of people who does not interact with the project. Note that some end-users belong to the rest of the world [Windtu_18:02].

End-users

End-users represents indeed a separate category of individuals, which is cross layers. It encompasses every persons using the designed product. This category is not related to stakeholders' layers. It is thus not depicted in the model (Figure 4.10).

In the early phase of the project one prototype only is developed (see below). This makes project leaders major end-users of the product, even if each of them might not use it (e.g. when collaborating remotely) [MyFood_05: 13]. The same phenomenon is observed in the other layers: project members and contributors do not necessarily own the product developed — especially in the early phases of the project. At the opposite, some end-users do not even interact with the project team [Aker_16:21, OEM_06:43].

Interactions among the layers

We now describe interactions observed among the layers we have just presented. We distinguish three types of interactions among the layers. First, *membership* details how does a stakeholder get from one layer to another. Then, *material interactions* focus on contributions or information flows among actors. Lastly, *social interactions* describe human relationships between stakeholder of one or the other layer.

First type: Membership

We first present how does one stakeholder access a more internal layer (i.e. how does one get more involved in the project). We will start from periphery, and go to the core of the model (m_1 to m_3). Then, in a second time, we will present how does one get less involved (m_4 to m_6). That means how does one leave a central layer to shift to the periphery. We will start from the core, and go to the periphery.

m_1: Becoming a contributor · Integrating the project community only requires the desire to contribute to the project [SolarO_31:29]. One's involvement can be minimal, such as giving a feedback or a single idea [SolarO_31: 54]. Such interactions notably occur via forums [OEM_14:22] or through emails to project leaders. However, first time contributors can also propose more substantial inputs [SolarO_32:03] — even if their integration in the project can be complex when there are not coordinated with project leaders [MyFood_30:16, SolarO_32:09] (see below).

m_2: Becoming a project member · Newcomers can also be directly integrated as project members. The difference with becoming a contributor is that their contributions are monitored by project leaders in this case. There are thus three ways of becoming a project member: asking if one can give a hand [MyFood_54:17], answering a call for contribution [Nautil_13:23, SolarO_06:39], or being directly asked by project leaders to take part in some activities [MyFood_53:49, Nautil_39:04]. Note that for one of the projects, an external organization (i.e. a project member) agree to join efforts with the related project leaders for working on a common objective [Bicitr_09:15].

m_3: Becoming a project leader · There are two major types of project leaders: those who initiated the project, and others that integrated the core team later on.

Most projects' leaders are original initiators of the project. Their position is due to legacy. We saw above that some project leaders are alone, even if it is not chosen [Windtu_31:46, Windtu_32:54]. For the others, all but two teams were created for the purpose of the project only. For example, leader of the project Biceps Cultivatus went to a call for participation event for PoC21 on their own, each one with a single project. They then decided to merge their singular ideas into one unique project [Biceps_03:28]. Exceptions to this are Sunzilla whose project leaders already did some similar projects together before starting working on their pliable solar panel system, and MyFood where leaders previously launched a startup together [MyFood_06:00, Sunzil_02:23, Sunzil_04:42].

Although it is less common, one can also become project leader due to one's involvement in the project [SolarO_14:42, VeloM2_04:17, Biceps_05:46]. What distinguish project leaders from project members is thus their involvement in the project. Through this greater engagement comes greater influence, but also responsibility [SolarO_29:44].

We have seen how one can be involved in a project. However, one can also leave a project, or at least get less involved. We present these interactions starting from the core of the model and heading to the periphery.

m_4: Leave project leadership · Most projects presented are recent (less than 3 years of existence). Due also to the small size of projects, observing a project leader leaving the project is uncommon. Moreover, we saw that leaders are personally involved in the project, and that most of them initiated it. A project leader leaving the project is hence rare.

However, one case hs been reported, where a project leader decided to detach himself from the leader group. This was due to time constraint [SolarO_28:42]. Since his involvement rate only changed, he became a project member *de facto*.

m_5: Leave project team · No case of project team leaving were explicitly reported. We can only suppose that one can leave the project team simply by not contributing anymore, for various reasons. These could be personal issues, strategical difference of opinion, etc. In the context of project forking, former members of the project were reported to continue to cooperate with the original project [OEM_13:47].

m_6: Leave project community · Like for the preceding case, we did not collect evidences about stakeholders leaving the project community. One can only suggest similar causes and similar consequences. One should, however, note that contributions of outside contributors have been described as 'one-shot'. Thus, porosity of borders between outside contributors and the rest of the world is greater.

Second type: Social interactions

Social interactions describes relationships between humans in one or the other layer. We describe below the various types of social interactions observed.

s_1: Among project leaders · Social interactions among project leaders are frequent, friendly, and informal. Indeed, most project leaders knew themselves prior to the beginning of the project, except for two projects [SolarO_02:43, VeloM2_03:12]. Project leaders are usually friends [Biceps_03:00, Bicitr_03:20], even if two projects started by gathering volunteering and motivated persons for the purpose of the project [SolarO_02:43, VeloM2_03:12].

Project leaders are usually located in the same geographical area. This makes easier when it comes to build a prototype that is unique and is thus done in one location. Aker is a notable exception: working fully remotely was the option chosen by project leaders from the beginning [Aker_03:16]. At the opposite, Bicitractor and Nautiles were subjected to this situation [Bicitr_32:54, Nautil_06:29]. In-between lies SolarOSE, that mixed on-line (3D modeling, conceptual design) and *in situ* design activities ('design sprints', prototyping). In this later case, only one prototype was build.

Organization among project leaders is organic [Aker_05:12, MyFood_44:16]. Roles are set according to one's skills [Biceps_22:59]. However, this organic organization also causes some difficulties [Biceps_17:17], since leadership is implicit and thus its perception might differ among leader, notably from a strategical point of view.

s_2: Project leaders with the project team · Project leaders have to manage project members. Besides contributing themselves, they foster contributions [VeloM2_37:13]. However, they also have to deal with the fact that projects members contribute on their spare time [Aker_05:39], and are hence less involved.

There are some difficulties due to collaborating with others [VeloM2_42:43, Shower_05:36]. Working alone takes more time, but also enables to iterate more quickly [Windtu_34:22].

Since there is no hierarchical enforcement strictly speaking, diplomacy is thus a key [SolarO_27:50]. However, project leaders still have a hierarchical position regarding project members [SolarO_26:50]: they notably cut short strategic decisions.

s_3: Project leaders with the project community · The role of project leaders is to give momentum to the project: their involvement sets the pace to the project [SolarO_28:42, Bicitr_15:12, SolarO_29:58]. Giving momentum means making people feel useful [SolarO_09:28], even if they do not produce any tangible input. Project leaders also motivate others to contribute [Shower_24:52, OEM_24:06]. Indeed, the project progress through single contributions [Aker_06:12] even if most of this work is done by project leaders [OEM_24:33]. These also share the vision, i.e. give sense to others contributions [Nautil_16:29].

Giving momentum is critical. Indeed, contributors are volunteering. So project must be attractive [Windtu_33:47] and leaders have thus to 'seduce' potential contributors. Being attractive means showing some results to make people involved [Windtu_33:47], what makes finding contributors in the early phases difficult.

s_4: Project team with end-users · Beside developing the product, one role of the project team is end-users trouble-shooting [Windtu_18:02] (notably when the latter try to build the product by themselves), since they are the most expert on it. Project leaders also aim at interacting with end-users to get feedback [Aker_16:21, Bicitr_10:24, OEM_39:15].

Third type: Tangible interactions

Tangible interactions describe relationships between stakeholders that involve a boundary object (i.e. something tangible).

t_1: Outside contributors with Project team · Contributions from outside contributors are difficult to take into consideration by the team, because they might not fit the project (in terms of timing, structure, or scope) [MyFood_30:16]. Another reason is that these contributors often do not involve in the project [Sunzil_25:39], what makes difficult to have influence on it.

However, more mature projects use another approach: their outside contributions are indeed organic and not monitored. They are added if they fit the project [OEM_29:46], but might also lead to external spin-off [OEM_13:47].

t_2: Project members with Project leaders · The distinctive characteristic of project members' contributions compared to those from outside contributors, is that they are monitored by project leaders [SolarO_06:39].

Project members contribute to the project in various forms: taking part in some design activities [SolarO_06:39, Nautil_14:41], funding [Bicitr_27:29] and business [Shower_16:44], support activities, giving ideas. These contributions are based on their expertise [Biceps_21:02]. Contributions are brought digitally via forums [OEM_11:21], or through *in situ* contributions [SolarO_06:50, Nautil_17:58, VeloM2_12:37]. They are easier to integrate when they are about software rather than hardware [OEM_10:59].

t_3: Project leaders with project team · Projects leaders are in charge of contributions incorporation and release. When an iteration of the prototype is done, project leaders broadcast information with the project team. We call this a *minor release* (see below) [Nautil_09:52]. Once a prototype reaches a sufficient maturity, its design is frozen and documented. This documentation is then publicly broadcast. We call this a *major release.*

Several tools are used to manage and broadcast contributions: website, wikis, forum, Trelo, cloud hosting [SolarO_16:27, Shower_42:17, MyFood_46:54]. Projects notably use external platforms to broadcast their project with the rest of the world. In any case, collaboration is eased through geographical proximity, even if a few projects manage contributions remotely [Shower_17:58, Bicitr_23:01, Windtu_32:35]. One also observes the use of web sites as broadcast channel (personal [VeloM2_44:57], or specialized ones [Shower_10:52]).

These platform enable reaching numerous people. However, they suffer limitations notably their lack of flexibility and interaction [VeloM2_45:

56, Sunzil_26:43], what was already highlighted by Bonvoisin and Boujut (2015). Ideas for improvement are possible interaction with project members, flexibility of the platform, multilingual support, P2P end-users interaction [Windtu_20:31].

More globally, as highlighted through the example of Nautiles, there is a need for shared language [Nautil_02:34] among stakeholders that do not share the same background.

t_4: End-users with Project team · The main input from end-users is feedback, as well as requests for improvement [Bicitr_32:36]. Indeed, most improvement ideas comes from end-user [Bicitr_14:50]. End-users contribute via project forums on the Internet or directly by contacting project leaders. These contributions can be voluntary, or monitored by project leaders. Note that some end-users can also have no interaction with the project community at all.

Synthesis

The model presented in Figure 4.10 on page 124 shows the stakeholders structure, as well as the different types of interactions between layers of this structure. A 'layered' shape is observed, constituted with a core of a few but very active members around which gravitate less implicated stakeholders. Project leaders appear to have a critical role, as they centralize most information, interaction, and contribution.

This model, combined with the activities model presented below, is further discussed in Part 5.

iii Activities model

The second model we constructed presents the different activities carried out during the open-design process. Like traditional models of designing processes, it starts with a gap (i.e. the difference between a need and current products that aim at fulfilling it), and produce a plan (i.e. the unambiguous description of the to-be-produced product).

This model, depicted in Figure 4.11 on the following page, consists in a sequence of activities with two concentric feedback loops. Moreover, the five central activities are considered as a continuum, rather than clearly distinct phases. Finally, the last activity — broadcast — appear singular.

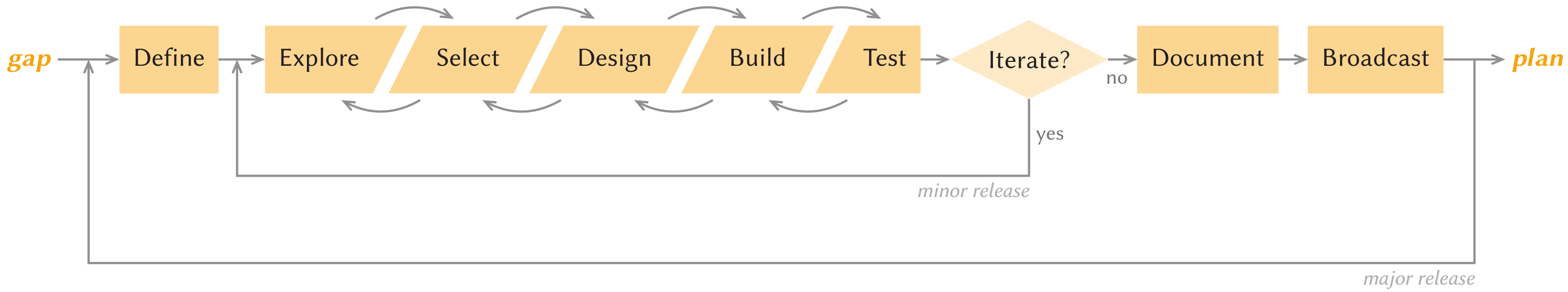


Figure 4.11
Activities model — We observe a continuum of phases from *Explore* to *Test*, as well as two feedback loops: an internal and an external one corresponding to minor and major release, respectively.

Model's elements

Input: the gap

As stated in the literature review, the gap (or need) do not differ in open-design projects compared to traditional design projects. However, we observed that most projects leaders invest their spare time in the project. This makes that needs to be addressed share two characteristics: first project team members have a personal interest in this need [Nautil_12:23], and second, this need is auxiliary – i.e. there is no urgent need to solve it.

Motivations for starting such a project are various: 'openizing' existing project [Biceps_03:05], merging similar projects together [Biceps_04:45], taking back control on everyday-life technology [Biceps_14:00, MyFood_03:21], just for fun [Bicitr_04:34], by self interest [VeloM2_03:12, OEM_19:04, Shower_02:29], for a personal need [Sunzil_02:59], or for making existing systems more accessible to anyone [Windtu_08:37].

In some other cases, the targeted need can be the output of a previous project [Biceps_10:44, Sunzil_09:07, Windtu_02:06, OEM_11:57], it might come from end-users [Bicitr_14:50, VeloM2_36:45, Aker_09:58], or be self selected [Nautil_17:34]. A risk inherent to these bottom-up projects is to develop a product with a low market fit [Nautil_12:23], i.e. a market push product [MyFood_38:16].

Define

For each project, the first activity undertaken is to refine the scope of the project and to set objective and constraints taken in consideration. This step is clearly coherent with existing design methodologies (cf. Howard et al., 2008)

Project leaders clarify the need addressed [VeloM2_33:30, Biceps_17:17, Sunzil_21:30, Shower_29:16], pursued objectives, and targeted users [Windtu_48:00]. These set objectives can be:

- to enable manufacturing by oneself [MyFood_14:17, Biceps_06:11, Biceps_09:27], i.e. a DIY product [SolarO_24:04];
- to be accessible and pedagogical [Biceps_12:20, OEM_20:07];
- to ease the construction [Bicitr_26:57, Shower_30:19, Windtu_07:27] and the control of the product [Windtu_54:30];
- to lower the cost [SolarO_10:33, Windtu_03:28];
- to focus on the ergonomy [VeloM2_21:33], the sustainability and usability [Nautil_12:23], the modularity [OEM_28:23], or the adaptability of the product [Windtu_54:15, Nautil_49:26, Bicitr_13:32];
- to define the type of expected solution (a proof of concept only [Biceps_13:26, Biceps_18:22], a prototype only [Sunzil_10:13], plans only, or a specific

building process [Windtu_23:31]);
- to meet specified performance [SolarO_24:35, Windtu_23:40, Windtu_24:14];
- or to be open-source [Biceps_07:04, Windtu_08:47].

Project leaders might also explicit a deliberately set constraints. These can be:
- to use of usual tools and material only [Biceps_06:50, Biceps_11:04, Bicitr_26:57, Windtu_07:27];
- to respect industry standards [Biceps_18:22];
- to finish the development by a given dead-line [Nautil_49:23, Aker_07:22, Sunzil_09:51];
- to reduce the technological level and tools needed [Windtu_07:27, Windtu_08:47].

Projects might also put up with external endured constraints, such as a limited choice of available resources [Shower_30:12, Shower_38:10, Sunzil_09:51], and limited funding [Shower_29:58].

Despite a need-refining step at the beginning of the process, we observe little abstraction of main functions to-be-embodied by the product — except for one project [Nautil_49:26]. Similarly, requirements are not made explicit except for two project [SolarO_06:31, Nautil_22:38].

Feedback loops will be detailed later. One can, however, already note that these objectives and constraints are updated at each iteration, notably based on reached state of development [Bicitr_17:31].

Once this road-map (i.e. the task to tackle) is set, actors aims at developing a satisfactory system. This means designing a system and testing its actual behavior. Following steps — recalling major steps of a traditional designing process — are undertaken in each project but with various formalization level. Some projects explicitly detail steps and formalize in-between boundary object. Some others undertake them in a concurrent continuum with frequent switch from one activity to another and multiple forward or backward 'jumps' from one activity to another.

Explore

The *explore* phase is not prominent during the first iteration, but it later gains importance.

Indeed, most projects start small, and "were not meant to be a product" [Sunzil_10:13]. Thus, they are often not structured from the beginning. This way, the first iteration shows little research: an *a priori* product is build based on product leaders' assumptions of what should be the solution [Shower_35:04]. In next iterations, projects are detailed in sub-elements, and project leaders focus separately on each specific sub-objective [Bicitr_23:44].

Exploring is often based on searching similar existing systems [Shower_29:29] and abstracting solution principles that the product will emulate [Bicitr_25:38, Bicitr_26:52]. For that, one use the Internet [Bicitr_26:29, Bicitr_26:57], specialized content [MyFood_52:25], and scientific publications [SolarO_10:13]. Team know-how is, however, a limiting factor, as well as funding and products availability and knowledge [Shower_08:47, Shower_29:58, Shower_29:35]. Only one team used specific techniques such as oriented creativity to find new ideas [Nautil_26:46].

Select

Ideas selection is mostly driven by resources' availability [Shower_31:29, SolarO_08:14]. Indeed, most projects use off-the-shelf design. Since exploration is not thorough, a first feedback loop might occur here: if a selected solution is not 'designable' (due for example to a lack of resources), then a new way is explored.

Decisions are taken by consensus. However, a hierarchical decision might be required sometimes. Those who are the most invested in the project have then more power in the decision taking [SolarO_26:13, SolarO_26:50]. Being less invested in the project means having less power — even as project leader [SolarO_28:42]. We should, however, note that decisions are also taken by a rule of thumb [SolarO_24:35].

Design

Design activities are neither well structured, nor use specific designing techniques. They thus fall within the framework of DIY design (Atkinson, 2006).

The design phase is sometimes not made explicit, nor separated from the prototyping [Bicitr_11:56, Windtu_04:06]. It involves sketches, and sometimes 3D modeling [Sunzil_23:25]. (In this case, mainstream gratis software are used [SolarO_15:19].) Designing might also show that a solution is not satisfactory, and thus lead back to the *explore* step [Biceps_18:12].

A notable difference with traditional designing process is that a special attention is drawn upon the manufacturing process [Biceps_07:21]. This process can be crowdsourced [SolarO_06:39]. External professional inputs indeed makes the project progress [VeloM2_05:47].

For the majority of projects, 3D modeling is not used for designing. Only one project did all in 3D [SolarO_21:04]. Some projects did not use 3D modeling at all [Bicitr_11:21, Sunzil_19:27]. In other cases it might be used for volume and dimensions testing [Biceps_19:12, Shower_41:11]. However, it usually comes after paper sketches [VeloM2_48:55], since it takes a lot of time [MyFood_20:17] because stakeholders are not familiar with it. 3D modeling is thus used for communication and archival purpose. Another major reason is the later use of CNC manufacturing [Windtu_06:21]. When done online [SolarO_15:19], only one person modifies files offline and the other commenting [Aker_03:35]. However, collaborating is made difficult due to the cost or required skills of 3D modeling software [Nautil_57:08]. Thus, mainstream ones are usually used [Shower_41:11].

Prototyping

Prototyping is a critical part of the open-design process. Prototypes 'cristallize' the design and enable to iterate thereon.

Prototyping occurs even if design was purely digital [SolarO_06:59]. One can observe two types thereof. The first type is the prototyping of a sub-element of the system. A few projects used mock-ups [Sunzil_17:18], or tested some subsystems [SolarO_07:25]. However, most prototypes belong to the second type: they are full scale products. The first prototype build is most of the time a proof of concept [Shower_19:35]. Then, through incremental improvement [Bicitr_20:29], this prototype is made better. Two strategies are observed: either building a new one, or upgrading the existing one [Bicitr_05:06]. In some cases, prototypes are the output of the project (when no open-source release was initially intended) [Bicitr_05:06].

Test

Small-scale testing occurs all along previous steps [Windtu_02:21, Shower_32:52]. Most projects also conduct proper testing in real use conditions to validate their product [Bicitr_12:04, Windtu_23:54, OEM_05:19, MyFood_58:03, Windtu_25:02]. These tests are used as information for the next step: the *iterate?* gate.

Iterate?

The *Iterate* gate aims to validate the development of the product: if the prototype is satisfactory and if the product evolved significantly since previous documenting, then a *major release* is decided. Otherwise, a *minor release* only occurs. A minor release means broadcasting information to project members only, and starting a new incremental designing process. A major release means to document and broadcast the result of the designing process with anyone, before starting the process again with updated objectives. We observed that requirements' formalization is poor (see above). Projects are validated 'by default', i.e. as long as they are not 'not usable' [Bicitr_18:49, MyFood_40:31]. In other words, when they are considered 'good enough'. The validation of the product is thus often not formalized.

Document

Documenting is a crucial activity in open-design processes.

Indeed, when a traditional project delivers sources, open-design projects also details the manufacturing process and building instructions. They also supply additional information: what trials have been done, bill of material, bill of tools, etc. [SolarO_20:17]. This step is crucial [Windtu_27:12]. However, it requires specific skills [Windtu_28:00, Biceps_22:59].

This activity comes in addition to the development, i.e. once the design is frozen [Shower_41:36, Windtu_04:52, VeloM2_26:03, Shower_23:45, Windtu_26:41]. Indeed, documenting the product requires a significant amount of work and a lot of time [VeloM2_26:03, Windtu_26:41]. Thus, these steps are done at the end [OEM_14:48, Sunzil_21:45]. Design is hence formalized and broadcast only on frozen state.

Broadcast

Documented design is then broadcast. This step differs from traditional designing processes [Biceps_23:53, MyFood_14:56], yet critical.

Multiple broadcasting platform are used (personal websites, specialized platforms, cloud storage, etc.). Broadcasting issues are related to openization issues. For example, project leaders do not want to broadcast their work in progress because of related responsibility [Shower_22:34]. Another issue is to select what to open [Nautil_48:29]. Note that when they broadcast the plan, project members put it at the disposal of anyone. They thus do not control who will access and (re)use this information. Moreover, they usually aim to promote their design, in order to let the project community grow.

Output: the plan

The *plan*, or solution definition (i.e. the output of the process), is constituted of three elements: the plans of the product, the documentation, as well as product prototype (i.e. a 'protoduct').

The documentation come in addition to plans. It consists of experience feedback and global information about the concept [VeloM2_27:33, Biceps_14:50], manufacturing manual [SolarO_20:01, VeloM2_27:33, Windtu_19:46], bill of materials, tools, and detail of sizing [SolarO_20:17], list of cost

[MyFood_23:29]. Various mediums are used: 3D files, text and pictures, video [Windtu_11:20].

Some project share as much information as possible [Shower_42:34]. However, not everything lies in the documentation for each project [Biceps_10:02]: for example the list of requirement is not in it [SolarO_21:37]. Similarly, in the case of a project affiliated with a company, all information is not broadcast [MyFood_22:14, MyFood_34:42]. Broadcasting is also limited by platform feature [VeloM2_45:56].

Regarding 'plans' of the product, there is no definitive version since products always evolve [Bicitr_12:54]: a release freezes a prototype's design only when it reaches a certain maturity state. This solution might indeed be the starting point of future projects (forking, spin-off) [OEM_15:34]. Thus, the final state of the product is a tested and working prototype that is, however, not perfect [Bicitr_08:57].

One can observe that products studied share similar characteristics: a central module with plug-able add-on [Bicitr_13:47, VeloM2_37:22], modularity [VeloM2_08:37, OEM_10:19], being a pedagogical medium [VeloM2_35:51], off-the-shelf design [OEM_35:56], low cost [MyFood_09:09]. Compared to open-source software, we note that specifics of hardware imply a higher fabrication cost [Biceps_35:08] (which can be a hurdle to contribution). This implies that only one prototype is built [SolarO_30:38], and material sourcing plays a critical role [Shower_33:14, Sunzil_20:05].

Interactions among elements

After having presented each activity (or element) of the model, we now investigate their arrangement.

Global structure

The global structure resembles cyclic designing methodologies, constituted of an iterated sequence of similar activities.

Since a few project leaders only are trained designers, an intuitive process is followed. Thus, an informal V-model approach [OEM_17:42, MyFood_12:02] is usually followed, i.e a usual problem solving approach that one would follow without being expert designer [SolarO_08:40]. In some project, no specific process is explicitly followed [Windtu_22:34, Aker_11:16, Shower_07:32].

The objective is to obtain tangible results as soon as possible [MyFood_20:57] (even if some projects had a long-term planning [SolarO_06:04]). However, at the contrary of traditional V-model approaches, this approach is highly iterative [MyFood_05:13, Shower_08:47, Bicitr_07:30].

Activities continuum

Due to the amateurism of stakeholders, the process followed is often not explicit and activities within one iteration often merge together.

Listed activities are not necessarily done in a specific order: sometimes the exploratory phase of the design is neglected and designers directly process to prototyping (build and test) [Bicitr_23:54, Bicitr_26:29]. We thus observe a continuum of various actions between the 'Explore' and the 'Test' phases, rather than distinct and delimited activities. This makes the formalization of in-between boundary object lower.

Moreover, we observed forwards and backwards jumps from one activity of the central continuum block to another.

Internal feedback loop (the minor release)

We depicted the global process as cyclic, with iteration after each completion of the whole process (i.e. major releases). However, another feedback loop exists within the process.

Designing process progress through iterations. Objective resetting is done by comparing prototype with expected objective [VeloM2_06:49]. For each iteration new requirement or constraints are considered [Nautil_45:16]: industrialization, lowering costs [Shower_06:12], etc. New constraints might also come from outside the project [Shower_38:22, MyFood_42:20].

We observe a recurrent use of try-and-fail approaches in projects [Bicitr_07:30]. A new iteration might lead to start again from scratch [Bicitr_10:51], or to update what is not sufficient [Bicitr_20:01]. An iteration is the place for knowledge [Bicitr_18:40] and skills capitalization [Shower_39:59]. It also enables to deeply change design [Bicitr_10:51] (for example by integrating new skills or technologies [Sunzil_03:53]) and add features [MyFood_42:20]. Thus, iterations are organized as follows: identifying current limitation, choosing issues to tackle, and improve prototype [Shower_39:59].

Boundary objects used

Various boundary objects are used during the process. However, they are often not formalized.

The most widespread boundary object is sketches [Bicitr_21:40, Nautil_56:11, VeloM2_48:42]. Some mock-ups are used too [Sunzil_18:22], but not often [VeloM2_50:10]. Mock-ups are usually the prototype itself. We also observe that having multiple prototypes is difficult [Shower_18:21], since, in contrast with software, it is difficult to have twice the same configuration and producing .

Indeed, we observed earlier that most project leaders are not trained designers. They are thus less prone to use digital tools and are less efficient with them. Boundary objects are thus not digitized during the designing process [VeloM2_48:55] (even if it is not the case for all project [MyFood_40:01]). However, digitalization of boundary objects must occur because of the later use of CNC machine.

Synthesis

The model presented in Figure 4.10 on page 124 shows the different activities carried out during the open-design process, and their arrangement. Activities resemble those found in the scientific literature on the designing process: we observe the same set of major activities with a similar arrangement. Only the last step (*broadcast*) appear singular to open-design. However, one can observe an internal feedback look and a late but prominent *communication* step that makes this model singular.

This model, combined with the stakeholders' model presented above, is further discussed in Part 5 and notably compared with models reported in the literature.

4.3.4 Method: Validation of models and of the modeling method

The second experiment presented in this chapter aims to model the open-design process, for one of the types of open-design practices described in the previous experiment (cf. Table 4.5 on page 105). We have detailed above the method we used to construct models of the designing process, as well as two models produced via this method. The question is now to validate these models and to ensure that they are accurate representations of the investigated open-design type.

To test our hypothesis H2, we should thus measure the internal and the external validity of each model, as well as the reliability and the robustness of our modeling method. We detail here which indicator we chose in order to test whether these requirements are met.

i Dataset

Our models are based on the data we collected: the interviews transcripts. These transcripts were divided into 1056 segments representing semantic units. These segments are thus the connection between models and data.

To validate our models and modeling method, we can then look at these segments. This allow us to use statistical tools for that.

We have thus created a database constituted of $I = 1056$ individuals (or observation, that is each segment), and $J = 45$ categorical, or qualitative, variables (each concept). We chose concepts as main variables (instead of codes or categories) because they appear to have the right level of 'zoom' into the data: we have not too much of them in order to find common traits among segments (unlike codes), yet enough to underline fine differences (unlike categories). The architecture of our database is then the following: The entry v_{ij}, which is the intersection of row $i \in [1 .. I]$ and column $j \in [1 .. J]$, holds the value corresponding to the category of the j-th variable possessed by the i-th individual. Its value is *true* (or 1) if the i-th segment was tagged with the j-th concept, *false* (or 0) otherwise. Each segment can thus be represented by its coordinates in a vector space with J dimensions.

In addition to these active variables, our database is also initially constituted of two supplementary variables: the unique identification tag of each segment (UID) and the project it refers to ($Project$). Based on the document you are currently reading, we also constructed, for each model, the boolean variable is_cited that equals *true* if the segment is cited in Subsection ii or iii of Section 4.3.3 in this document; and equals *false* otherwise. We thus created two variables is_cited: one for the stakeholders model and another for the activities model, looking at Subsection ii or iii, respectively. The computation of this latter variable is done through a self-written script that extracts segments cited in above mentioned subsections and update our database accordingly. Finally, we also defined the boolean variable $is\_defined$ as detailed above.

To run the Multiple Factor Analysis (MFA), we also distinguished groups among the variables. As variables in our database represent the concepts we defined in our grounded theory based approach, these variables (or concepts) were grouped per category, in order to match the concept-to-categories transition table.

ii Models' internal validity

The first question to answer is: "Are our models accurate and unbiased? Do they truly summarize data on which they are based?" This means that we want to assess the internal validity of our models, which is the extent to which they genuinely represent an aspect of the phenomenon modeled.

We present below a series of implications that links the questions asked above (the requirement — that is the internal validity of our model) with the measure of a quantifiable variable (the indicator).

A model is accurate and unbiased means that this model is internally validated (*a*). This implies that the model represents a given facet of collected data (*b*). Indeed, each of our models does not summarize all data's content: each model depicts a specific aspect of the designing process, which is only a part of the data. This implies that, for each model, cited segments represent modeled categories well (*c*). Indeed, each model specifically represent segments belonging to one or several given categories (see below). This implies that each model represents a defined set of categories well (d_1), and that the modeling of these categories is not skewed (d_2). In other words, we must answer following questions, respectively: "Does the model represent the data it is supposed to model?" and "Is the representation of these data unbiased?" (that is "Are the projects represented similarly in the raw data and in the model?").

Let us assign the binary variable *is_cited* to each segment. This variable equals 1 if the segment is cited in the construction of the model, 0 otherwise. Let us also define the binary variable *is_modeled* for each segment. This variable holds 1 if the segment belongs to one of the categories considered for the current model ('human' for the stakeholders' model, 'process', 'boundary object', or 'product' for the activities' model), and 0 otherwise.

D_1 means thus that there is a link between the *is_cited* and *is_modeled* variables (e_1). In other words, that there is a link between segments belonging to the *is_cited* and the *is_modeled* groups (f_1).

D_2 means that the representation of modeled category is unbiased. It implies that concepts of modeled categories are similarly represented in cited segments as in all segments (e_2) — i.e. no concept is over-represented in cited segments. This implies that there is no link between each of modeled categories and the *is_cited* variable (f_2).

To measure the existence or absence of a link between two groups of variables, we ran a multivariate analysis on our segments database. Indeed, each segment (representing an excerpt of a given interview) can be defined through its membership (or not) to each of the different concepts we used. We thus created as many boolean variables as the number of concepts. Then, we defined, for each segment, whether it was assigned to a given concept. Using these variables, we can then map each segment as a point in a vector space constructed using each concept as a dimension (the dimension of this vector space thus equals J, i.e. the total number of concepts).

Because our dataset (see above) is constituted of categorical (or qualitative) variables, and because we want to measure the influence of groups of variables (i.e. the categories to which each group is related to), we chose to run a MFA as multivariate analysis — cf. Husson, Lê, et al. (2016). To compute the MFA, we used *R*'s package *FactoMineR* (Husson, Josse, et al., 2017). The objective of the MFA is to reduce the dimension of this vector space, as well as to define most explanatory dimensions in this vector space — i.e. orthogonal axes that maximize the inter-individual variability (Greenacre, 2007). The MFA also provides quantitative indicators that measure the links between groups of qualitative variables, and the contribution of each group in the construction of the vector space. (A MFA is thus similar to a Multiple Correspondance Analysis (MCA), except that the MFA focuses on the contribution of groups of variables, instead of simply variables themselves, and weights the influence of each group. Here, groups of variables (i.e. of concepts) are the categories we defined to cluster concepts — the latter being the variables used to construct the vector space.)

The question is now to measure whether the is_cited and $is\_modeled$ variables (f_1), as well as the is_cited and modeled categories (f_2), are related. In both statements, we want to measure the strength of the link between two groups of variables. For that, we use the L_g coefficient that represents the projected inertia of every variables of the group K_m on those of the group K_n (Husson, Lê, et al., 2016). It is defined as

$$L_g(K_n, K_m) = \sum_{k \in K_n} \sum_{l \in K_m} \operatorname{cov}^2 \left(\frac{x_{.k}}{\sqrt{\lambda_1^m}}, \frac{x_{.l}}{\sqrt{\lambda_1^n}} \right)$$

where:

- $\operatorname{cov}(u, v)$ is the covariance between the two jointly distributed variables u and v;
- K_n is the group corresponding to the is_cited variable (i.e. it has made up of one variable only);
- K_m is the group whose link with is_cited is measured: a group constituted with concepts — or variables — of one category only for f_2, and the group corresponding to the $is\_modeled$ variable for f_1;
- $x_{.k}$ and $x_{.l}$ are variables of the group K_m and K_n, respectively.
- λ_1^m and λ_1^n are the first (i.e. the largest) eigenvalue of the group K_m and K_n, respectively.

In order to ease the measuring to the strength of the link, we normalize the L_g coefficient. We thus define the Rv coefficient that is bounded between 0 and 1. $Rv(K_n, K_m) = 0$ means that all variables of the groups K_n and K_m are not correlated. $Rv(K_n, K_m) = 1$ means that there is a very strong link between both groups of variables (that is both groups are similar modulo a homothetic transformation). $Rv(K_n, K_m)$ is defined as:

$$Rv(K_n, K_m) = \frac{L_g(K_n, K_m)}{\sqrt{L_g(K_n, K_n)} \cdot \sqrt{L_g(K_m, K_m)}}$$

Our objective is to measure if a category (i.e. a group $K_m = Cat_i$ for f_2, or the group $K_m = is\_cited$ for f_1) is linked with the group $K_n = is\_cited$. Based on the definition of Rv, we set 0.1 as the criterion to compare Rv against in order to determine the existence of a link or not between two groups of variables.

F_1 hence implies that the normalized similarity coefficient between the group of cited segments and the groups of modeled segments is greater than 0.1 (g_1). That is:

$$Rv(is\_cited, is\_modeled) \geq 0.1$$

F_2 implies that for each category i, the normalized similarity coefficient between the group of cited segments and the groups of segments belonging to each category ($Rv(is\_cited, Cat_i)$) is strictly lower than 1 (g_2). That is:

$$\forall i \in [1 .. N_{cat}], \; Rv(is\_cited, Cat_i) < 0.1$$

where N_{cat} is the number of relevant categories and Cat_i the group of variables of the i-th category.

This first part of the validation can be summarized as following:
Validation requirement: Models' internal validity.
Questions to be answered: Does the model represent the data it is supposed to model? Are the representation of these data unbiased?
Criteria measured: $Rv(is\_cited, is\_modeled) \geq 0.1$ and $\forall i \in [1 .. N_{cat}]$, $Rv(is\_cited, Cat_i) < 0.1$, respectively.

iii Models' external validity

The second question to answer is "Can the model be generalized?" This means that we want to assess the external validity of a model, which is the extent to which the model is valid beyond the context in which it was constructed.

To measure the external validity of a model, the latter must be compared with sets of situations (here, open-design projects) different from the ones used to construct it. Due to a lack of resources, we were not able to properly compare our model with other sets of data. Our model's external validity was thus not tested. This point is discussed as a limitation of our study.

iv Reliability of the modeling process

Both previous questions focused on models themselves. However, we also need to validate our modeling method. The third question to answer is then "Is our modeling method independent of the processing from a given experimenter?" This means that we want to assess the reliability of our modeling method, which is the extent to which the modeling process would give the same result if repeated several times by different persons.

Just like for the internal validity, we now present a series of implications linking the requirement to the indicator.

The modeling process is reliable (*a*) implies that based on the same data, one would obtain the same model if one follows the same process (*b*). This implies that two different persons would create the same model based on the same data (*c*). This implies that two different persons would code data similarly, that is both persons agree on the coding of data (*d*). The coding was divided into three parts:

1. assigning major and minor codes to segments (Step 5 in Figure 4.7 on page 116),
2. defining to which concepts are related major codes (Step 6),
3. and defining to which category are related concepts (Step 7).

This implies that: using I1's (a first investigator — i.e. us) major codes, I2 (a second independent investigator) would attribute the same major codes to each segments (d_1); using I1's concepts, I2 would attribute the same concept as I1 to each of the major codes (d_2); and using I1's categories, I2 would attribute the same category as I1 to each concept (d_3). Due to resources limitation, we will not evaluate d_1. So this implies that, respectively: using I1's concepts, I2 would attribute concepts with a substantial agreement with I1 to a representative sample of I1's major codes (e_2); and using I1's category, I2 would attribute the same category to every I1's concepts (e_3). Because we used more than 300 different major codes, we sampled the set of major codes in order to ease the measuring of reliability. This was yet not necessary for concepts, as their number is limited (less than 50). It thus implies that, respectively: when I2 assigns I1's concepts to a representative sample of random major codes, the agreement between investigators I1 and I2 is substantial (f_2). and when I2 assigns I1's categories to each concepts, the agreement between I1 and I2 is substantial (f_3).

According to the definition of the strength of agreement by Landis and G. G. Koch (1977), the 'substantial agreement' between both observers is defined as

$$\kappa_C > 0.6$$

where κ_C represents Cohen's kappa (Cohen, 1960). The latter is defined as:

$$\kappa_C = \frac{p_0 - p_e}{1 - p_e}$$

where p_0 is the agreement between both observers ("the proportion of units in which the judges agreed") and p_e the expected accuracy by change ("the proportion of units for which agreement is expected by chance") (ibid., p. 39).

To measure f_2, we randomly select a representative sample of major codes. The sample size of major codes used was defined using Cantor's formula (Cantor, 1996), and computed using the `N.cohen.kappa` function of *R*'s *irr* package (Gamer et al., 2012). (The total number of major codes being equal to 347, and the probability to record a positive diagnosis being estimated as 2.5% we selected $N_s = 74$ of them to ensure a power of 0.8 and a statistical significance à 0.05.) As there are only 45 concepts mapped with 7 categories, we did not found necessary to sample concepts. Random samples of major codes, and list of concepts were presented to independent researchers who were, however, familiar with the topic. We also give them the list of all concepts and category we used, respectively.

These researchers were asked to assign from one to three concepts of the list to each major code.

P_0 is defined as following:

$$p_0 = \sum_{i \in 1}^{N_s} \frac{\sum_{j \in 1}^{N_c} \frac{agree(i,j)}{N_c}}{N_s}$$

where:

- $agree(i, j)$ equals 1 if either both I1 and I2 assigned the j-th concept to the i-th major code of the sample, or if both I1 and I2 *did not* assign the j-th concept to the i-th major code of the sample — and 0 otherwise (that is when only one of the investigator assigned a concept to the major code);
- N_c is the total number of concepts (here, $N_c = 45$).

P_e is defined as the chance expectancy.

In other words, considering Table 4.9 on the facing page that synthesize the amount of times investigators agreed or not, p_0 and $p1$ equals the following:

$$p_0 = \frac{\alpha}{\alpha + \beta + \gamma + \delta} + \frac{\delta}{\alpha + \beta + \gamma + \delta}$$

$$p_e = \frac{\alpha + \beta}{\alpha + \beta + \gamma + \delta} \cdot \frac{\alpha + \gamma}{\alpha + \beta + \gamma + \delta} + \frac{\gamma + \delta}{\alpha + \beta + \gamma + \delta} \cdot \frac{\beta + \delta}{\alpha + \beta + \gamma + \delta}$$

This third part of the validation can be summarized as following:

Table 4.9
Synthesis of investigators' agreement

		I2	
		assigned	did not assign
I1	assigned	α	β
	did not assign	γ	δ

Validation requirement: Modeling reliability.
Questions to be answered: Would two different persons generate the same model if they used the same method and the same data?
Criteria measured: κ_C(*Major codes* → *Concepts*) > 0.6 and κ_C(*Concepts* → *Categories*) > 0.6.

v Robustness of the modeling process

Lastly, the fourth question to answer is "Would the outcome of the modeling be significantly different if a small part of the data changed?" This means that we want to assess the robustness, which is the extent to which the modeling process is not sensible to a variation in the input data. In other words, it measures the independence of the modeling process from a particular set of data.

The modeling process is robust (*a*) implies that no project is over-weighted in the description of the model (*b*). This implies that no project is significantly over-represented in the construction of the model (*c*). This implies that over segments used (i.e. cited) in the construction of the model, no project has a significant contribution in the construction of most representative dimensions of the vector space (*d*).

To measure the contribution of each project in the model's construction, we use a multivariate analysis on our segments database. More precisely, because our dataset (see below) is constituted of categorical (or qualitative) variables we chose to run a Multiple Correspondance Analysis — cf. Husson, Lê, et al. (2016). To compute the mca, we used *R*'s package *FactoMineR* (Husson, Josse, et al., 2017). The complete disjonctive table is notably automatically computed by the package. (A mca is similar to a Principle Component Analysis (pca), but is dedicated to categorical variables instead — as it is the case here. Unlike for the assessment of the internal validity of the model, we do not need here to measure the contribution of *groups* of variables — i.e. the categories. We thus do not need to use a mfa and can use a lighter method that is the mca.)

As a multivariate analysis, the objective of the MCA is to reduce the dimension of the vector space constructed by all concepts (the dimension of this vector space thus equals J) as well as to defined the most explanatory dimensions in this vector space (i.e. orthogonal axes that maximize the inter-individual variability). The MCA also provides quantitative indicators that measures the contribution of supplementary categorical variables (here, the *project* a segment belongs to) between qualitative variables.

The question is now to measure *ex post* the influence (or weight) of each project in the model. We thus want to measure if the variable *Project* has an influence on the construction of the model. For that, we run a MCA on the sub-database constituted of cited segments only. We then look at major (or most representative) dimensions of created vector space. We consider a dimension as representative if it explains more than 5% of the variance of segments' coordinates in the vector space — that means that this axis represents the diversity of data well.

D then implies that no project significantly explains variations in data on each of these representative dimensions (e). This implies that on these representative dimensions, each barycenter representing segments of a single project has a coordinate that is not significantly different from 0 — zero, i.e. the origin (f).

To assess f, we first define — for each model — the most representative dimensions, based on the eigenvalue thereof. Then, we look at coordinates of the barycenter of each project along each of the major dimensions. To assess if the coordinate significantly differs from 0, we use the "*value test*" defined by Escofier and Pagès (2008). Assuming a normal distribution of barycenter coordinates, we compared the *value test* with the standard normal distribution (Husson, Lê, et al., 2016). Thus, assuming a confidence level of 95%, f implies that *values test* should not differ of more than a standard deviation (i.e. 1.96) from 0 (e), that is:

$$\forall p \in \{projects\},\ \forall d \in \{dimensions_{Var>5\%}\},\ |\text{v.test}(p,d)| < 1.96$$

This fourth part of the validation can be summarized as following:

Validation requirement: Modeling robustness.

Questions to be answered: Would the outcome of the modeling be significantly different if a small part of the data changed?

Criterion measured: $\forall\ p \in \{projects\},\quad \forall\ d \in \{dimensions_{Var>5\%}\}$, $|\text{v.test}(p,d)| < 1.96$.

4.3.5 Result and analysis of the validation

We present below the results and analyses of the validation of both our models and our modeling method. The structure of this section follows the four criteria we assessed: models internal and external validity as well as the robustness and the reliability of our modeling method. For each criterion, we first present the result of the assessment and then analyze it.

i Models internal validity

The internal validity measures if a model genuinely represents an aspect of data used to construct it. We linked this requirement with two indicators — both of them being based on the normalized similarity coefficient between two groups of variables (R_v):
- $R_v(is\_cited, is\_modeled)$ to measure the link between cited segments, and those supposed to be modeled by the given model — we expect the show the existence of a link;
- $Rv(is\_cited, Cat_i)$ to measure the link between cited segments, and those belonging to a given category — we expect to show the absence of a link.[7]

Results

The Table 4.10 on the following page presents the values of R_v for relevant pairs of groups of variables and for both models. The normalized similarity coefficient between a group and itself obviously equals 1. We also note that R_v is commutative (i.e. $R_v(is\_cited, is\_modeled) = R_v(is\_modeled, is\_cited)$).

In the upper part of the table, we observe that for both models, there is a link between cited segments and those supposed to be modeled. This is because we read $R_v(is\_cited, is\_modeled) > 0.1$.

For what regards the unbiased representation of categories in models, we observe in the lower part of the table that the normalized similarity coefficient between the group of cited segments and each group representing a given category, all values of $R_v(is\_cited, Cat\_i)$ are smaller than 0.1. This indicates the absence of link between these groups of segments. We also note that, logically, there is a link between modeled segments and the core category of the model (e.g. $Rv(is\_modeled, cat\_human) = 0.2507$ for the stakeholders model).

[7] *Category* refer here to the highest type of segments' cluster, as shown at the Step 7 in Figure 4.7 on page 116.

Table 4.10
Normalized similarity coefficient (R_v) between groups of variables for both models.
Reading example: For the stakeholder's model, $R_v(is\_cited, cat\_process) = 0.0242$. *Note that the table is presented complete, yet we grayed values not required for the analysis.*

Model	**Stakeholders**		**Activities**	
Group of variables	*is_cited*	*is_modeled*	*is_cited*	*is_modeled*
is_cited	1.0000	0.1069	1.0000	0.1548
is_modeled	0.1069	1.0000	0.1548	1.0000
cat_na	0.0205	0.0755	0.0287	0.1115
cat_human	0.0657	0.2507	0.0367	0.0366
cat_process	0.0242	0.0449	0.0735	0.2446
cat_boundary.object	0.0204	0.1189	0.0440	0.0334
cat_open	0.0005	0.0105	0.0015	0.0520
cat_project	0.0417	0.0809	0.0244	0.0154
cat_product	0.0026	0.0041	0.0441	0.0402

Analysis

To assess the internal validity of our models, we first measured the normalized similarity coefficient between the *is_cited* and *is_modeled* groups. We observe that for stakeholders and activities models, $R_v(is\_cited, is\_modeled)$ is greater than 0.1 (0.1069 and 0.1548, respectively). This shows the existence of a link between cited segments and the supposed to be modeled ones.

We can note that the strength of the link between the group of cited segments and the ones supposed to be modeled — yet greater than 0.1 — is low. ($R_v = 1$ means that both groups of segments are identical modulo an homotetic transformation in the vector space.) This is likely due to the large number of uncited yet modeled segments in the construction of our models, as shown in Table 4.11. (For example, in the construction of the stakeholders model, 100 segments were cited out of the 100 + 256 = 356 segments belonging the modeled category — here, 'human'.) This phenomenon is obviously due to the synthetic description of the model.

Cited segments coming from categories not modeled are due to explanations of the context of our model. (For example, our stakeholders' model is not about boundary objects, yet we refer to them at some point in the description of the model.)

Table 4.11
Count of segments in the *is_cited* and *is_modeled* groups for both models.

	Stakeholders		**Activities**	
	is_modeled	*¬is_modeled*	*is_modeled*	*¬is_modeled*
is_cited	100	35	153	27
¬is_cited	256	665	292	584

To assess the internal validity of our models, we also measured the normalized similarity coefficient between the *is_cited* and groups representing concepts of each category (the *cat_x* groups). Table 4.10 on page 152 shows that each value of R_v is lower than 0.1. This highlights the unbiased representation of categories in our models.

We can thus summarize our analysis as following:

Criteria measured: $Rv(is\_cited, is\_modeled) \geq 0.1$ and $\forall i \in [1 .. N_{cat}]$, $Rv(is\_cited, Cat_i) < 0.1$.

Results: For the stakeholders model: $Rv(is\_cited, is\_modeled) = 0.1069$ and all $Rv(is\_cited, Cat_i)$ are smaller than 0.0657; for the activities model: $Rv(is\_cited, is\_modeled) = 0.1548$ and all $Rv(is\_cited, Cat_i)$ are smaller than 0.0735.

Conclusion regarding the requirement: We consider both our models as internally validated.

Questions answered: The models do represent data they are supposed to model, and the representation of these data is unbiased.

ii External validity

To measure the external validity of a model, it must be compared with sets of data (here, open-design projects) different from the ones used to construct it. Due to a lack of resources, we were not able to properly compare our model with other sets of data. Our model's external validity was thus not tested.

Therefore, we cannot strictly infer that our models can be generalized to every projects of DIY open-design, or even to other types of open-design. However, some aspects argue in favor of the value of our models. These models were constructed based on a set of a dozen of projects. This corpus was not formed by researchers of this study — what minimizes observer's bias. Projects selection also ensure the homogeneity of projects. Moreover, we observed that they encompass a wide variety of practices — what makes our models more inclined to be representative of the open-design type we investigated.

iii Modeling process reliability

To measure the reliability of the construction of our model, we asked a researcher external to our project (yet familiar with the topic) to both cluster major codes we defined into concepts (using the ones we defined), and to cluster concepts we defined into categories (using the ones we defined). We expect to show that both investigators agree on the clustering.

Results

Table 4.12 summarizes results of investigators' agreement for both clustering. There results enable us to compute Cohen's kappa for both clustering. We find that:

- $\kappa_C(\textit{Major codes} \longrightarrow \textit{Concepts}) = 0.7544$
- $\kappa_C(\textit{Concepts} \longrightarrow \textit{Categories}) = 0.7238$

According to Landis and G. G. Koch (1977) definition of the strength of agreement regarding Cohen's kappa, we consider that there is a substantial agreement between both investigators.

Analysis

According to Landis and G. G. Koch (ibid.) definition of the strength of agreement regarding Cohen's kappa, and considering that $\kappa_C(\textit{Major codes} \longrightarrow \textit{Concepts}) = 0.7544$ and $\kappa_C(\textit{Concepts} \longrightarrow \textit{Categories}) = 0.7238$, we can say the is a substantial agreement among investigators.

Despite concluding results, we acknowledge that comparing multiple evaluations would have been more robust that comparing only two investigators. In such case, to evaluate the agreement among all investigators, the Cohen's kappa cannot, however, be generalized to more that two observers. One should then use Fleiss' kappa (Fleiss, 1971).

We can summarize our analysis as following:

Criteria measured: $\kappa_C(\textit{Major codes} \longrightarrow \textit{Concepts}) > 0.6$ and $\kappa_C(\textit{Concepts} \longrightarrow \textit{Categories}) > 0.6$.

Results: $\kappa_C(\textit{Major codes} \longrightarrow \textit{Concepts}) = 0.7544$ and $\kappa_C(\textit{Concepts} \longrightarrow \textit{Categories}) = 0.7238$.

Conclusion regarding the requirement: We consider our modeling method as substantially reliable.

Questions answered: Two different persons would generate the same model if they used the same method and the same data.

Table 4.12
Result of investigators' agreement.

		Original clustering			
		Major codes to Concepts		***Concepts to Categories***	
		assigned	*did not assign*	*assigned*	*did not assign*
Confirmation clustering	*assigned*	77	26	34	7
	did not assign	30	2901	7	239

iv Modeling process robustness

To measure the robustness of our modeling process, we measured whether a given project has a significant contribution in the vector space constructed with cited segments. In other words, if a project significantly influence the construction of a model. We expect to show that no project significantly impacted the construction of our models.

Results

For that, we measured the barycenter of this project segments' coordinates, and test if the coordinate significantly differs from 0 on each of most representative dimensions of the created vector space. We ensure the latter using the *value test* of the project on a dimension and test if differs of less than a standard deviation from the origin (assuming a 95% confidence interval).

For both models created, 9 dimensions were considered as significant (i.e. each of them explain more than 5% of the variance of segments' coordinates). The variance they explain is detailed in Tables A.5 and A.6 on page 230 and on page 231, for stakeholders and activities models, respectively.

In these tables, we show for each major dimensions (columns), both the barycenter's coordinate and the value test for each project (rows). The first line of the row represents the coordinate of the barycenter on the given dimension, and the second is the value test. We highlighted value test greater than 1.96 or lower than -1.96 (meaning that related barycenter significantly differs from the origin on that given dimension).

Analysis

To evaluate the robustness of our modeling, we measured on most representative dimensions of the vector space created by concepts, the coordinates of cited segments' barycenter for each project. Tables A.5 and A.6 on page 230 and on page 231 show that for both models, most projects' barycenter do not differ from the origin — what shows the unbiased representation of projects in models. However, on some dimensions, one or more projects appear over- or under-weighted (that is, their coordinate are significantly above or below 0). We here acknowledge a limitation of our modeling, even if only a few coordinates are in this case. It might be due to the fact some interviews contained more relevant information for the construction of the models. This phenomenon is accentuated by the low number of interviews (11) we used to construct models. It is thus difficult to balance every project on all dimensions.

We can summarize our analysis as following:

Criterion measured: $\forall\, p \in \{projects\}, \quad \forall\, d \in \{dimensions_{Var>5\%}\}$, $|\text{v.test}(p,d)| < 1.96$.

Results: For the stakeholders model, over 99 barycenter coordinates (11 projects, over 9 dimensions), 8 test values are greater than 1.96 or lower than -1.96; for the activities model, over the same amount of barycenter coordinates, 8 values test are also greater than 1.96 or lower than -1.96.

Conclusion regarding the requirement: We thus consider our modeling as fairly robust.

Questions answered: The outcome of the modeling would not be significantly different if a small part of the data changed.

4.3.6 Synthesis and discussion

Based on results of this experiment (models, as well as the validation of both the latter and the modeling method) and on their analysis, we now conclude regarding the second hypothesis.

i Major results of the study

The experiment presented in this chapter aimed at testing our second hypothesis. This hypothesis states that *using a grounded theory-based approach enables the construction of models of the designing process for a given type of open-design practices.* We thus presented a method to construct models of designing practices based on the grounded theory approach. This method uses semi-directive interviews of open-design projects' leaders. We then implemented this method and developed two models. The first represents stakeholders in open-design projects and their interactions (Figure 4.10 on page 124). The second represents the designing activities undertaken in open-design projects and their arrangement (Figure 4.11 on page 134). Lastly, we analyzed both models and the method followed to construct them via statistical analyses.

The stakeholders' model we developed shows a layered structure, constituted of different categories of participants that have various levels of engagement in the project and who are coordinated differently. We detailed three kinds of interactions between those layers: the membership (how does one get from one layer to another?), tangible interactions (interactions that involves an exchange of data or a physical participation — i.e. contributions to the project), and social interactions (human relationships between stakeholders of different layers).

The model of designing activities we developed shows strong similarities with existing designing models described in the scientific literature. Major archetypal designing phases can indeed be found in our model. However, we observed a blurredness in boundaries between activities, what makes them rather consist in a continuum of activities with informal jumps from one activity to another. We also observed a strong internal feedback loop during the designing cycle, with a system of major and minor releases. Moreover, creating the documentation and broadcasting sources of the product plays a critical role in a project's success.

Through models analysis, we were able to confirm that both models produced are internally valid. However, we could not evaluate their external validity. Through the analysis of our modeling method, we found that the latter is substantially reliable when repeating the process. We also show that our modeling is fairly robust. Using more interviews to construct our models would help increase the robustness of the modeling.

ii Limitations

Corpus of projects

We noted that projects selected are various yet homogeneous. Their number remains, however, limited. Although one would need a lot of resources to run the qualitative analysis on a large set of projects, studying eleven real cases makes difficult to ensure the external validity of our models.

We can also note that our methodology is based on interviews of projects leaders only. The study could be enriched by using interviews of multiple projects leaders of the same project. One should be careful though to balance contribution of each project to the construction of our model. The model could also be enriched by taking in consideration other stakeholders, even if their weak involvement in the project would imply to interview numerous project members or outside contributors.

We noted that interviews were conducted at the end of the designing process. Using *ex post* analysis makes us rely on participants' memory only. This might alter the faithful reporting of events and undervalue the presence of singular events.

Finally, using interviews only makes our methodology more easily reproducible. However, models could be enriched by integrating different sources of data (e.g. on-field observations, analysis of emails or boundary objects, etc.).

Models and modeling process analysis

The grounded theory is a constructivist approach that generate qualitative results. It is thus difficult, and kind of artificial, to quantitatively measure such a process. Similarly, quantitatively measuring a model that is qualitative is not easy nor straightforward.

When presenting our quantitative measuring variables, we detailed implications linking the requirement and its indicator. Their converse are, however, not always fully true, what makes these two propositions not equivalent. How to measure models and modeling techniques is thus a topic to further explore.

As for the external validity of our models, we mentioned that we did not gather enough data on external projects. As mentioned above, comparing a model with real case projects is not straightforward. It is also resources consuming, and require access to numerous data. This point is, however, crucial and is the objective of future work.

Duplicability of the modeling process

As part of the grounded theory approach, our modeling process is constituted of multiple iterations with feedback corrections. It is not a straightforward process, but rather subjective — what makes it hardly computable. Although subjectivity does not mean inaccuracy, such a modeling process relies on investigators skills. This makes our the modeling process we described hardly identically duplicable.

However, as observed through the measuring of the reliability of our modeling process, our modeling technique is yet repeatable.

iii Feedback on H2

The research question addressed in this study is: *How to model the open-design process, in the development of tangible products?* The second hypothesis we put forward to answer it is: *Using a grounded theory-based approach enables the construction of models of the designing process for a given type of open-design practices.*

As detailed in this chapter, the grounded theory based modeling technique we developed enabled us to construct two models of the open-design phenomenon: one about projects' stakeholders and their interactions, another about designing activities and their arrangement. We used statistical techniques to validate both the models and their constructing process. We were able to infer the internal validity of our models, as well as the fair robustness and the reliability of their constructing process. However, we had not enough resources to properly measure our models' external validity.

Hence, *we consider our second hypothesis H2 as not completely validated.*

Synthesis

The question addressed in this research is *how to model the open-design process, in the development of tangible products?*

To answer this question, we first put forward the following hypothesis: *A systematic search and review of scientific literature enables the formalization of a typology of open-design practices.* To test this hypothesis, we conducted a systematic search and review based on 624 entries, results of our query in the *Scopus* database. This review enabled us to present quantitative insights on current findings about open-design. The latter appears as an emerging but growing topic. However, research thereabout is fragmented. This review also enabled us to develop a typology of open-design practices, which distinguishes three main sets of practices gathered under the term *open-design*. These types are related to the status of stakeholders in open-design projects and to the one of their intended end-users. They are named *DIY*, *meta-design*, and *industrial ecosystem*. Based on results of this first experiment, we consider H1 as validated.

We also put forward a second hypothesis: *Using a grounded theory-based approach enables the construction of models of the designing process for a given type of open-design practices.* To test this hypothesis, we developed a grounded theory based approach for modeling the open-design process, and implemented it. Our modeling technique is based on semi-directive interviews of 11 open-design projects' leaders, who took part in the *PoC21* innovation camp. Transcripts of these interviews are coded and abstracted in order to construct descriptive models rooted on facts. We constructed two models: the first one describes stakeholders of the designing process and their interactions, the second presents activities they carry out. In a second phase, we tested models obtained, as well as our modeling method, via statistical analyses. Our models appeared internally validated. However, we were not able to measure their external validity. As for the modeling methods, we consider it to be reliable and fairly robust. Therefore, we consider H2 as not completely validated.

Now, we will compare our models regarding the ones reported in the literature and detailed contribution as well as implications of our research.

5

A global model of 'do-it-yourself open-design', and other contributions

We have just presented experiments we carried out to test both hypotheses we put forward. We found that H1 is validated and H2 not completely validated. During the testing of H2, we produced two models of the open-design process. The question now is what new knowledge can be found in these models? What can be learned from them about open-design? For that, we need to review the models' results and compare them to current scientific practice. This part first presents and then analyzes a global model that summarize results obtained in the second experiment. It then details the contributions as well as the limitations of our research from both scientific and industrial points of views. For a conclusion, we will elaborate on the future work to which our study leads in Part 6.

Part 5 A global model and other contributions

Chapter 5.1
A global model of DIY open-design

In the second experiment of our study, we developed two models about two different facets of the open-design process (see Figures 4.10 and 4.11 on page 124 and on page 134, respectively). These models specifically depict one of the types of open-design we identified in the first experiment (see Section 4.2.5 on page 105): the 'DIY open-design '. Our first model describes stakeholders and the second designing activities carried out during such design projects. These models are detailed on pages 123 and 133 onward, respectively.

In this chapter, we combine both models to present a global perspective on DIY open-design. The global model thus obtained is first presented and compared over a second phase to existing models described in the literature (Chapter 5.2).

5.1.1 Global model overview

Our global model (Figure 5.1 on page 167) aims at combining results detailed in the previous Part. Indeed, both models developed in the second experiment depict different yet complementary aspects of a same set of practices: the DIY open-design. The first model presents stakeholders — i.e. who are people taking part in such projects? — and the second details designing activities — i.e. what is done in such projects?

As these aspects complement one another, we present them combined in a two dimensional space, where each aspect is represented via one axis: horizontal for the series of designing activities, vertical for the stakeholders' layers. We can thus answer the question '*who* does *what*?'

Moreover, we also represent the flow of information between stakeholders' layers and designing activities. The main flow of information is highlighted using dark arrows, and feedback using lighter ones. We also depicted boundary objects used, and layers they are broadcast to. Formalized boundary objects are represented via bullets on the dark arrows. If a boundary object is broadcast to (or comes from) multiple layers, a bullet is set in each relevant layer. Note that this does not imply different type of media for broadcasting this information.

5.1.2 Global model detailing

To detail our global model, we chose to present it chronologically, that is in the order in which activities take place. Observations made about previous models remain valid here: the order in which activities are presented is theoretical. In the practices, this order might be disrupted, notably within the core activities. Hence, we list below each activity of the process, and detail which type of stakeholders contributes to the process, as well as to the input and output thereof.

i Define

Input

Except for the 'rest of the world' layer — which, by definition, does not interact with the project team — all stakeholders of the project community may provide information on the need.

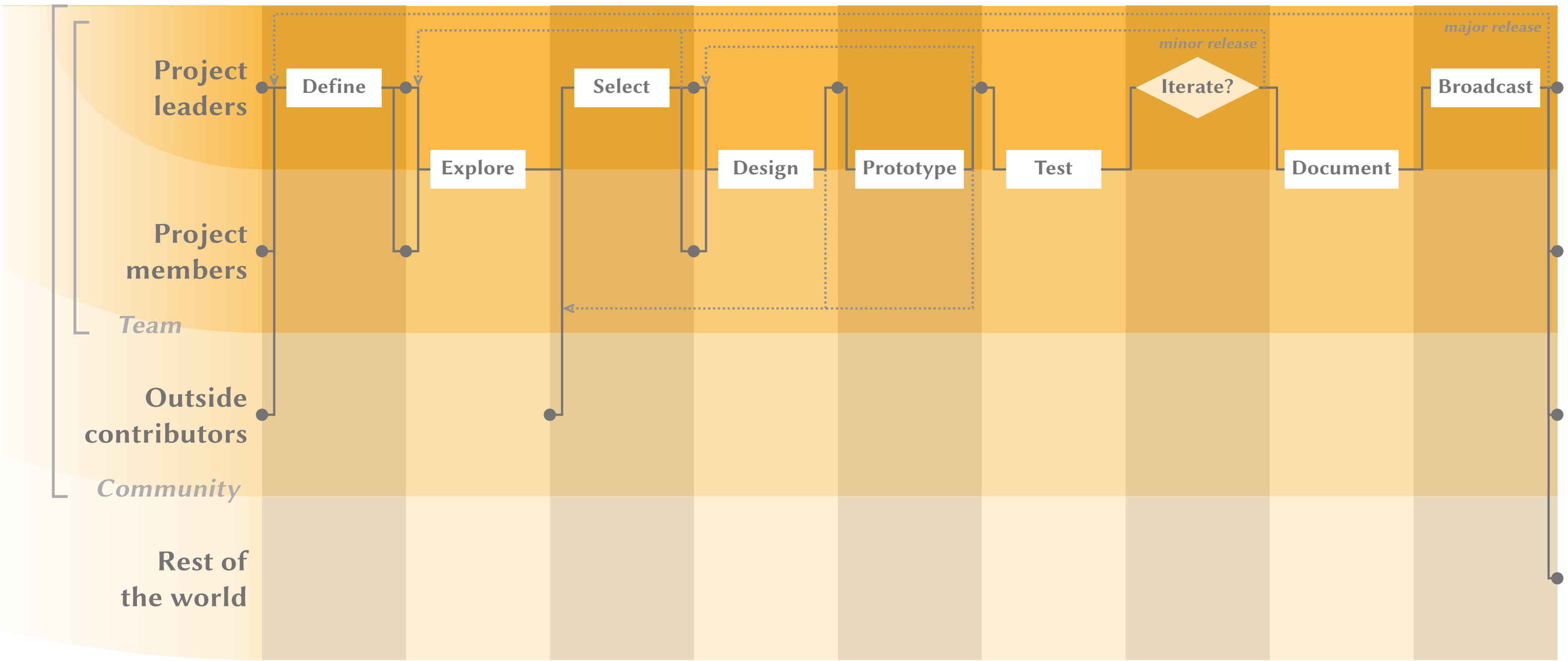
The most obvious and most frequent case is project leaders identifying a gap between existing objects and their own expectation. This is indeed the starting point of most projects. However, other stakeholders might also contribute to the need definition: project members can suggest new features, and they can (like outside contributors too) also report bugs or expected improvements.

This need definition is either informal, or formalized through a to-do-list. Depending on projects, this to-do list might be restricted to the project team, or public. This latter solution — which is frequent in F/LOSS development who use online forges — is notably used in projects in which software plays a critical role, or in projects with numerous stakeholders.

Process

The objective of the *define* phase is to select needs to be addressed during the current designing cycle among those listed, as well as constraints to be taken into consideration.

Figure 5.1
Global model



We noted that the development process is cyclic and incremental. Every identified needs might thus not be considered as requirement for the current iteration, but kept for a later one.

The *define* process is carried out exclusively by project leaders: as persons in charge of the project, they are the ones who select criteria to consider during the current iteration of the designing process. One should note that if project leaders decide not to address some of the needs suggested by project members or outside contributors, the latter might want to create spin-off projects, i.e. to 'fork' current project.

Output

At the end of the *define* phase, a set of objectives is defined. These objectives are rarely defined through measurable variables with intervals of tolerance, or through a proper bill of specification. They rather consist in a list of behaviors (less frequently, of functions) that the product is expected to fulfill at the end of the designing cycle. This list is broadcast to the whole project team. However, its formalization varies among projects. It can be not formalized at all, a simple list of behaviors, a list of functions, or in some rare cases include quantified objectives. Designing constraints are mostly not explicited.

ii Explore

Input

The input of the *explore* phase is the direct output of the previous activity (*define*). This phase can focus on the full system, or on one of its features only. (In this latter case, multiple instances of the *explore* phase are conducted, either simultaneously or in succession.) The division of the system into sub-systems (or features) is detailed in terms of components, rather than into functions to fulfill.

Process

The objective of the *explore* phase is to list the different possible solutions that could fulfill a given feature of the product.

We observed that this phase is often neglected and concatenated with the *select* one (see below). When executed, this step is based on a review of already existing systems fulfilling a function considered. This review is either based on search of mainstream systems via a web search engine for simple features (e.g. a suspension system for a human-powered vehicle), or one more specialized literature — patents, scientific articles, etc. — in the case of more complex systems (e.g. aquaponics, solar concentrator). Creativity tools other than brainstorming (such as bio-mimetism) are rarely used.

Both project leaders and project members take part in this phase. Project members take part in this step notably when they have an expertise related to the function considered. For example, one member who has an extended knowledge on one aspect might list the different alternative when other project members will not participate.

Output

Most of the time, the output of this phase is not formalized as this phase is directly followed with the next one — except in the case of complex features. Otherwise, the solution that appears to be the best (according to implicit criteria) is selected — see below.

iii Select

Input

The *select* phase is based on the set of alternatives listed in the previous phase. The choice among these alternative can also be enriched with results from the *test* phase showing that a previously chosen alternative is not satisfactory. Finally, solutions might be directly suggested by outside contributors.

Process

The *select* phase is directly linked with the *explore* one: it serves to define which alternative to chose among the ones listed in the latter phase.

However, these two phases are part of a continuum. We indeed noted that no quantifiable criteria are clearly explicited in the *define* phase. Moreover, the *explore* phase is often not formalized nor exhaustive. This makes that these both phases are often concurrent: during the exploration of alternatives, if one of them appears good enough, it is selected and the explore phase ends. If one find no successful alternative, then one stops and goes back to the explore phase. In some instance the select phase is thus the absolute evaluation of one alternative (“is this solution good enough?”), rather that a choice among several alternatives (“which one is the most appropriate?”).

The selection is thus made by project leaders via *a priori* assumptions on the considered alternative. What also impacts the *select* phase is the off-the-shelf design strategy followed by most projects: a chosen alternative might finally be rejected due to products availability, their price, etc.

Output

The output of this phase is the idea of a concept to be implemented. For example a suspension system via shock absorbers, or a linear Fresnel solar concentrator. This idea is generally not clearly formalized, but is communicated to the whole project team. It is yet this idea that later drives the design activity.

iv Design

Input

Once the idea of solution to be implemented is defined, it serves as input of the *design* phase.

Process

The objective of the *design* phase is to concretely define how to implement the selected solution.

The difference between the *select* and the *design* phases is that the former focuses on the principle of a solution (i.e. "what type of system will perform a specific function?", or "how to perform the thermal insulation of a kettel?"), when the latter focuses on the implementation thereof. This phase consists in providing a description of the to-be-realized product. Note that some projects do not formalize this step and directly 'jump' to the implementation of the selected option into the prototype (via a try-and-fail approach).

This phase is carried out by project leaders. Other project members can take part in some activities depending on their skills.

Designing activities are neither well structured, nor use specific designing techniques. Similarly, designing tools used are often pen and paper only, even if some projects use mainstream 3D modeling software as well.

Output

In some cases, the design is not formalized at all — especially when the *design* phase merges with the *prototype* one. When formalized, the design is chiefly made explicit through sketches and drawings. 3D modeling tools might also be used: some projects use them as part of the design phase, when some others digitized their drawings only when necessary for CNC machining, or for sources broadcasting.

The output in not properly broadcast among project members, it is only used as input of the *prototype* phase. It also serves as input of the *explore* one to iterate on the search for a solution, and is used in the *communicate* phase as well to document the design.

V Prototype

Input

The input of the prototype phase is simply the output of the design phase.

Process

Prototyping is a critical phase of the open-design process. The objective of this phase is to implement the designed solution. It serves two purposes. First, as designs are rarely formalized, building a prototype is the only way to test chosen and designed solution, as well as to make it real. Second, the *prototype* phase is used to manufacture one exemplar of the product, like for any regular end-user.

Just like the *explore* and the *select* phases, the both *design* and *prototype* phases are often carried out concurrently. The latter consists in the implementation of the designed solution in a prototype. These prototypes are chiefly 'protoducts', i.e. full-scale prototypes used both for testing purpose and as-is by project leaders.

The built of a prototype is limited by technology and resources available to and mastered by those manufacturing it. Two major strategies exist: updating an existing prototype, or constructing a new one. Major changes in the design requiring a new prototype to be produced mostly occur after a so-called 'major release' (see below).

Project members can take part in the construction of the prototype — notably when it requires a large work force. However, since only one prototype is realized at time, project members have to be co-located with project leaders who supervise this construction.

Output

The output of this phase is obviously the prototype. Most of the time, only one prototype is produced — except for mid-scale test in real use-conditions (see below).

vi Test

Input

The input of the test is the prototype produced or, in a few cases, the prototype of a sub-module.

Process

The objective of the *test* phase is to ensure that one or several of the listed features are fulfilled by the designed and built system. This part plays a critical role, as most design projects follow a try-and-fail approach.

We noted that requirements are not associated with measurable validation criteria. Testing aims thus as verifying that a given function is fulfilled well enough. In most cases, it consists in using the prototype and noticing if something should be improved. However, some projects planed quantifiable measurements too. They simulated a given environment (e.g. a certain wind speed for the wind-turbine, or the temperature of a heat transfer fluid) to measure a specified parameter.

Two projects also planed mid-scale real-case tests: they produced multiple prototypes (from 6 to 10) and gave them to end-users. They then gathered their feedback that served as input (*need*) for a later cycle.

Some testing can occur before the *build* phase, notably for testing sub-modules. It is, however, rare. In such cases, it can be considered as a part of the *select* phase.

Output

Results of the tests are key information for the *iterate* phase. However, tests results are rarely formalized. If so, they are later used on the *communicate* phase to be broadcast.

vii Iterate?

Input

The iterate gate is based on the tests results.

Process

The *iterate* gate is not a ‘phase’ *per se*. Its objective is to decide whether to proceed to a major or a minor release.

Indeed, we presented the open-design process as cyclic. However, we can distinguish between two types of iteration: major and minor ones. The choice that is the *iterate* step serves to chose among these two options. If the state of development of the prototype is satisfactory enough (and the development is stable) and if significant changes were made since last major release, project leaders decide to formally document it, and to broadcast this documentation. This is called a *major release*. (What also influence going for a major release might be a dead-line — i.e. a new version that needs to be documented, for an event for example.) Otherwise, test information are made available to project team only. This is called a *minor release*: design data remain internal to the project team. Both choices eventually end up with a new cycle starting. The difference lies in the time spent in the documentation, and the intended audience thereof.

Project leaders might also prefer not to start a new cycle, but rather go back to a certain phase of the development process. In this case, internal feedback loops are used instead.

Output

In the case of a minor release, design files (i.e. plans of the product) are made available to the project team only. They are not properly formatted nor broadcast.

At the opposite, for major releases, design data are use as input of the *document* phase.

viii Document

Input

All design data (sketches, CAD files, etc.), as well as other documents (pictures, videos, tests results, end-users feedbacks, etc.) are used as input of the *document* phase.

Process

The objective of this phase is to formalize a stabilized version of the design and to enrich the plan in order to facilitate the later (re)use of the project by others. For that, building instructions, notice, and other information are added to the plan of the product.

The whole project team take part in this process. As some tasks (e.g. documentation writing) are easily outsourced and executed remotely, and little skills are necessary, it makes easier for project members to participate.

As these tasks take time and are critical, the participation of project members is then fostered.

Output

The output is directly passed to the *broadcast* phase and is then not formalized.

ix Broadcast

Input

This phase directly comes after the *document* phase. Its input is then all the design documentation.

Process

The *broadcast* phase is the most distinctive compared to traditional processes. Its objective is to formalize and broadcast the *plan*, i.e. the design of the product. The goal is to make it widely accessible, so that future end-users can take over the design and potentially manufacture their own version of it. Broadcasting serves also to advertise the project and thus gain traction and contributors.

All documented information is put at disposal of the greatest number, through a dedicated website or using specialized platforms.

Output

The targeted audience is as wide as possible, and information is thus publicly released, even outside project community boundaries.

It consists of CAD files, building instructions, pictures, videos, descriptions, explanations, bills of tools and materials, budgets, etc. All information gathered during the designing process and worth it for a potential future user.

Chapter 5.2
Model analysis

Once our global model detailed, we now analyze its singularity as well as its similarity with models already described in the literature. For this, we split our analysis according to the five characteristics of a design project (see Figure 2.5 on page 38). We notably compare characteristics of our model of the DIY open-design process with the ones of the other types of design related to open-design we presented in Section 2.4.3.

5.2.1 Gap

The gap is the input of the designing process. The perception of a gap is what triggers a design project.

i Characteristics shared with other existing models

As in any other type of design we listed, the nature of the gap does not change in open-design projects. It remains the difference between current situation and a preferred one, as defined by Simon (1996). In Section 2.4.3, we indeed noted that the openness of a design project is not assessed according to the gap, as the latter is independent of the design project. (We consider refining the definition of the gap as an activity that is part of the designing process itself, rather than an update of the gap.)

Moreover, as noted by Balka et al. (2009), products impacted by open-design do not significantly differ from the ones developed traditionally in companies: products of "all degrees of complexity and innovativeness" are indeed developed within the open-design approach (ibid.). Due to criteria used by PoC21 team to select projects studied, the range of products developed we observed was nevertheless narrowed down. We yet observed purely mechanical products of a low (kits for urban agriculture) and medium complexity (a human-powered tractor), as well as mechatronical (solar tracking thermal concentrator) and electronical (energy production and consumption monitoring devices) products.

ii Distinctive characteristics

However, a notable difference is that projects leaders of DIY open-design projects are chiefly directly affected by the gap, as the contrary of most traditional design project where the increase of designer's empathy with end-users is a critical issue. Indeed, in open-design, project leaders are voluntary and thus tend to address problems they are concerned with. This is similar to amateur design (the Latin root of this word, *amator*, indeed comes from the verb *amare* meaning *to love*), where those engaging in designing activities are doing so in a pastime, i.e. because they like it (Atkinson, 2010).

Project members' motivation are diverse (see below). In our study, we received direct feedback from project leaders only, but these also recall motivations for other members of the project community. Their motivations make open-design singular, compared to traditional designing projects where the main incentive is financial (i.e. working on a project). However, we should note that these motivations are shared in other types of projects:

- recognition and exposure in the case of downloadable design (Avital, 2011; de Mul, 2016);
- altruism, or taking part in project working for the common good, as for some participants of F/LOSS projects (Baytiyeh and Pfaffman, 2010);
- taking part in the solving of a gap one is personally affected by, as in DIY (Atkinson, 2006);
- or self economically rational interest (learning, acquiring know-how, etc) as noted by Lerner and Tirole (2002) and Ghosh (2005).

Lastly, we observed a singularity of open-design processes (that is shared with every F/LOSS design projects): the existence of spin-off projects, i.e. a "fork" in the designing process (Kogut and Metiu, 2001). This principle is similar with the selling of intellectual property outside the borders of the company as it is the case in open-innovation (Bogers and West, 2010; Chesbrough and Appleyard, 2007; Henkel et al., 2014). The difference with the latter is that there is neither any financial nor contractual agreement between the source of information and those who use it. We, however, sometimes observe voluntary reciprocity between the initial project and its spin-off, where participants of spin-off projects contributes back to the forked project.

5.2.2 Activities

Activities encompasses the different steps of the design project and the arrangement thereof.

i Characteristics shared with other existing models

Our observation of open-design projects shows no difference in the *design* process in open-design projects compared to traditional ones. The design process — which is the mental process occurring during the designing process (see Figure 2.4 on page 37) — indeed remain constituted of two major abductive phases. We note that open-design is thus 'real design', in the sense that it is an instance of a mental process that is different from science (or engineering) and art.

As for the *designing* process — which is a process one a more concrete level, related to activities undertaken (see Figure 2.4 on page 37) — we observed that major phases compiled by Howard et al. (2008) can be found in the model we developed as well: *Define* refers to both "Establishing a need" and "Analysis of task"; *Explore* and *Select* refer to the "Conceptual design" phase; and *Design*, *Prototype*, *Test* as well as *Document* and *Broadcast* are encompassed in both the "Detailed design" and the "Implementation" phases.

We thus observe that, compared to other designing types, open-design share the same reasoning principle and the same set of activities.

ii Distinctive characteristics

However, the arrangement of these activities differ from most taught methods listed by Tomiyama, Gu, et al. (2009).

Indeed, we observed that activities inside a minor release (from *Explore* to *Test*) form a continuum instead of being well defined with clearly defined and well structured interfaces. This contrast with procedural methods for designing such as the one described by Pahl et al. (2007a) where boundary objects are well defined between two activities. Even in concurrent approaches, where activities overlap, phases are well defined as well (Yazdani and Holmes, 1999).

Another specifics is the existence of two main feedback loops: the major and the minor release. In cyclic processes, the designing process is iterated entirely (Wynn and Clarkson, 2005). There are obviously internal feedback loops during the designing process (in both cyclic and linear model). However, no one is predominant — as it is the case for the minor release in our model. A special feature of open-design is thus the *iterate?* gate that leads to either a major or a minor release.

Finally, a very distinctive activity in the open-design process in the prevailing of the rich documenting and broadcast of sources at the end of the process. The plan is hence made up of much more information that simple

CAD files or drawings of the object.

5.2.3 Stakeholders

Stakeholders are persons taking part in the designing process. Because types of open-design we defined are related to those who take part in the designing process (see Table 4.5 on page 105), specifics of open-design listed below are obviously relevant for the DIY type of open-design only.

i Characteristics shared with other existing models

We observed that when they are no trained designers, most project leaders have an engineering or scientific background.

In F/LOSS designing processes with decentralized and loose coordination, one observe behaviors similar to stigmergy,[1] as it is the case in construction work (Christensen, 2013). Stigmergy is a cooperation of stakeholders who are not coordinated towards a common objective, but where "the individual labour of each [stakeholder] stimulates and guides the work of its neighbour" (Grassé, 1982, quoted in Secretan, 2013, p. 66). We could have thought that it would be the case here, however, our observation do not confirm this. Indeed, in projects observed, we showed that the project community is centrally coordinated by project leaders. In the case of software, it is technically feasible and not resources consuming to *a priori* check whether an outside contribution is compatible with actual design or not. This enables to foster collaboration and submission of contributions (Weber, 2004; Leuf and Cunningham, 2001). However, it is not the case neither here nor in traditional design where we observe a centralized coordination. Indeed, implementing a potential solution is resource consuming. Moreover, we observed that sources are released at the end of the designing cycle (at the opposite of F/LOSS designing processes where broadcast source are almost continuously up-to-date — cf. Mockus et al., 2002) what makes difficult to contribute relevantly. Outside contributions in DIY open-design appear thus to be often beyond the scope or not adequate.

ii Distinctive characteristics

However, a specific feature of DIY open-design is that stakeholders are mostly amateurs, and voluntary. Mastering digital tools is also required.

[1]See for example the Matlab Online Programming Contest where participants build up on existing public answers to develop better ones (Gulley, 2001).

This then influence the type of persons getting involved in open-design projects (designers, people with scientific backgrounds, etc.). However, we acknowledge that demographic characteristics observed in interviewed project leaders are likely to be strongly influenced by the type of projects that took part in PoC21. Note that being amateur do not imply neither a lower expertise in design (Beegan and Atkinson, 2008), nor a lighter involvement in the project as shown in the case of F/LOSS development projects (Hertel et al., 2003; Crowston and Howison, 2006).

We stated above that project participants are coordinated by project leaders. However, this coordination is loose, notably because of the absence of hierarchical relationships between stakeholders. This differs from traditionally established roles in design teams (Sanders and Stappers, 2008).

The most distinctive feature is, however, the layered structure of stakeholders' roles. This structure, with participants gravitating — more or less close, according to one's involvement in the project — around a project core team, is similar to the "metropolis model" developed for crowdsourced systems (Kazman and Chen, 2009), where authors distinguish three layers in large open-source organization (namely "kernel", "periphery", and "masses") and establish comparisons with social networking systems.

5.2.4 Boundary objects

Boundary objects are formalized media for exchanging knowledge and information during and between activities — i.e. inputs and outputs of the sub-processes (Carlile, 2002).

i Characteristics shared with other existing models

Just like activities of the designing process are not intrinsically different from traditional types of design in open-design (see above), boundary objects in such projects also do not radically differ from traditional ones. The same steps require the same type of information to be transmitted from one activity to another. However, we observed a looser formalization of these boundary objects. Unlike in linear models (e.g. Pahl et al., 2007a) where required documents are specified at the end of each phase, the formalization is more often implicit in the open-design projects we observed. This resemble characteristics of amateur or DIY design. We hence would not expect to observe such behavior in other types of open-design such as in the 'industrial ecosystem' open-design.

We highlighted the preeminence of feedback loops in the model we developed. Despite the singularity of the importance of the minor release loop in DIY open-design, these feedback loops — that is, using results information or the output of a later phase as input for a former one — exist in other models, even linear ones. This is thus no specifics of open-design, albeit we underlined above that the continuum of activities (with potential back and forth jumps between phases) is specific to DIY open-design.

ii Distinctive characteristics

The distinctive characteristic of open-source designing processes is the broadcast of boundary objects outside of the designing team and the project community (Harhoff et al., 2003). This is to observe in the open-design models we developed as well. In addition, we detailed different layers of stakeholders — which are relative to their involvement in the project — and how boundary objects are broadcast to one or several levels at time. We can also observe that using boundary objects coming from outside the designing team resemble principles of open-innovation (Chesbrough, 2003b). The difference in open-design projects lies in the *free* use of this information (i.e. it is not potentially regulated by Non-disclosure Agreements).

The nature of boundary objects resemble the one of traditional designing processes, albeit their looser formalization tends to let users use less technical data. For example, most projects use mainstream 3D-modeling software only — such as SketchUp. Similarly, the bill of requirement is sometimes a simple itemization of expected behaviors of the final system.

However, we also observe new types of boundary objects, notably used in the plan: video, drawings, notices, etc. A couple of projects also emphasized on ‘teaching material’, that is, providing end-users sufficient knowledge on the system to understand its underlying principles (see for example principles of aquaponics or of the oxidization and preservation of the various type of food in project Biceps Cultivatus).

5.2.5 Plan

The plan is the deliverable of the designing process, i.e. its output. It is what is broadcast to all stakeholders’ layers and serve as input of the manufacturing process.

i Characteristics shared with other existing models

As in any design project, the output of the process is a plan, that is a definition of the to-be-realized product. It contains the definition and description of the product, enabling its later manufacturing (Cross, 2000; Ulrich, 2011). The outcomes of open-design processes are thus intrinsically different from the ones of traditional designing processes. However, as we detail below, the plan differs not in terms of intent but of content.

ii Distinctive characteristics

Beside the fact that the plan is broadcast outside the designing team — and thus intended and designed accordingly — as we noted above, we observed that it can be constituted of specific types of documents. Indeed, open-design projects are intended for the greatest number. Moreover, the development team aim to help end-users to be acquainted with the product (so that they have, in practice, the freedom to study and modify the system). Sources of design thus include notices and detailed explanations of the working principles of the underlying mechanism. This differ for example from downloadable design where most platforms provide CAD files only (de Mul, 2016).

Another difference is the existence of detailed building instructions. This serve to help end-users manufacture their own products — as there is no point in broadcasting a product definition that no one is able to realize. All this information is compiled into documentation that is broadcast along with the proper product definition.

We can also highlight the fact that we always observed the production of a full scaled prototype during the designing process. This prototype (or 'protoduct', or 'proof of concept') is not properly speaking broadcast, but plays a central role in the development of all documentation.

Chapter 5.3
Contributions of this study

In the previous chapter, we presented our global model of DIY open-design and then compared it with existing models. This allow us for now highlighting contributions of the study reported in this thesis.

5.3.1 A definition of open-design, and its mapping regarding related forms of designing

Our first contribution is the definition of *open-design* we coined (see on page 60). This definition goes together with a mapping of this notion regarding related forms of designing practices described in the literature (see notably Figure 2.8 on page 57).

Due to the bottom-up and decentralized nature of open-design, multiple terms are indeed used by practitioners to refer to their practices. One must also note that as open design is rooted in multiple approaches (F/LOSS as well as collaborative design, crowdsourcing, fab labs, etc. — see Section 1.3.1 on page 17). Thus, points of view are multiple and no one is acknowledged sufficient legitimacy to set a clear definition of the types of practices we referred to (unlike, for example, the FSF that is considered by practitioners as representative and legitimate to define what is *free software*).

As for the scientific community, we highlighted that the phenomenon we refer to is recent and emerging in the literature (see Figure 4.3 on page 91). We could not identify a unified global community studying this topic, and there is no consensus among academia on a definition — what leads to overlapping concepts, such as open-design and open-source innovation (see Section 2.4.4 on page 60).

Our definition — based on an analysis of existing types of designing practices — thus aims to serve as a basis for a more identifiable set of research on this promising phenomenon that is open-design. It is primarily intended for researchers, but is destined to practitioners for democratization purpose as well.

5.3.2 A typology of open-design

Our second contribution is the typology of open-design we constructed in our first experiment (see Chapter 4.2 on page 87).

This typology was defined based on a systematic search and review of the scientific literature related to the keyword `"open design"`. It enabled us to distinguish three types of open-design (see Table 4.5 on page 105). Each type shares similarities with the two others, but also possesses its own singularity. We highlighted that these types are related to the status of stakeholders taking part in the designing process ('private individuals' or 'companies'), as well as the one the design is dedicated to (idem). The 'Do-It Yourself', 'meta-design', and 'industrial ecosystem' types of open-design are then related to C2C, B2C, and B2B relationships, respectively.

This typology serves to better understand the diversity of practices gathered under the term *open-design*, and aims to complete the definition of open-design we coined by delimiting coherent sets of homogeneous practices. It is intended both for practitioners — in order to provide an overview of practices and highlight the interest of open-design in B2C or B2B contexts — and for researchers — again, for defining more homogeneous sets of practices and thus enable them to develop more accurate analyses as well as more relevant tools and methods for practitioners.

5.3.3 Models of the open-design process

Our third contribution is triple. It is constituted of both models of DIY open-design we constructed in the second experiment (see Chapter 4.3 on page 113) and of the global model we detailed in Chapter 5.1 on page 165.

First two models depict two different aspects of the designing processe in the context of the DIY open-design: activities carried out and their arrangement, and stakeholders taking part in this process. The third model is a synthesis of the two previous ones. It also enables to highlight flows of information and boundary objects between activities and across stakeholders layers. We also analyzed the singularity of this latter model, compared to models described in the scientific literature.

Going with these models together, we also highlight as a contribution the method we carried out for constructing these models (see Section 4.3.1 on page 114). This method, based on the grounded theory approach, is a practice-oriented bottom-up method for creating models of certain facets of a designing process. It appeared relevant to provide insights without *a priori* about an emerging phenomenon that seems different from already modeled practices.

These models are first intended to researchers, just like the methods we used. They should be used as a basis for further research on open-design, in order to develop and provide practitioners with relevant methods and tools. It should help them make the most out of this new approach to design. Our modeling method could also be duplicated for modeling other aspects of the designing process, or other types of design (such as the ‘meta-design’ and the ‘industrial ecosystems’ types of open-design). Our models are also intended to practitioners, in order to help them better understand their unaware practice and develop a reflexive approach about it.

6

Conclusion and future work

In previous parts, we presented the research conducted during our PhD. We now aim to close this thesis with a brief recap of the major points of our study. We will also list challenges that have now risen by the result of this work and that we consider accurate and relevant for future research.

Part 6 Conclusion and future work

Chapter 6.1
Summary

This study addressed the question *how to model the open-design process, in the development of tangible products?* It falls within the framework of the science of design, which aims at understanding and improving designing processes through the development of tools and methods for practitioners. Indeed, improving designing processes is essential, as it helps to create more relevant products that better meet end-users needs. Ultimately, this positively impacts companies' economic success. To improve designing processes, the science of design formalizes actual practices into descriptive models. These models serve to later develop prescriptive ones, as well as related methods and tools dedicated to practitioners. As practices differ from one approach of design to another, specific models are required for each approach in order to develop relevant support.

Open-design corresponds to the application of the open-approach to the process of designing tangible products. The open-approach is rooted in free software, a movement that arose in the software industry in the late 1970s. It aimed to grant to any end-user the freedom to run, modify, and broadcast the source-code of a software. These characteristics led to notable change in the designing process of such software: new stakeholders took part to it, new forms of collaboration arose, etc. These changes led to industrial successes. With the digitalization of the designing process and the democratization of product development, designing tangible products is now impacted by the open-approach — it is the open-design phenomenon.

The open-design process shares similar characteristics with the F/LOSS designing process. We thus expected similar benefits. However, the intrinsic difference between software and hardware (i.e. the fact that atoms cannot be duplicated at no cost and sent instantaneously across the globe — unlike bits) makes difficult to duplicate F/LOSS best practices into the designing of tangible products. Similarly, specific features of open-design makes it appear also different from traditional designing processes for tangible products. Little knowledge is yet formalized in the scientific literature about open-design. Hence the need for a descriptive model of the open-design process, in

order to later develop dedicated tools and methods that will help practitioners to make the most of this new approach to design.

This led us to the research question we addressed in our research: *How to model the open-design process, in the development of tangible products?*

To be relevant, a model must summarize a homogeneous set of practices. However, open-design appears as an umbrella term that encompasses a wide variety of practices. Our first objective was thus to refine our understanding of open-design by outlining the different sets of practices it gathers. The first hypothesis we put forward (H1) was then: *A systematic search and review of scientific literature enables the formalization of a typology of open-design practices.* To test this hypothesis, we conducted a systematic search and review of 624 entries indexed in the *Scopus* database (see Chapter 4.2 on page 87). We first removed false positives and categorized remaining entries according to their form and content (the type of research paper it is, the type of products it refers to, and the type of openness it describes). We then analyzed these meta-data to obtain quantitative insights on research about open-design. We also read the papers and developed a typology of open-design practices.

Once we had defined homogeneous sets of practices, our second objective was to model the designing process of one of these sets. As the open-design process appears singular and little knowledge about it has already been formalized, traditional modeling methods seemed inadequate in such context. At the contrary, the grounded theory is intended to construct models rooted on raw data, without *a priori* about existing theories. It had yet not been used for modeling designing processes. The second hypothesis we put forward (H2) was then: *Using a grounded theory-based approach enables the construction of models of the designing process for a given type of open-design practices.* To test this hypothesis, we interviewed project leaders of 11 projects that took part in the five-weeks long *PoC21* innovation camp (see Chapter 4.3 on page 113). These projects were all open-design projects and represented a variety of sectors: a pedal powered tractor for small and mid-sized farms, a household energy monitoring system, a bio-inspired energy-efficient kettle, etc. We then systematically analyzed interviews transcriptions via a grounded theory based approach: we divided transcripts into 1056 segments (each one representing a 'semantic unit'), and grouped them into codes, concepts, and then categories. Based on categories, we constructed two models of the open-design process.

Chapter 6.2
Conclusion

Through our first experiment, H1 appeared validated. Via the analysis of the literature, we depicted open-design as a recent but growing phenomenon (see Section 4.2.3 on page 94). However, research thereabout is circumscribed and not yet mature. Open-design has only been studied on a small scale and not directly nor globally; moreover its adoption in the industry remains limited. In the typology of open-design practices we formalized (see Section 4.2.5 on page 105), we identified three major types: *Do-it-yourself* corresponds to bottom-up initiatives, where end-users join efforts to develop products they care about. (This type of open-design is the one we modeled in the second experiment). *Meta-design* corresponds to systems developed by designers for helping end-users to develop their own products. It consists in creating a favorable environment and provides support therefor. *Industrial ecosystems* correspond to private or corporate entities that open up their product designs and processes in order to develop an efficient and fair ecosystem. It is acknowledged as the purest form of open-design by some authors.

In our second experiment, we constructed two models of the 'DIY open-design ' process. The first model focuses on stakeholders taking part in this process (Figure 4.10 on page 124). We identified four 'layers' of stakeholders organized concentrically. The core is constituted with a few project leaders who coordinate the project. Around them gravitate project members, and further, outside contributors. These stakeholders take part occasionally in activities of the designing process. The difference between them is that the former was coordinated by projects leaders, when the latter simply provides input to the project. Lastly, the rest of the world does not interact with the project, yet can access the design data (in order, for example, to manufacture their own product themselves). End-users of the product are found in all the different layers.

The second model explored the activities of the designing process, and their arrangement (Figure 4.11 on page 134). In this model, we found major steps of traditional designing processes described in the literature. The singularity of the model notably lies in the last phase that is the broadcasting of design sources. Indeed, unlike traditional processes where plans of the product are kept internal and sent to relevant stakeholders, we observed that sources of the design are available to anyone, freely. Moreover, project leaders promote their designs, in order to make the project community grow.

Once we had constructed these two models, we evaluated their internal and external validity, as well as the robustness and the reliability of our modeling method, via statistical analyzes. We found our models internally valid, and the modeling method reliable and fairly robust. However, we were not able to properly test the external validity of our models due to the lack of another project to compare with our model. Thus, our second hypothesis, H2, appeared not completely validated.

Finally, we combined both previous models in order to provide a global perspective on the 'DIY open-design ' process (Figure 5.1 on page 167). This model details the different activities carried out, which stakeholders take part in it, as well as the flow of boundary objects and who they are shared with. As stated above, it shows that the flow of activities resembles the one of traditional models. Frequent and informal jumps from one activity to another (forwards or backwards) are highlighted by the low formalization of boundary objects and multiple feedback loops. However, this singularity is better highlighted in the description of these activities that can be found in Section 4.3.3. Taking contributions coming from the project team into consideration is also specific to open-design processes, which is just like the final broadcast of the source of design to the different layers.

This study is among the first to investigate the open-design process from the perspective of the science of design. We presented here an original typology of open-design practices. We also modeled the designing process via a singular method, which we validated through statistical analyses.

Chapter 6.3
Future work

The topic of this thesis could be further investigated. We now list an agenda for future research on open-design.

A first objective would focus on our modeling method. Indeed, the external validity of models still need to be formally tested. This modeling method should be further developed, notably to ensure its duplicability. One should also compare it with other modeling methods.

A second objective would focus on descriptive models of open-design. n this study, we modeled only one of the types of open-design practices we identified in the first experiment. It would be beneficial to model the other types as well: this should enable better understanding, and thus foster their development. Dedicated support (methods, tools) could also be specifically developed to make the most of them.

A third objective would focus on prescriptive models of open-design and related support. An objective of descriptive models of designing processes is to help researchers to later develop prescriptive models and related models and tools. This movement (first bottom-up, and then top-down) highlights the applied nature of the science of design. Beyond extending mankind's knowledge *per se*, its objective is to support and improve practitioners' processes, in order to increase quality and relevance of designed products.

Back matter

Back matter

References

A

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Supplementary material for the first experimentation

Table A.1
Number of entries per author

Entries per author	Number of authors	Author names
4	1	Raasch C.
3	6	Balka K.; Baurley S.; Herstatt C.; Pearce J.M.; Phillips R.; Silve S.
2	10	Barber P.R.; Cangiano S.; Edgar R.; Fornari D.; Goossens R.; Lash A.E.; Rowley M.I.; Scholz A.; Tullis I.D.C.; Vojnovic B.
1	275	…
	292	

Table A.2
Number of entries per journal

Entries per journal	Number of journals	Journal Names
6	1	Design Journal
4	1	Lecture Notes in Computer Science
2	7	Advanced Material Research; Nucleic Acids Research; Proc. - IEEE Military Communications Conf. MILCOM; Proc. of the Asia and South Pacific Design Automation Conf., ASP-DAC; Proc. of the ASME Design Eng. Tech. Conf.; Proc. of the Int. Workshop on Rapid System Prototyping; NULL
1	82	…
	91	

Table A.3
Number of entries per journal's keyword

Entries per journal's keyword	Number of keyword	Keywords
20	1	design
14	1	computer software
12	1	open systems
11	1	open source software
10	2	computer aided design; computer simulation
8	2	manufacture; open sources
7	2	hardware; product design
6	3	article; computer architecture; computer operating systems
5	5	database systems; design platform; embedded systems; open-source hardwares; technology
<5	878	...
	896	

Table A.4
Number of entries per author's keyword

Entries per authors' keyword	Number of keyword	Keywords
31	1	open design
7	1	open source
6	1	open innovation
4	2	co-design; open source software
3	3	assistive technology; collaboration; open hardware
2	18	android; appropriate technology; beekeeping; citizen science; co-creation; collaborative design; components; crowdsourcing; cubesat; design; design education; methodology; open source hardware; participatory design; performance; software framework; sustainable development; wiki
1	265	...
	291	

Supplementary material for the second experimentation

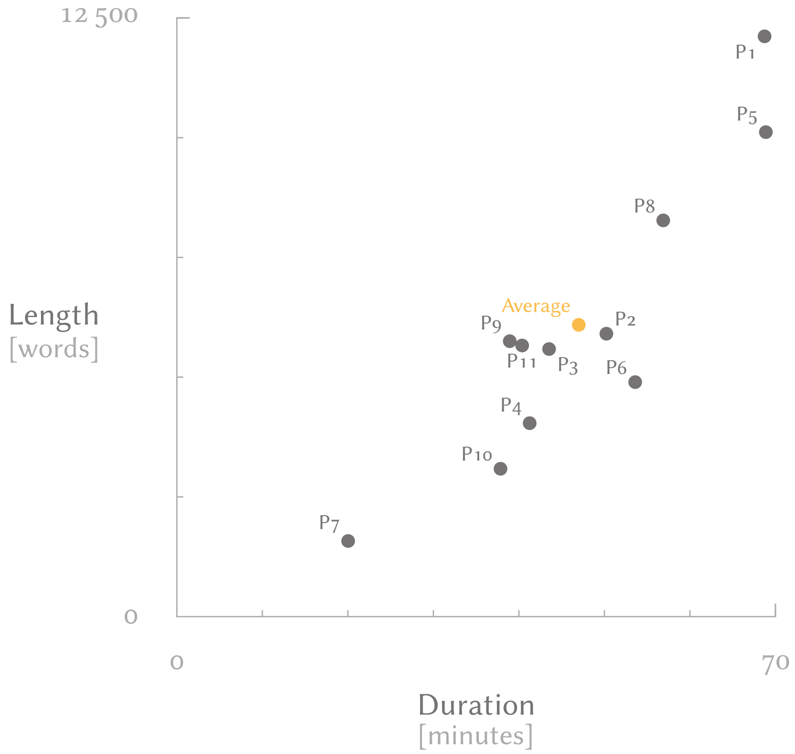

Figure A.1
Interviews' length (in minutes of recording) and duration (in number of transcribed words).
P1 *to* P11 *correspond to one project (hence one interview) each. For confidentiality reasons, we anonymized results.*

Table A.5

Coordinates of projects' barycenter and related values test on most representative eigenvectors of the vector space constructed using segments cited in the description of the stakeholders' model.

Reading example: The eigenvector 2 explains 8.418% of the total variance among cited segments' coordinates in the vector space. On this eigenvector, the coordinate of the barycenter of segments belonging to the project SolarOSE *is -0.069. This coordinate is not significantly different from the origin, as related value test equals -0.354. Statistically significant value test are highlighted. The top part of the table recall the significance of each eigenvector, indicating the percentage of variance among segments' coordinate it explains.*

Eigenvector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
% of variance	9.124	8.418	7.785	6.581	6.531	6.410	5.847	5.453	5.023
Cumulative % of variance	9.124	17.54	25.33	31.91	38.44	44.85	50.70	56.15	61.17
MyFood	-0.322	0.129	-0.352	-0.393	-0.117	-0.222	-0.168	-0.059	-0.146
	-1.217	0.489	-1.331	-1.487	-0.443	-0.839	-0.634	-0.223	-0.553
Showerloop	0.326	0.368	-0.286	0.036	-0.031	0.079	-0.292	-0.043	-0.094
	1.124	1.270	-0.987	0.125	-0.107	0.273	-1.007	-0.147	-0.326
SolarOSE	-0.309	-0.069	-0.175	0.104	-0.037	-0.216	0.151	-0.163	-0.106
	-1.581	-0.354	-0.898	0.533	-0.188	-1.106	0.772	-0.835	-0.541
OEM	-0.244	-0.208	-0.131	-0.014	-0.183	0.005	-0.095	0.560	-0.020
	-1.111	-0.947	-0.597	-0.065	-0.831	0.021	-0.431	2.549	-0.090
Nautiles	-0.214	0.135	0.928	-0.346	-0.201	0.071	0.218	-0.067	0.434
	-0.703	0.443	3.041	-1.135	-0.658	0.232	0.715	-0.221	1.422
VeloM2	0.483	-0.108	-0.008	0.247	-0.290	0.732	-0.034	-0.267	-0.077
	1.828	-0.407	-0.032	0.933	-1.099	2.768	-0.130	-1.010	-0.293
Aker	-0.029	0.634	-0.386	0.257	0.323	0.188	-0.316	0.029	0.004
	-0.073	1.583	-0.965	0.641	0.806	0.469	-0.790	0.072	0.009
Windturbine	-0.291	-0.388	0.032	0.387	0.770	0.084	0.433	-0.242	-0.190
	-0.954	-1.273	0.104	1.267	2.523	0.276	1.420	-0.791	-0.623
Biceps-Cultivatus	0.723	-0.127	-0.050	0.343	0.678	-0.449	0.076	-0.049	0.813
	2.239	-0.394	-0.156	1.061	2.100	-1.391	0.234	-0.152	2.518
Sunzilla	0.051	-0.335	-0.159	-0.440	-0.117	-0.274	-0.095	-0.101	-0.059
	0.116	-0.762	-0.361	-0.999	-0.265	-0.622	-0.215	-0.230	-0.135
Bicitractor	0.265	0.166	0.535	-0.224	-0.227	-0.006	-0.040	0.138	-0.190
	1.086	0.680	2.192	-0.918	-0.931	-0.025	-0.164	0.565	-0.779

Table A.6
Coordinates of projects' barycenter and related values test on most representative eigenvectors of the vector space constructed using segments cited in the description of the activities' model.
Reading example: The eigenvector 3 explains 6.796% of the total variance among cited segments' coordinates in the vector space. On this eigenvector, the coordinate of the barycenter of segments belonging to the project SolarOSE *is -0.513. This coordinate significantly differs from the origin, as related value test (-2.431) is lower than -1.96. Statistically significant value test are highlighted. The top part of the table recall the significance of each eigenvector, indicating the percentage of variance among segments' coordinate it explains.*

Eigenvector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
% of variance	9.192	7.176	6.796	6.425	6.204	5.800	5.721	5.201	5.120
Cumulative % of variance	9.192	16.37	23.16	29.59	35.79	41.59	47.31	52.51	57.63
MyFood	0.237	0.341	0.037	-0.116	0.040	0.048	-0.018	0.174	-0.124
	1.023	1.475	0.160	-0.502	0.175	0.206	-0.076	0.755	-0.534
Showerloop	0.228	0.030	-0.002	-0.247	-0.121	0.347	-0.049	-0.175	-0.163
	1.195	0.155	-0.012	-1.300	-0.637	1.824	-0.260	-0.921	-0.859
SolarOSE	0.310	-0.016	-0.513	0.065	0.170	0.035	-0.110	0.427	0.160
	1.468	-0.077	-2.431	0.307	0.805	0.168	-0.521	2.020	0.758
OEM	-0.264	-0.022	-0.204	0.225	-0.183	-0.262	0.188	-0.534	0.416
	-0.858	-0.073	-0.661	0.730	-0.595	-0.851	0.610	-1.735	1.350
Nautiles	-0.408	0.029	0.183	-0.464	-0.063	0.378	0.208	-0.045	0.253
	-1.251	0.088	0.562	-1.426	-0.192	1.160	0.639	-0.140	0.777
VeloM2	-0.060	0.045	0.006	0.164	0.191	-0.642	-0.347	-0.303	-0.113
	-0.241	0.182	0.023	0.662	0.773	-2.591	-1.400	-1.223	-0.455
Aker	0.744	-0.648	-0.189	0.361	-0.096	0.238	-0.068	0.662	0.164
	1.500	-1.308	-0.380	0.728	-0.193	0.481	-0.138	1.335	0.330
Windturbine	-0.724	0.335	0.307	0.574	-0.112	0.610	-0.024	0.005	0.335
	-3.618	1.675	1.533	2.870	-0.559	3.048	-0.121	0.027	1.676
Biceps-Cultivatus	-0.013	-0.095	0.262	-0.327	-0.170	-0.281	0.400	0.133	-0.468
	-0.065	-0.464	1.273	-1.591	-0.830	-1.365	1.948	0.645	-2.280
Sunzilla	0.142	-0.128	-0.257	-0.123	-0.052	0.138	-0.331	0.331	0.074
	0.485	-0.439	-0.878	-0.419	-0.177	0.471	-1.129	1.132	0.252
Bicitractor	0.133	-0.344	0.056	0.009	0.222	-0.458	0.049	-0.258	-0.039
	0.699	-1.808	0.292	0.050	1.169	-2.407	0.258	-1.356	-0.204

Table A.7
List of 'major codes' and associated 'concepts'

Major code	Occurence	Related concepts
leader background	31	core team, skills
product design activity	18	design process phase
product development process	18	development process
outside contributors	17	contributors
collaboration	15	human interactions
open-source	14	open
sources	13	boundary objects
design objective	13	objective, design, start
outside contribution	12	human interactions, contributors
project objective	12	objective, project
use of 3D	10	3D
initial motivation	9	start, motivation
design inputs	9	inputs, design process
boundary objects	9	boundary objects
feedbacks	9	contributors
design constraint	8	constraint, design process
leader skills	8	core team, skills
product development	7	development process
design process	7	design process
PoC activity	7	PoC
product development issue	7	development process, issue
decision making	7	design process, management
design process step	6	design process phase
iteration	6	iteration
product design process	6	design process
working alone	5	design process, contributors
project progress	5	development process, time
outside contributions	5	human interactions, contributors
start of the project	5	start, project
first prototype	5	boundary objects, prototyping
3D modeling	5	boundary objects, 3D
skills needed	4	skills
project development	4	development process

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
documenting	4	documenting, sources
collaboration tools	4	tools, human interactions
open-source issue	4	open
needed skills	4	skills
boundary object	4	boundary objects
project managment	4	management
leader role	4	core team, management
process structuring	4	development process
project process	4	development process
external contribution	4	human interactions, contributors
design activity	3	design process phase
project issue	3	project, issue
occasional contributors	3	contributors
feedback	3	human interactions
start of project	3	start, project
sources broadcasting	3	sources, open
design activities	3	design process phase
product features	3	product
project inputs	3	inputs, project
unrequested contributions	3	contributors, human interactions
core team	3	core team
project issues	3	project, issue
iterations	3	iteration
opening sources	3	sources, open
3D tools	3	3D, tools
open issue	3	open
leader involvement	3	core team
sources broadcasting plateform	3	boundary objects, human interactions
second prototype	3	prototyping
l entreprise vs le projet	3	business, development process
state of the project before PoC	3	PoC
project steps	3	development process phase
project beginning	3	project, start
area of interrest	2	project nebula

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
open-source business model issue	2	business, open
leaders relationships	2	core team, human interactions
type of product	2	product
motivation	2	motivation
process	2	development process
second iteration	2	iteration
work organization	2	management
design process activity	2	design process phase
project motivation	2	start, motivation
opening	2	na
collaboration issues	2	issue, collaboration
state of project at PoC beginning	2	PoC
relationship with contributors	2	contributors, human interactions
product development methodology	2	development process
collaboration with other open-source projects	2	collaboration
PoC outcome	2	PoC, product
defining as open-source	2	open
publishing sources	2	sources, open
core team involvment	2	core team
design sprint	2	design process phase
PoC21 issue	2	issue, PoC
documentation	2	sources, documenting
motivation for external contributors	2	motivation, contributors
leader relationships	2	core team, human interactions
CT background	2	core team, skills
core team relationship	2	core team, human interactions
3D tool	2	3D, tools
project step	2	development process phase
collaboration issue	2	collaboration
skills acquiring	2	skills
structure - organization	2	management

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
PoC issue	2	issue, PoC
design constraints	2	constraint, design process
during PoC	2	PoC
product feature	2	product
PoC added value	2	PoC
usually issues in OD projects	2	issue, open, development process
project business model	2	business
contribution	2	contribution
design sprints	2	design process phase
core team size	2	core team
current state of the project	2	development process
joining ct	2	core team
PoC objective	2	PoC
power relationships	2	human interactions
role of non-scientific contributors	2	contributors
design process progress	2	design process
leader team size	2	core team
product design	2	design
background contributors	1	contributors, skills
design location	1	geographical location
design motivation	1	motivation, design process
dows of closed-source	1	sources, issue
what have been done during PoC	1	PoC, development process
external stakeholders	1	contributors
stakeholders location	1	core team, geographical location
motivation for open	1	open, motivation
prototypes	1	prototyping
collaboration tool	1	tools, collaboration
fablabs	1	strategy, design process
leave job	1	business, core team
4th prototype	1	prototyping
task distribution	1	management
3D modelign	1	3D

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
project start	1	project, start
project constraint	1	constraint, development process
core team role	1	core team
project distinctive feature	1	PoC
issue	1	issue
material used	1	hardware
PoC issues	1	issue, PoC
sharing plateform	1	sources
product development strategy	1	development process, strategy
improvement	1	prototyping
external contributors input	1	inputs, contribution
contributors background	1	contributors, skills
design methodology	1	design process
key improvement in OD design	1	open, design process
contributors spontaneous inputs	1	contribution, inputs
issue open-source	1	open, issue
process activities	1	development process phase
open issues	1	open, issue
leader location	1	core team, geographical location
use of open-source material	1	open, hardware
project activity	1	development process phase
initial design issue	1	design, issue
difference between classical and open design	1	open, design process
contributions	1	contribution
external contributors background	1	contributors, skills
cause	1	motivation
iteration process	1	iteration
outside contribution limitation	1	contribution, issue
intent in open-design	1	open, motivation
project contributors	1	contributors

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
PoC positive points	1	PoC
product developent skills	1	development process, skills
outside contributor	1	contributors
open-design contraints	1	open, constraint
global project orientation	1	objective, contribution
open	1	open
outside contributors involvement	1	contributors
iteration duration	1	iteration, time
open-source objectif	1	open
sources shared with	1	sources
design steps	1	design process phase
open-source development skill	1	skills, development process, open
digital collaboration	1	digital, collaboration,
design requirements	1	constraint, design
design solution	1	design
core team activities	1	core team, development process
open specificities	1	open
OSS vs OSH	1	open, hardware
sources sharing platform	1	sources
upgrades	1	iteration
stakeholders participation	1	contribution
advantages of project	1	open, project
development approach	1	development process
open-souce	1	open
team fundation	1	core team
obstacle to opening sources	1	issue, open, sources
process duration	1	development process, time
acquiring new skills	1	skills
project documenting	1	sources, documenting
development cost	1	business, development process
area of interest	1	project nebula
product objective	1	product
collaborative tools	1	collaboration, tools
project duration	1	time, development process

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
contributor background	1	contributors, skills
localization	1	geographical location
update of subsystem	1	iteration
inputs	1	inputs
previous experience with open-source	1	open, skills
team involvment	1	core team
team composition	1	core team
improvements	1	skills, design process
product development activities	1	development process phase
core team PR	1	human interactions, core team
design development	1	design process
CT numbe	1	core team
type of information	1	boundary objects
process issues	1	development process, issue
desgin intentions	1	product, objective
core team join	1	contributors, core team, human interactions
acceptancy criteria	1	constraint, design process
list of requirement	1	boundary objects
PoC application	1	PoC
design sprint contributors	1	contributors, design process
iteration objective	1	iteration
hardware sources	1	sources, hardware
leader geographical location	1	core team, geographical location
external contributors	1	contributors
third prototype	1	prototyping
external requested contributors	1	contributors
team location	1	geographical location, core team
apports PoC	1	PoC
design process starting point	1	start, design process
vision of open	1	open
3D modeling tools	1	3D, tools

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
documentation objective	1	documenting
product objectives	1	product
project activities	1	development process phase
product development success criteria	1	development process
distinctive feature of hardware	1	hardware
design for user	1	design process, user
development issue	1	development process, issue
sharing sources	1	sources, open
objective 3rd prototype	1	prototyping
untried ideas	1	development process
role repartition	1	management
what does open mean	1	open
design solutions	1	design
broadcasting sources	1	sources
project	1	project
product development process activity	1	development process phase
open-source development issue	1	open, issue, development process
dealing with unmastered skills	1	skills, issue
project structuration	1	communication, digital
PoC contribution	1	PoC, contribution
design for user issue	1	design process, issue
product development activity	1	development process
open good aspect	1	product, open
modularity	1	product
sources openness	1	sources, open
PoC outcomes	1	PoC
applying to PoC	1	PoC
product development features	1	development process
leader motivation	1	core team, motivation
impact of open	1	open
design changes	1	constraint, iteration
motivation for the project	1	start, motivation
building instructions	1	sources
leaders relationship	1	core team, human interactions

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
sharing platform	1	sources
spontaneous contribution	1	contribution
business outputs	1	business
issues	1	issue
amout of contributors	1	contributors
interaction with end-users	1	human interactions, user
design main issue	1	design process, issue
strategic orientation	1	strategy, core team
financial relationship	1	business
problem solving approach	1	design process
project structuring	1	development process
criteres utilisateur	1	product
leader common points	1	core team
new prototype	1	prototyping
state at the project when applying for PoC	1	PoC, development process
development support	1	contributors, project nebula
project initiative	1	project, start
CT assets	1	core team
project spin off	1	development process, open
use of collaboration tools	1	collaboration, tools
working along	1	collaboration, management
project strategy	1	project, strategy
recrute team members	1	core team
difference between corporate and DIY projects	1	business, design process
prototyping	1	prototyping
product issue	1	issue, product
expectation for PoC	1	PoC
outside interest	1	user
about PoC	1	PoC
process improvement	1	collaboration, skills, design process
status	1	core team
expected contributions	1	contribution
skills learning	1	skills
design process steps	1	design process phase

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
product design methodology	1	design process
use of forums	1	communication, contribution
previous experience in open	1	open, skills
team structuring	1	management, core team
length of project	1	time, development process
objective of iteration	1	iteration
boundary objects at PoC	1	boundary objects, PoC
contributors contribution	1	contribution, contributors
project sources	1	sources
leader added value	1	core team
product design activities	1	design process phase
participant's opinion	1	communication, digital
communication medium	1	communication, boundary objects
design skills	1	skills
contribution managment	1	contribution, management
acquired skills	1	skills
PoC	1	PoC
integrating core team	1	core team, management
stakeholders background	1	core team, skills
relations among leaders	1	core team, human interactions
second prototype objective	1	prototyping
leader relationship	1	core team, human interactions
material sourcing	1	hardware
finding contributors	1	contribution
outside contributors background	1	contribution, skills
cross project interaction	1	collaboration
social issue	1	human interactions, issue
collaboration with other projects	1	collaboration
key issue	1	issue
used tools	1	tools
PoC experience	1	PoC
improvement for next iteration	1	iteration
project contributions	1	contribution
contributors managment	1	management, contributors

(to be continued on the next page)

(continued)

Major code	Occurence	Related concepts
leader investment	1	core team
process constraint	1	constraint, development process
collaboration between project	1	collaboration
outside contributor involvement	1	contributors
PoC21 objective	1	PoC
open-design limitation	1	open, issue

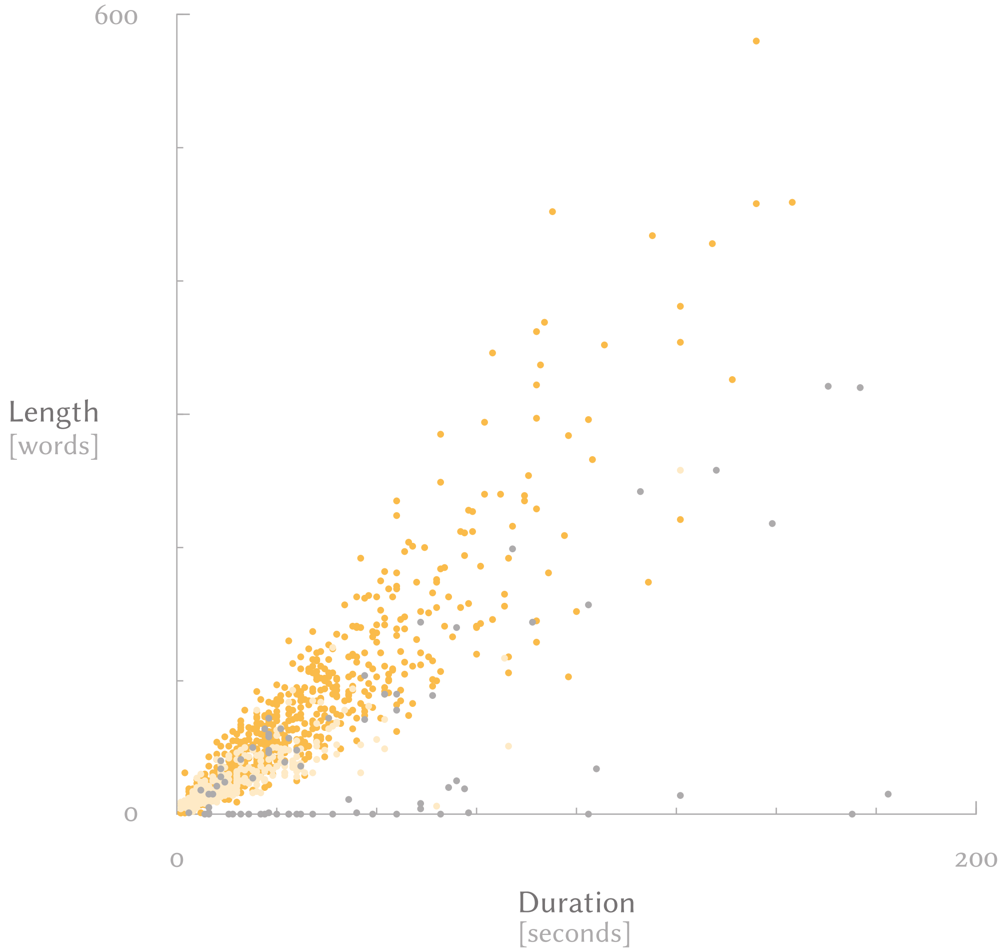

Figure A.2

Segments' duration (in seconds of recording) and length (in number of transcribed words).

Orange dots (●) represent segments corresponding to interviewee answers. Light orange ones (●) to interviewer's questions. Gray dots (●) correspond to other non-relevant segments (greetings, out-of-topic discussions, technical issues, etc.). Segments with a certain duration and no or a very few words correspond to non-relevant part of the interview that had not been transcribed fully. Note that 4 outliers are not displayed within boundaries of this graph. They are long segments constituted on non-relevant discussion between interviewer and interviewee.

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Pictures credit

FIGURE 2.2: adapted from '*Sun*' and '*Gear*' by Jean-Philippe Cabaroc⋆, '*Vector*' by Desbenoit⋆, '*Icons*' by Freepik from www.flaticon.com.

FIGURE 3.2: adapted from '*Creativeity*' by Chameleon Design⋆, '*Book Science*' by Thomas Helbig⋆, '*Question mark*' by To Uyen⋆, '*Pentagon*' and '*Hexagon*' and '*Heptagon*' by Il Capitano⋆.

FIGURE 4.1: adapted from '*Creativeity*' by Chameleon Design⋆, '*Book Science*' by Thomas Helbig⋆, '*Question mark*' by To Uyen⋆, '*Pentagon*' and '*Hexagon*' and '*Heptagon*' by Il Capitano⋆.

FIGURE 4.2: adapted from '*Newspaper*' by Anton Kovalev⋆, '*Tag*' by Shmidt Sergey⋆, '*Statistics*' by Hermine Blanquart⋆, '*R logo*' by The R Foundation (under license CC-BY-SA 4.0).

FIGURE 4.6: adapted from '*Conversation*' by Hans Draiman⋆, '*Microphone*' by Jaime Serra⋆, '*File*' by Galaxicon⋆, '*PoC21 logo*' and '*30$ turbine logo*' and '*Open Energy Monitor logo*' and '*Shoverloop logo*' by PoC 21.

FIGURE 4.7: adapted from '*File*' by Galaxicon⋆, '*Square Picture*' by Andrejs Kirma⋆.

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It was edited and set into type using pdfLaTeX,
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Open-Design

Modeling the open-design process
in the development of tangible products

Open-source revolutionized the software industry through a public, decentralized, and asynchronous development paradigm that fosters collaboration among peers. New practices and stakeholders disrupted the designing process, yet led to industrial successes. Due to the digitalization and democratization of the designing process, this approach now spreads to the development of tangible artifacts. This is open-design.
However, open-design currently appears as an umbrella term that encompasses from amateur do-it-yourself projects to sector-scale industrial collaborations. It is not clear either, how these practices relate to existing designing approaches. Finally, little knowledge about the open-design process is formalized. This impedes the development of adequate tools for helping practitioners to make the most of it.
Therefore, we investigated how to model the open-design process in the development of tangible products. First, we developed a typology of open-design practices based on a systematic search and review of the scientific literature. Then, we selected one of the types identified and modeled the different facets of the designing process (activities carried out, stakeholders involved, and boundary objects used) in this context, using a grounded theory-based approach.
Through our literature review, we mapped open-design in relation to existing designing approaches, and to coined a new definition thereof. Based on 624 papers indexed in the *Scopus* database, we identified three types of practices — do-it-yourself, meta-design, and industrial ecosystem — which are related to the status (professional or amateurs) of the processes' stakeholders and addressees. We also constructed two models of the 'do-it-yourself open-design' process using semi-directive interviews of 11 project leaders who took part in the *PoC21* innovation camp. They depict open-design as a designing process influenced by both open-source software development and amateur design. We tested the quality of our models and our modeling method via statistical analysis.
This study aims to be a cornerstone for future research on open-design by providing an overview of practices linked to this phenomenon. Our descriptive models should serve researchers for providing practitioners of open-design projects with relevant tools and methods. Our modeling method could also be applied in other contexts to formalize uninvestigated designing practices.

Étienne Boisseau PhD thesis defended on September 28, 2017

Open-Design

Modélisation du processus de conception ouverte dans le cadre du développement de produits tangibles

L'open-source a révolutionné le secteur informatique par une nouvelle approche publique, décentralisée, et asynchrone de la conception qui encourage la collaboration entre pairs. De nouveaux acteurs et pratiques ont bouleversé le processus de conception, mais aussi donné lieu à des succès industriels. Cette approche se répand aujourd'hui à la conception de produits tangibles, à cause de la numérisation et la démocratisation de ce processus — c'est la conception ouverte.

Nombre de pratiques hétérogènes sont cependant regroupées sous ce terme. Les liens avec les pratiques existantes ne sont pas non plus clairement identifiés. Enfin, peu d'informations à propos du processus de conception ont été formalisées dans la littérature scientifique. Cela freine le développement d'outils pertinents qui permettraient aux concepteurs d'exploiter pleinement les spécificités de la conception ouverte.

Ainsi, nous nous sommes intéressés à la modélisation du processus de conception ouverte, dans le cadre du développement de produits tangibles. Nous avons d'abord élaboré une typologie des pratiques via une revue systématique de la littérature. Ensuite, via une approche par théorisation ancrée, nous avons construit des modèles mettant en lumière les différentes facettes du processus de conception : phases, acteurs, représentations intermédiaires.

À travers notre état de l'art, nous avons défini et cartographié la conception ouverte et les notions connexes. Par l'étude de 624 entrées de la base de données *Scopus*, nous avons identifié trois types de pratiques : *do-it-yourself*, *meta-design*, and *industrial ecosystem*. Elles sont liées au statut (amateur ou professionnel) des concepteurs et destinataires du processus. Nous avons aussi construit deux modèles du “do-it-yourself open-design” à partir d'interviews semi-directifs de 11 participants à des projets de conception ouverte. Cette approche apparaît influencée à la fois par le logiciel libre et la conception amateur. La qualité de nos modèles et de notre modélisation a été validée par l'outil statistique.

Cette étude ambitionne d'être une référence pour de futures recherches sur la conception ouverte, en proposant un panorama détaillé des pratiques liées à ce phénomène. Nos modèles descriptifs doivent servir de point de départ pour développer des outils pertinents à l'intention des praticiens. Notre méthode de modélisation peut également être répliquée dans d'autres contextes pour formaliser des processus encore non cartographiés.

Étienne Boisseau

Thèse de doctorat soutenue le 28 septembre 2017

Liste des tableaux

Table des figures

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Annexes

Le second modèle construit est à propos des activités de ce processus. Dans ce modèle, nous retrouvons les principales étapes des processus de conception classiques décrites dans la littérature. La singularité de notre modèle réside surtout dans la dernière phase qui est la diffusion du plan. En effet, à l'inverse des processus classiques, l'aboutissement du processus de conception est ici mis à la disposition de tout un chacun.

Ces deux modèles, ainsi que notre méthode de modélisation, ont été évalués par l'outil statistique. Nous avons montré que nos modèles sont valides internement, et que notre modélisation est fiable et robuste. Néanmoins, nous n'avons pu évaluer la validité externe des modèles. Nous considérons donc notre seconde hypothèse comme non complètement validée.

Ces deux modèles ont été combinés au sein d'un troisième, plus global, qui met également en lumière les flux d'informations entre les acteurs et activités. Nous avons vu que, au-delà de la dernière phase de diffusion du plan, la singularité du processus de conception ouverte se trouve plus au niveau de chacune des activités (et la manière dont elle est réalisée), que de leur type ou agencement.

6.3 Perspectives

Nous voyons trois pistes principales pour poursuivre ces travaux. La première concerne notre méthode de modélisation du processus de conception. Nous n'avons en effet pas pu évaluer la validité externe de nos modèles. Cela serait donc une piste à explorer, tout comme la comparaison formelle de notre méthode par théorisation ancrées avec d'autres méthodes classiques. Enfin, notre méthode pourrait être développée afin de facilité sa réplicabilité dans d'autres contextes.

La seconde piste se concentre sur les modèles descriptifs de la conception ouverte. En effet, nous n'avons modélisé le processus de conception que pour l'un des types de pratiques identifiés. Il serait alors intéressant de modéliser également les autres types afin de faciliter leur appropriation par les chercheurs et les praticiens.

Enfin, la troisième piste vise le développement de modèles normatifs. En effet, au-delà d'accroître la compréhension des pratiques industrielles existantes, l'un des objectifs majeurs des sciences de la conception est d'améliorer ces pratiques par la proposition de modèles normatifs et le développement d'outils support associés. Ainsi, cette troisième piste mènerait au développement de supports pour les praticiens en se reposant sur nos modèles descriptifs.

une grande variété de secteurs : un tracteur à propulsion humaine pour fermes de petite et moyenne dimension, un système de gestion et suivi de consommation énergétique pour particuliers, une bouilloire bio-inspirée, etc. Nous avons ensuite analysé de manière systématique les retranscriptions de ces interviews à l'aide d'une démarche par théorisation ancrée. Nous avons divisé ces retranscriptions en 1056 unités sémantiques, que nous avons codées et regroupées en concepts puis en catégories. C'est à partir de ces catégories que nous avons défini deux modèles du processus de conception ouverte.

6.2 Conclusion

Via notre première expérimentation H1 apparait validée. À travers l'analyse de la littérature, nous avons présenté la conception ouverte comme un phénomène récent mais en croissance. Néanmoins, la recherche sur cette thématique reste limitée et peu mature. Ce phénomène n'a été étudié qu'à petite échelle et pas globalement. De plus, son adoption industrielle est elle aussi limitée. Dans la typologie des pratiques que nous avons formalisée, nous avons défini trois types :

Do-it-yourself qui correspond à des initiatives de terrain dans lesquelles des utilisateurs finals joignent leurs forces afin de développer des produits qui leur importent.

Meta-design qui correspond à des systèmes développés par des professionnels à l'intention de particuliers afin que ces derniers puissent eux-mêmes concevoir leurs propres produits. Cela consiste à développer des outils support à l'intention des utilisateurs finals.

Écosystèmes industriels qui correspondent à des entités privées qui ouvrent leurs produits et processus afin de favoriser l'apparition d'un écosystème efficace et juste.

Dans notre seconde expérimentation, nous avons construit deux modèles du type de pratiques *Do-it-yourself*. Le premier modèle met en avant les participants du processus de conception ouverte dans un tel contexte. Nous avons identifié quatre strates concentriques. Le cœur est composé d'une poignée d'acteurs principaux qui coordonnent le projet. Autour d'eux gravitent les membres du projet et les contributeurs extérieurs. Les participants de ces deux strates prennent part de manière occasionnelle au processus. La différence entre les deux est que les premiers sont coordonnés par les acteurs principaux. Enfin, le reste du monde ne prend pas part au processus, mais a cependant accès aux données de conception. Les utilisateurs finals du produit se trouvent dans l'ensemble des strates.

secteurs. La conception de produits tangibles ne fait pas exception.

La conception ouverte partage des caractéristiques des processus de développement de logiciels libres. Il est légitime d'attendre donc les mêmes avantages en termes de réactivité et pertinence de la solution développée, de facilité de maintenance, de traçabilité et de sécurité, etc. Néanmoins, il existe une différence intrinsèque entre ces deux approches : le caractère rival des atomes qui empêche leur partage à coût marginal non-nul. Ainsi, la transposition des bonnes pratiques du logiciel aux produits tangibles n'est pas si évidente. Pour autant, les connaissances sur la conception ouverte n'ont été que peu formalisées dans la littérature scientifique. Cela freine le développement d'outils et méthodes dédiés qui permettrait aux praticiens de tirer parti de cette approche.

Cela nous amène donc à la problématique de nos travaux : « Comment modéliser le processus de conception ouverte dans le cas du développement des produits tangibles ? »

Afin d'être pertinent, un modèle doit représenter un ensemble homogène de pratiques. Pourtant la conception ouverte apparaît comme un concept vague sous lequel est regroupé une grande diversité de pratiques. Ainsi, notre premier objectif a été d'affiner notre compréhension de ce phénomène en catégorisant ces pratiques. Notre première hypothèse a donc été : « Une revue systématique de la littérature scientifique permet de formaliser une typologie des pratiques de la conception ouverte. » Pour tester cette hypothèse, nous avons conduit une revue systématique portant sur 624 articles répondant au mot-clef « open-design » et provenant de notre requête dans la base de données *Scopus*. Nous avons écarté les faux positifs, et catégorisé les entrées restantes en fonction de leur contenu. Nous avons ensuite analysé quantitativement ces métadonnées et lu les articles afin de proposer une analyse qualitative de leur contenu, ce qui a abouti à la formulation d'une typologie des pratiques de la conception ouverte.

Après avoir défini des groupes de pratiques homogènes, notre second objectif a été de modéliser l'un de ces processus. Comme ces pratiques apparaissent singulières et qu'elles n'ont été que peu formalisées, les méthodes de modélisation classiques ne semblent pas adaptées. Par contre, l'approche par théorisation ancrée est indiquée dans de tels cas. Pour autant, elle n'a pas encore été appliquée pour modéliser des processus de conception. Ainsi, notre seconde hypothèse a été : « Utiliser une approche par théorisation ancrée permet de construire des modèles du processus de conception ouverte pour l'un des types de pratiques identifié ». Pour tester cette hypothèse, nous avons interviewé les acteurs principaux de onze projets qui ont participé au camp d'innovation PoC21. Ces projets de conception ouverte représentent

Chapitre 6
Conclusion et perspectives

Cette dernière partie a pour objective de clore cet abrégé en rappelant brièvement les principaux points marquants de notre thèse et en concluant par rapport à la problématique qui a porté nos travaux. Nous terminerons en évoquant des pistes pour des recherches futures qui semblent se dessiner à la lumière des résultats de nos recherches.

6.1 Synthèse

Cette thèse s'est intéressée à la problématique suivante : « Comment modéliser le processus de conception ouverte dans le cas du développement des produits tangibles ? ». Elle s'inscrit dans le cadre des sciences de la conception. Cette discipline cherche à comprendre et formaliser les pratiques existantes afin de, dans un second temps, proposer des modèles normatifs ainsi que leurs outils associés. L'objectif étant d'améliorer les processus de conception, afin de concevoir plus efficacement des produits répondant mieux aux besoins des utilisateurs finals, et donc, en fin de compte, d'améliorer la compétitivité des entreprises. De nombreuses approches de la conception existent. Elles diffèrent peur leurs contextes et leurs objectifs. Il est important de modéliser ces différentes approches afin de pouvoir tirer profit de leur singularité.

La conception ouverte correspond à l'application de l'approche ouverte au processus de conception de produits. C'est approche ouverte prend racine dans le mouvement du logiciel libre qui a émergé aux États-Unis à la fin des années 1970. Ce mouvement visait à garantir à chaque utilisateur d'un logiciel la liberté d'utiliser, modifier et partager celui-ci comme il le souhaite. Ces caractéristiques ont fortement impacté la manière dont ces logiciels ont été développés : de nouveaux acteurs (généralement des utilisateurs finals amateurs) ont pris part au processus de conception et des nouvelles formes de collaborations décentralisées et asynchrones ont vu le jour. Pour autant, ces changements ont donné lieu à des succès industriels dans le secteur informatique. Peu à peu, cette approche s'est répandue à de nombreux

V Plan

Le plan correspond à l'ensemble des documents décrivant de manière univoque le produit à réaliser, permettant sa fabrication ultérieure de manière autonome. Dans le cas de la conception ouverte, ces plans comprennent des fichiers 3D, mais aussi une large documentation permettant à l'utilisateur final de s'approprier le produit (procédures de fabrication et de montage, détails des dimensionnements, notices explicatives, etc.). Ce dernier point est singulier à la conception ouverte.

5.3 Apports de notre recherche

Les apports de nos travaux sont multiples. Tout d'abord, nous avons proposé une définition de la conception ouverte. Cette définition va de pair avec une cartographie des approches de la conception liée à la conception ouverte (Figure 2.5). Cette définition est à l'intention essentiellement des chercheurs. Elle doit permettre une meilleure compréhension de ce phénomène nouveau, et le développement de recherches partageant une vision commune de ce phénomène.

Ensuite, nous avons proposé une typologie des pratiques de la conception ouverte (voir Tableau 4.1). Cette typologie permet de mieux appréhender les pratiques diverses regroupées sous le terme de conception ouverte. Elle permet également aux chercheurs d'identifier des types de pratiques homogènes afin de pouvoir les modéliser et développer des outils et méthodes adaptés à chacun d'eux.

Enfin, nous proposons trois modèles du processus de conception de produit ouverte (Figures 4.6, 4.7, et 5.1). Ces modèles ont été validés internement, et la méthode utilisée pour les construire apparaît fiable et robuste. Ces modèles ont été construits à l'intention des chercheurs en sciences de la conception. Ils ont pour premier objectif d'améliorer la compréhension de ce phénomène nouveau mais en forte croissance qu'est la conception ouverte. Ces modèles doivent également, dans un second temps, servir de base pour développer des modèles normatifs de ce processus et des outils et méthodes afférents. Mais ces modèles peuvent également servir aux praticiens afin qu'ils prennent conscience des processus parfois sous-jacents et puissent améliorer leurs pratiques dans une démarche réflexive.

5.2 Analyse du modèle

i Besoin

Le besoin (plus exactement sa perception par un utilisateur final ou un concepteur) est ce qui déclenche la conception. On observe que de nombreux types de produits sont conçus de manière ouverte. Néanmoins, on distingue deux tendances : des objets simples du quotidien, et des systèmes complexes mais grand-public.

ii Activités

Le type d'activités présentes dans le processus de conception ouverte et leur arrangement sont similaires aux archétypes de processus classiques. Néanmoins la présence de deux boucles majeures de rétroaction, avec l'une donnant lieu à la formalisation et la diffusion du plan apparaît comme caractéristique de la conception ouverte. Mais c'est surtout cette dernière étape qui est singulière.

Néanmoins, la spécificité du processus de conception ouverte est plus perceptible au niveau de comment est réalisée chacune des activités que de l'agencement de celles-ci. Ce niveau de détail n'était cependant pas celui choisi pour notre modélisation.

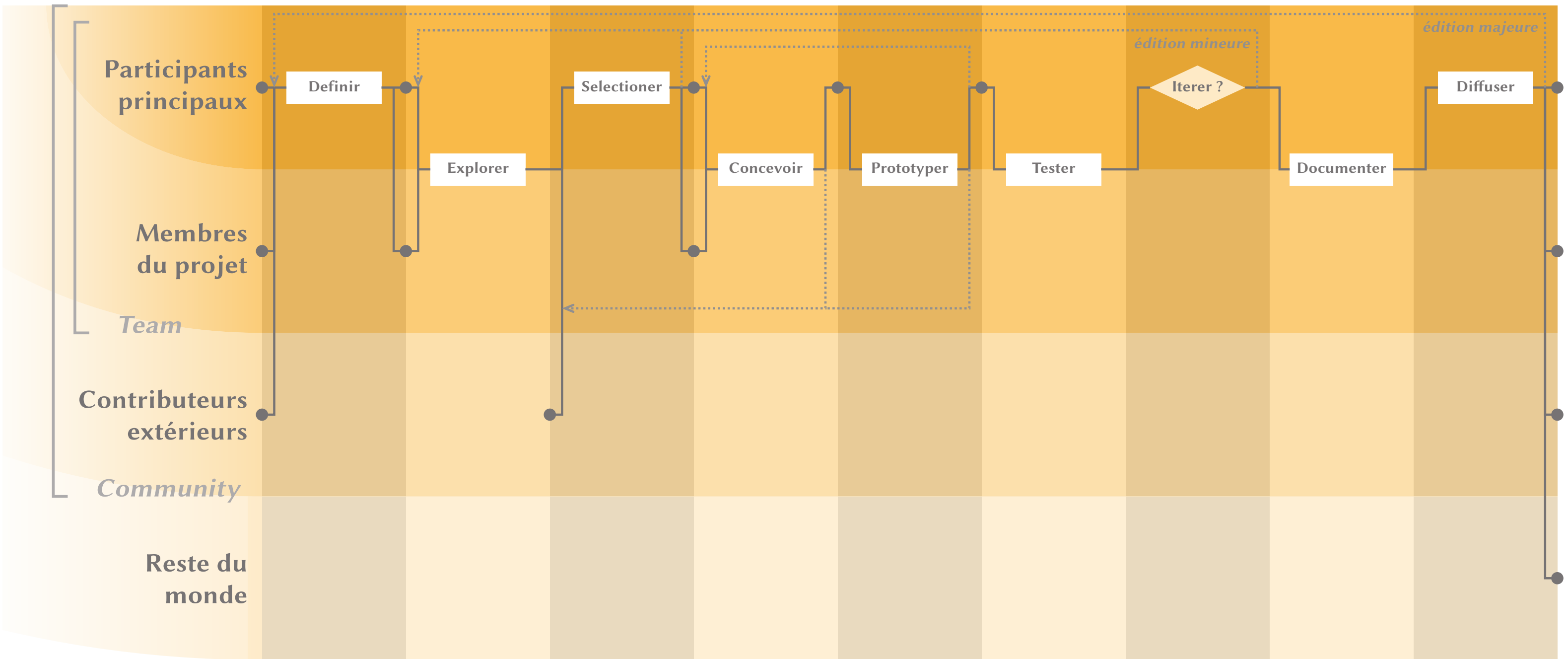
iii Acteurs

La présence d'acteurs divers, volontaires et amateurs, au sein du processus de conception ouverte n'est pas sans rappeler les processus de développement de logiciels libres. Pour autant, la gestion des acteurs et de leurs contributions apparaît ici plus centralisée que dans le secteur informatique. Cela semble notamment dû au manque d'outils permettant de collaborer efficacement à distance et de manière asynchrone.

iv Représentations intermédiaires

Quant aux représentations intermédiaires, elles apparaissent bien moins utilisées qu'au sein des processus classiques. Cela est notamment dû au manque d'expertise des acteurs de ce processus, et d'outils adapter pour collaborer à distance. Les représentations utilisées sont majoritairement des dessins et schéma non formalisés. Des modélisations 3D du produit sont aussi utilisées, notamment pour permettre leur fabrication ultérieure par machines-outils à commande numérique.

Figure 5.1
Modèle global



Chapitre 5
Un modèle global du processus de conception ouverte, et autres apports

Nous venons de présenter deux expérimentations qui visaient à valider les deux hypothèses que nous avons émises. Ces dernières cherchent à répondre à la problématique de notre recherche qui est de modéliser le processus de conception ouverte dans le développement de produits tangibles.

Durant ces expérimentations, nous avons notamment produit deux modèles du processus de conception ouverte. La question est désormais d'analyser ces nouvelles connaissances : que nous apprennent-elles sur la conception ouverte ? Pour cela, nous présentons tout d'abord un troisième modèle, global, qui conjugue les deux modèles précédents. Ce modèle global est ensuite analysé et comparé aux modèles existants dans la littérature. Enfin, nous soulignons les autres apports de notre thèse.

5.1 Un modèle global du processus de conception ouverte

Nous avons développé deux modèles du processus de conceptions ouverte : le premier concernant les acteurs de ce processus, le second leurs activités. Ces deux facettes correspondent à des dimensions complémentaires du processus. Nous les avons donc combinés dans un modèle global (Figure 5.1) qui répond à la question « *Qui* fait *quoi* ? ». De plus, ce modèle global met en avant les flux d'informations entre les étapes et à travers les différentes strates d'acteurs, ainsi que les représentations intermédiaires utilisées.

Table 4.9

Coordonnées des barycentres et valeurs test associées pour chaque projet selon les dimensions représentatives de l'espace vectoriel construit en utilisant les segments cités dans la description du modèle des activités.

Dimension	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
% variance	9.124	8.418	7.785	6.581	6.531	6.410	5.847	5.453	5.023
% variance cumulée	9.124	17.54	25.33	31.91	38.44	44.85	50.70	56.15	61.17
MyFood	-0.322	0.129	-0.352	-0.393	-0.117	-0.222	-0.168	-0.059	-0.146
	-1.217	0.489	-1.331	-1.487	-0.443	-0.839	-0.634	-0.223	-0.553
Showerloop	0.326	0.368	-0.286	0.036	-0.031	0.079	-0.292	-0.043	-0.094
	1.124	1.270	-0.987	0.125	-0.107	0.273	-1.007	-0.147	-0.326
SolarOSE	-0.309	-0.069	-0.175	0.104	-0.037	-0.216	0.151	-0.163	-0.106
	-1.581	-0.354	-0.898	0.533	-0.188	-1.106	0.772	-0.835	-0.541
OEM	-0.244	-0.208	-0.131	-0.014	-0.183	0.005	-0.095	0.560	-0.020
	-1.111	-0.947	-0.597	-0.065	-0.831	0.021	-0.431	2.549	-0.090
Nautiles	-0.214	0.135	0.928	-0.346	-0.201	0.071	0.218	-0.067	0.434
	-0.703	0.443	3.041	-1.135	-0.658	0.232	0.715	-0.221	1.422
VeloM2	0.483	-0.108	-0.008	0.247	-0.290	0.732	-0.034	-0.267	-0.077
	1.828	-0.407	-0.032	0.933	-1.099	2.768	-0.130	-1.010	-0.293
Aker	-0.029	0.634	-0.386	0.257	0.323	0.188	-0.316	0.029	0.004
	-0.073	1.583	-0.965	0.641	0.806	0.469	-0.790	0.072	0.009
Windturbine	-0.291	-0.388	0.032	0.387	0.770	0.084	0.433	-0.242	-0.190
	-0.954	-1.273	0.104	1.267	2.523	0.276	1.420	-0.791	-0.623
Biceps-Cultivatus	0.723	-0.127	-0.050	0.343	0.678	-0.449	0.076	-0.049	0.813
	2.239	-0.394	-0.156	1.061	2.100	-1.391	0.234	-0.152	2.518
Sunzilla	0.051	-0.335	-0.159	-0.440	-0.117	-0.274	-0.095	-0.101	-0.059
	0.116	-0.762	-0.361	-0.999	-0.265	-0.622	-0.215	-0.230	-0.135
Bicitractor	0.265	0.166	0.535	-0.224	-0.227	-0.006	-0.040	0.138	-0.190
	1.086	0.680	2.192	-0.918	-0.931	-0.025	-0.164	0.565	-0.779

Table 4.8

Coordonnées des barycentres et valeurs test associées pour chaque projet selon les dimensions représentatives de l'espace vectoriel construit en utilisant les segments cités dans la description du modèle des activités.

Dimension	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
% variance	9.192	7.176	6.796	6.425	6.204	5.800	5.721	5.201	5.120
% variance cumulée	9.192	16.37	23.16	29.59	35.79	41.59	47.31	52.51	57.63
MyFood	0.237	0.341	0.037	-0.116	0.040	0.048	-0.018	0.174	-0.124
	1.023	1.475	0.160	-0.502	0.175	0.206	-0.076	0.755	-0.534
Showerloop	0.228	0.030	-0.002	-0.247	-0.121	0.347	-0.049	-0.175	-0.163
	1.195	0.155	-0.012	-1.300	-0.637	1.824	-0.260	-0.921	-0.859
SolarOSE	0.310	-0.016	-0.513	0.065	0.170	0.035	-0.110	0.427	0.160
	1.468	-0.077	-2.431	0.307	0.805	0.168	-0.521	2.020	0.758
OEM	-0.264	-0.022	-0.204	0.225	-0.183	-0.262	0.188	-0.534	0.416
	-0.858	-0.073	-0.661	0.730	-0.595	-0.851	0.610	-1.735	1.350
Nautiles	-0.408	0.029	0.183	-0.464	-0.063	0.378	0.208	-0.045	0.253
	-1.251	0.088	0.562	-1.426	-0.192	1.160	0.639	-0.140	0.777
VeloM2	-0.060	0.045	0.006	0.164	0.191	-0.642	-0.347	-0.303	-0.113
	-0.241	0.182	0.023	0.662	0.773	-2.591	-1.400	-1.223	-0.455
Aker	0.744	-0.648	-0.189	0.361	-0.096	0.238	-0.068	0.662	0.164
	1.500	-1.308	-0.380	0.728	-0.193	0.481	-0.138	1.335	0.330
Windturbine	-0.724	0.335	0.307	0.574	-0.112	0.610	-0.024	0.005	0.335
	-3.618	1.675	1.533	2.870	-0.559	3.048	-0.121	0.027	1.676
Biceps-Cultivatus	-0.013	-0.095	0.262	-0.327	-0.170	-0.281	0.400	0.133	-0.468
	-0.065	-0.464	1.273	-1.591	-0.830	-1.365	1.948	0.645	-2.280
Sunzilla	0.142	-0.128	-0.257	-0.123	-0.052	0.138	-0.331	0.331	0.074
	0.485	-0.439	-0.878	-0.419	-0.177	0.471	-1.129	1.132	0.252
Bicitractor	0.133	-0.344	0.056	0.009	0.222	-0.458	0.049	-0.258	-0.039
	0.699	-1.808	0.292	0.050	1.169	-2.407	0.258	-1.356	-0.204

Table 4.6
Coefficient de similarité normalisé (R_v) entre deux groupes de variables, pour chacun des modèles.

Modèle	**Acteurs**		**Activités**	
Groupe de variables	*is_cited*	*is_modeled*	*is_cited*	*is_modeled*
is_cited	1.0000	0.1069	1.0000	0.1548
is_modeled	0.1069	1.0000	0.1548	1.0000
cat_na	0.0205	0.0755	0.0287	0.1115
cat_human	0.0657	0.2507	0.0367	0.0366
cat_process	0.0242	0.0449	0.0735	0.2446
cat_boundary.object	0.0204	0.1189	0.0440	0.0334
cat_open	0.0005	0.0105	0.0015	0.0520
cat_project	0.0417	0.0809	0.0244	0.0154
cat_product	0.0026	0.0041	0.0441	0.0402

apparaît fiable et robuste.

vi Conclusion

Par cette expérimentation, nous avons pu construire deux modèles du processus de conception ouverte. Le premier se concentre sur les différents acteurs de ce processus et leurs interactions. Le second sur les différentes activités de ce processus et leur agencement. Nos modèles apparaissent valides internement, et notre modélisation fiable et robuste. Cependant, nous n'avons pu évaluer formellement la validité externe de nos modèles (c'est-à-dire leur propension à être généralisés). Ainsi, nous considérons que notre seconde hypothèse n'est validée que de manière incomplète.

Table 4.7
Synthèse de l'accord entre les expérimentateurs.

		Groupement original			
		Major codes à Concepts		***Concepts à Categories***	
		attribué	*non attribué*	*attribué*	*non attribué*
Grouppement de confirmation	*attribué*	77	26	34	7
	non attribué	30	2901	7	239

Faute de ressources et de temps, cela n'a pu être vérifié rigoureusement. Ce point est identifié dans les limitations de notre étude.

Nous avons aussi cherché à valider la fiabilité de notre processus de modélisation. C'est-à-dire répondre à la question : « Est-ce que la reproduction de notre méthodologie par un autre expérimentateur mènerait au même résultat ? ». Pour cela, nous avons évalué le degré d'accord dans le codage de nos données (regroupement des codes majeurs en concepts, et regroupement des concepts en catégories). Nous avons pour cela utilisé le test du Kappa selon la définition de (Cohen, 1960), et la grille de lecture proposée par (Landis et Koch, 1977).

Enfin, nous avons cherché à évaluer la robustesse de notre modélisation. C'est-à-dire répondre à la question : « Est-ce que nos modèles sont sensibles à une petite variation dans les données d'entrées ? » Pour cela, nous avons évalué si la variable « Projet » de notre base de données était significativement non-nulle sur les dimensions principales de notre espace vectoriel. N'ayant pas la nécessité d'évaluer l'impact d'un groupe de variables (mais seulement d'une variable), nous avons utilisé une forme simplifiée de l'analyse factorielle multiple qui est l'analyse des correspondances multiples. Nous avons ensuite regardé la position du barycentre de chaque groupe de segments correspondant à un projet en particulier sur les principales dimensions (i.e. celles expliquant plus de 5% de la variance) de notre espace vectoriel. Nous avons mesuré si cette coordonnée était significativement différente de 0 (signifiant par là que le projet n'avait pas d'influence significative, et donc n'était pas surreprésenté dans les segments cités) à l'aide de la valeur test. Présupposant la distribution des coordonnées des barycentres comme répondant à une loi normale (ce qui est acceptable vu que les barycentres sont en eux-mêmes des moyennes), nous comparons donc cette valeur test à la loi normale centrée réduite. Avec une valeur-p de 5%, nous considérons donc que le barycentre est significativement différent de 0 si la valeur absolue de la valeur test est supérieure à $1,96$.

v Résultats et analyse de la validation

Les résultats de la validation interne de nos modèles, ainsi que de la fiabilité et de la robustesse de notre modélisation sont présentés respectivement dans les Tableaux 4.6, 4.7, ainsi que 4.8 et 4.9.

Il apparaît que nos modèles sont valides internement (les faibles taux R_v s'expliquent notamment par le grand nombre de dimensions de notre espace vectoriel et la présence de quelques segments cités venant de catégories non modélisées afin de mieux contextualiser no modèles), que notre modélisation classiques, le plan est destiné à des acteurs en particuliers, tandis qu'ici, il est mis à la disposition du plus grand nombre.

iv Protocole : validation des modèles et de la modélisation

La deuxième phase de notre expérimentation est la validation de nos modèles et de notre méthode de modélisation. Celle-ci est réalisée à l'aide de l'outil statistique : en effet, notre corpus de retranscription peut être considéré comme une base de données, caractérisée à l'aide des différents concepts associés ou non à chaque segment.

Nous cherchons tout d'abord à évaluer la validité interne de nos modèles. Cela vise à répondre aux questions : « Est-ce que nos modèles sont justes et non biaisés ? Est-ce qu'ils représentent exactement les données sur lesquels ils reposent ? » Pour cela, nous utilisons une analyse multivariée, et en particulier l'analyse factorielle multiple (Husson et al., 2016). Elle a été réalisée à l'aide du package *FactoMineR* de *R*. Cette analyse vise d'abord à construire un espace vectoriel à l'aide des différents concepts utilisés pour caractériser nos segments. Chacun de ces segments peut être ensuite représenté comme un point de cet espace vectoriel (ici, à 45 dimensions). L'objectif de l'analyse multivariée est de trouver les dimensions les plus représentatives de cet espace. Un de ces résultats est également la mesure du lien entre des groupes des variables (ici constitués à l'aide des différentes catégories regroupant l'ensemble des concepts). Cette mesure est représentée par le coefficient L_g qui correspond à l'inertie projetée de l'ensemble des variables d'un premier groupe de variables sur un second. Plus cette mesure est grande, plus les groupes de variables sont liés. Afin de pouvoir comparer ces coefficients, on les normalise par rapport à la dimensionnalité de chacun des deux groupes, ce qui donne le coefficient R_v. (La dimensionnalité correspond à coefficient d'inertie d'un groupe sur lui-même.) $R_v = 1$ signifie que les deux groupes sont totalement liés (à une homothétie près dans l'espace vectoriel), $R_v = 1$ signifie que les deux groupes ne sont pas liés. Nous cherchons à montrer que le groupe des segments cités est liés au groupe des segments des catégories modélisées dans un des modèles donnés ($R_v = 0,1$). Cela montre que le modèle rend bien compte des catégories modélisées. Nous cherchons aussi à montrer que cette représentation n'est pas biaisée, c'est-à-dire que les catégories ne sont pas déformées dans la construction du modèle ($R_v < 0,1$).

Pour évaluer la validité externe de nos modèles — c'est-à-dire répondre à la question « Est-ce que nos modèles peuvent être généralisés à l'ensemble du type de conception ouverte considéré ? » — il nous faut comparer ces modèles à un ensemble de projets n'ayant pas servi à construire ces modèles.

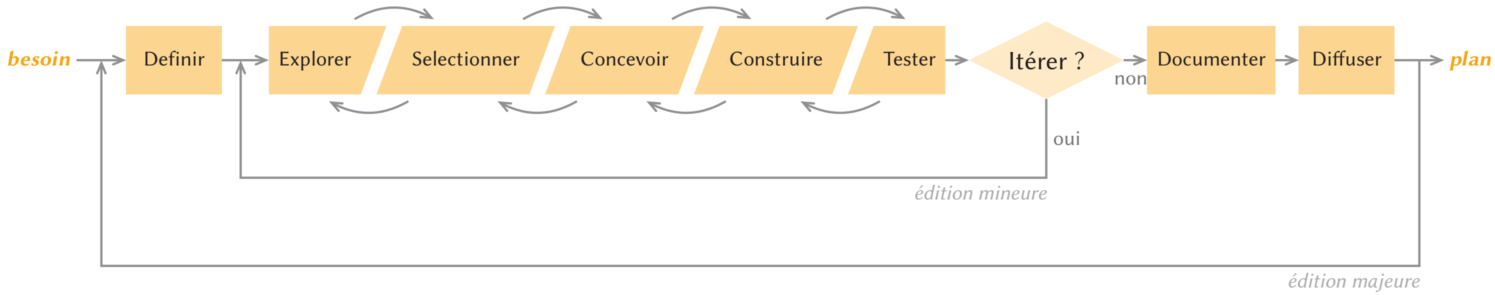


Figure 4.7
Modèle des activités — Nous observons un continuum de phases entre l'étape *Explorer* et *Tester*, ainsi que deux boucles de rétroaction.

Table 4.5
Categories, leurs concepts respectifs et nombre de segments

Categorie	# segments	Concepts (# segments)
Human	361	core team (91), contributors (81), skills (68), human interactions (66), management (26), collaboration (15), geographical location (6), project nebula (4), communication (4)
Process	294	development process (82), design process (63), start (39), design process phase (39), design (19), iteration (19), tools (14), development process phase (10), time (9)
Project	158	issues (40), project (37), objective (27), motivation (21), constraint (16), business (13), strategy (4)
Boundary objects	148	boundary objects (43), sources (27), 3D (22), contribution (17), prototyping (16), inputs (15), documenting (8)
Open	102	open (62), PoC (40)
Product	28	product (16), hardware (6), user (3), digital (3)
N/a	323	questions (165), introduction and closing (108), interruption (50)

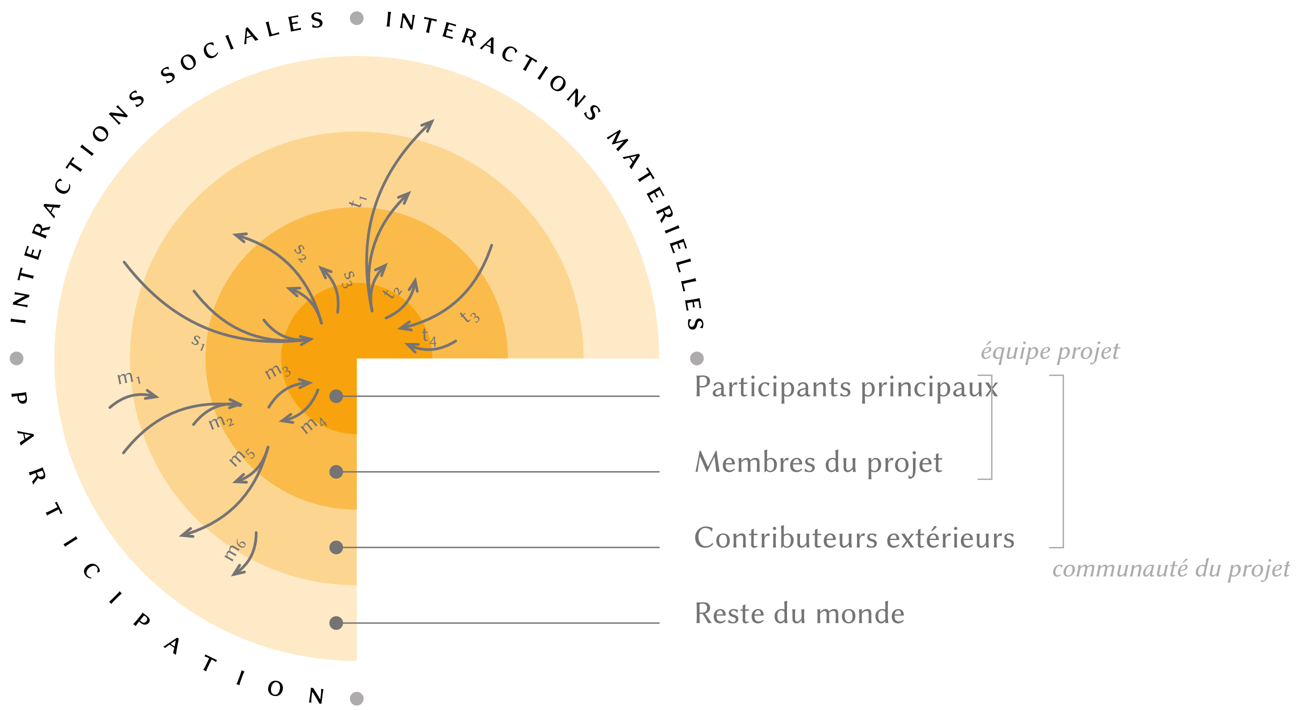


Figure 4.6
Modèle des acteurs — Quatre strates et deux groupes d'acteurs interagissent selon trois types de relations.

ont donné lieu à la composition de 8 catégories. Celles-ci sont présentées dans le Tableau 4.5.

iii Analyse : deux modèles de la conception ouverte

Comme indiqué ci-dessus, nous avons construit deux modèles.

Le premier est présenté dans la Figure 4.6. On observe une structuration des acteurs en strates concentriques, avec un cœur restreint composé d'un petit nombre de participants principaux autour duquel gravite les autres membres du projet (qui sont moins impliqués dans le projet mais agissent quand même en concertation avec les acteurs principaux), les contributeurs extérieurs (qui contribuent eux aussi au projet, mais de manière moins encadrée), et enfin le reste du monde. Les utilisateurs finals se retrouvent dans l'ensemble de ces couches. Nous avons également mis en avant les interactions entre ces couches qui sont de trois types : l'appartenance à un statut (comment l'on accède à une couche spécifique), les interactions sociales (qui décrivent les relations sociales entre acteurs de strates différentes), ainsi que les interactions matérielles (qui mettent en jeu une représentation intermédiaire).

Le second modèle représente les différentes activités mise en œuvre durant le processus de conception ouverte (voir Figure 4.7). Ce modèle est composé de macro-étapes similaires aux processus de conception classiques. Néanmoins, on observe un bloc central constitué d'un continuum d'activités qui sont exécutées de manières itératives et avec de fréquents sauts dans un sens ou dans un autre. De plus, la dernière étape — la diffusion du plan — est propre aux approches ouvertes : en effet, dans les processus de conception

Table 4.4
Presentation des projets étudiés dans la seconde expérimentation

Nom du projet	Pays	Description
30$ wind turbine	GBR	une éolienne construite à l'aide de matériaux recyclés
Aker	USA	kits modulaire pour agriculture urbaine
Kitchen-B	FRA	éléments de cuisine pour mode de vie durable
Bicitractor	FRA	tracteur à pédales pour fermes de petite et moyenne taille
Faircap	PER	filtre à eau antibactérien imprimé en 3D pour 1$
Nautiles	BEL	bouilloire écologique bio-inspirée
Open Energy Monitor	GBR	système de gestion énergétique pour foyer privé
MyFood	FRA	serre connectée autonome
Showerloop	FIN	douche à recyclage d'eau en temps réel
SolarOSE	FRA	concentrateur solaire
Sunzilla	DEU	générateurs solaires mobiles et modulaires
VéloM2	BEL	modules multifonction pour vélo cargo

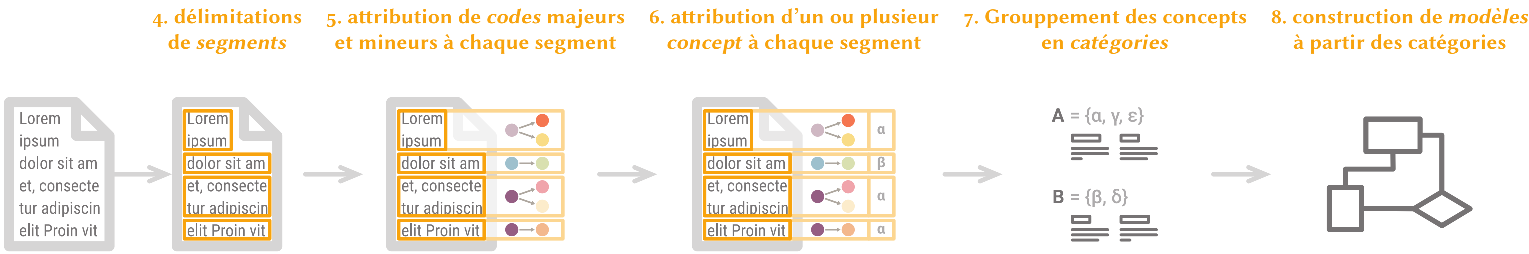


Figure 4.5
Protocole de la seconde expérimentation : analyse de données par théorisation ancrée.

Nous avons tout d'abord choisi un corpus homogène de projets de conception ouverte. Nous avons choisi les 12 projets ayant pris part au camp d'innovation de 5 semaines PoC21. Nous avons ensuite interviewé les principaux participants de ces projets lors d'entretiens semi-directifs de trente à quarante-cinq minutes chacun. Nous avons interviewé une personne par projet, afin de ne pas déséquilibrer notre perception du phénomène en surreprésentant les projets ayant plus de participants. Ces entretiens, enregistrés avec l'accord du participant, ont ensuite été retranscrits manuellement en suivant les guides de la retranscription naturalisée (Schegloff, 1997).

Ces retranscriptions constituent le corpus de base que nous avons formalisé par théorisation ancrée. Tout d'abord, nous les avons découpées en segments. Chaque segment correspond à une unité sémantique. Nous avons ensuite codé ces segments, en utilisant des codes multi-nominaux (Dumez, 2013) : à chaque segment est attribué un code majeur (qui décrit l'idée générale exprimée dans le segment) ainsi qu'un ou plusieurs codes mineurs (qui, eux, qualifient le contenu exprimé par rapport à l'idée générale à laquelle il se rapporte). Ces codes ont ensuite été regroupés en concepts. Ces derniers ont ensuite eux-mêmes été regroupés en catégories qui ont été caractérisées. C'est à partir de ces catégories que nous avons construit nos modèles : un premier qui révèle l'organisation des différents acteurs intervenant dans le processus de conception ouverte, et un second qui met en avant l'ensemble des activités effectuées et leur agencement. L'ensemble du processus de construction des modèles s'est déroulé de manière itérative.

ii Résultats de la modélisation

Le Tableau 4.4 présente les différents projets qui ont pris part à PoC21. L'ensemble des enregistrements s'élève à huit heures et quarante minutes, ce qui correspond à 67012 mots retranscrits. Nous avons identifié 1056 segments, qui ont été caractérisés avec 1069 codes différents. 347 d'entre eux sont des codes majeurs. Ces derniers ont été regroupés en 45 concepts qui cette thématique nous est apparue encore peu mature, mais grandissante. Nous avons aussi pu formaliser une typologie des pratiques de la conception ouverte via une revue systématique de la littérature scientifique. Nous considérons donc notre première hypothèse comme validée.

4.3 Expérimentation 2 : Modélisation du processus de conception ouverte

L'objectif de cette seconde expérimentation est double. Notre seconde hypothèse indique qu'une démarche par théorisation ancrée permet de modéliser le processus de conception ouverte pour l'un des types de pratiques détaillées ci-dessus. Cela implique donc dans un premier temps de construire ces modèles, puis, dans un second temps, de les valider. La présentation de cette expérimentation se divise donc en deux phases : tout d'abord la modélisation et ses résultats, ensuite, la validation de ces résultats par l'outil statistique.

i Protocole : Modéliser le processus de conception ouverte

La modélisation par théorisation ancrée est un processus systématique et normé (Glaser et Strauss, 1967 ; Dumez, 2013). Nous avons procédé en deux grandes étapes : le recueil de données (Figure 4.4), puis leur modélisation (Figure 4.5).

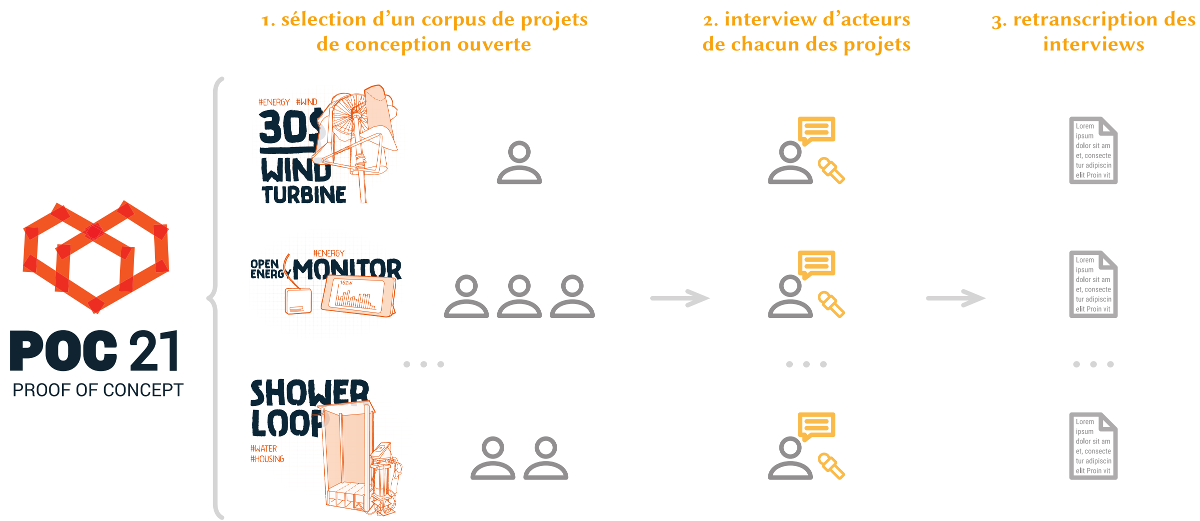


Figure 4.4
Protocole de la seconde expérimentation : recueil de données par interviews semi-directifs d'acteurs de projets de conception ouverte.

Table 4.3

Synthèse de l'impact de l'approche ouverte sur la conception de produits

Paramètres du processus	**Entrée**	**Processus**			**Sortie**
	Besoin	**Activités**	**Acteurs**	**Repres. interm.**	**Plan**
Ce qui ne change pas	– type de problèmes pas radicalement différant	– « pas de traits caractéristiques notables » trouvés (Balka et al., 2009)	– aucun rôle ne disparaît, même s'ils évoluent – compatible avec exigences professionnelles	– pas de changement radical (schémas, dessins) – haute importance dans la collaboration asynchrone et décentralisée	– touche une grande variété de secteurs
Ce qui change avec la conception ouverte	– fabriquer et non plus seulement posséder – besoins identifiés par les utilisateurs-concepteurs eux-mêmes	– processus itératif avec diffusion de résultats intermédiaires – alternances de phases en ligne et hors ligne	– hybridation des rôles et organisation en communautés – structure en « bazar » – participants bénévoles (avec plusieurs niveaux d'implication) – de nouvelles compétences requises – hiérarchie méritocratique	– RI numérisées utilisées entre activités seulement – utilisation de plateformes pour échanger entre participants – nouvelles questions sur la propriété intellectuelle	– nouveaux types de documents diffusés – personnalisation et adaptabilité du produit

Table 4.2

Catégories utilisées pour catégoriser les entrées de notre requête dans la base de donnée *Scopus*.

Type	Catégorie	Nb d'entrées	Signification	Remarque
meaning	methodology	240	Open-design refers here to the method used to lead a study. An open-design study is a survey, where neither the experimenter nor participants are aware if the latter belong to the control group or not. E.g., *« METHODS : The study was of randomized open design and was conducted at multiple centers in Europe. »*	Most of these papers belongs to medicine studies
	topology	136	Design refers here to the shape of a product. Open-design is thus a product, which form is open (as in « the door is open »). E.g., *« The open design of most aquaculture systems allows the transmission of pathogens from the environment or from wild fish to the farmed fish. » « The semi-open design of the domes moderates the problems of strong wind, humidity, and temperature gradients associated with OTCs. »*	16 of these paper refers to the same system, that is a magnetic resonance imaging scanner.
	true positive	106	Open-design matching previously coined definition. E.g., *« They discard the 10-year-old IBM AT architecture in favor of more flexible, open designs. » « Single design tools have to be integrated into an open design system ('Framework'), together with an integrated design data base and a common and comfortable user interface. » »*	Papers belongs to this category « by default », i.e. if no information would make it belong to another (or a new) category.
	problem	51	Open refers here to an issue or a question that has no solution yet, or that might accept multiple solutions — and when this issue/question is about design E.g., *« As a work in progress, the new algorithm is presented with open design decisions. » « considering as the input design space the open design variables associated to the subsystem descriptions »*	-
	structure	36	Open refers here to a system that has connection with the outside of a system. So a system that is not closed or isolated from the external environment. E.g., *« Security through obscurity has always been ineffective. Some open designs have also been proposed. » « advanced metering infrastructure, open design and renewable energy connection and so on in distribution grid. »*	-
noise	n/a	21	(1) When the result does not refer to a single work, (2) when the paper is in a language not spoken by authors, or (3) when the entry could not be accessed by authors (1) E.g., proceedings of a conference, referenced as one single paper ; (2) Five papers written in Chinese and one in Italian ; (3) One entry written in 1990.	-
	duplication	17	When the result refers to a publication have already been referenced.	The identification of duplication have been done manually.
	irrelevant	17	When the word *design* follows *open* by chance. E.g., *« two methods of endotracheal suctioning : closed vs. open. Design : A prospective, randomized, controlled study. »*	Often the case for two following keywords.

Table 4.1
Types de pratiques de la conception ouverte dans le développement de produits tangibles, et leurs caractéristiques.

Types de conception ouverte	**Do It Yourself**	**Meta-design**	**Industrial ecosystem**
Par	amateurs	professionnels	professionnels
Pour	amateurs	amateurs	professionnels
Description	initiatives privées où des utilisateurs finals joignent leurs forces pour développer des produits qui leur importent.	concepteurs aidant les utilisateurs finals à concevoir leurs propres produits en développant un environnement et les outils adaptés	entreprises ouvrant leurs conceptions dans le but de favoriser un écosystème industriel efficace et durable
Motivations	répondre à des besoins de niche ou spécifiques, réduire les coûts	accroître l'assiette d'utilisateurs, personnalisation de produits	partager les coûts et risques de développement, accélérer le processus de conception, réduire la dépendance envers un fournisseur, promouvoir des standards
Relié à	DIY, user innovation, co-design	mass customization, decentralized manufacturing	open standards, open (source) innovation
Exemples	RepRap	Arduino	Thin Film Partnership Program [1]

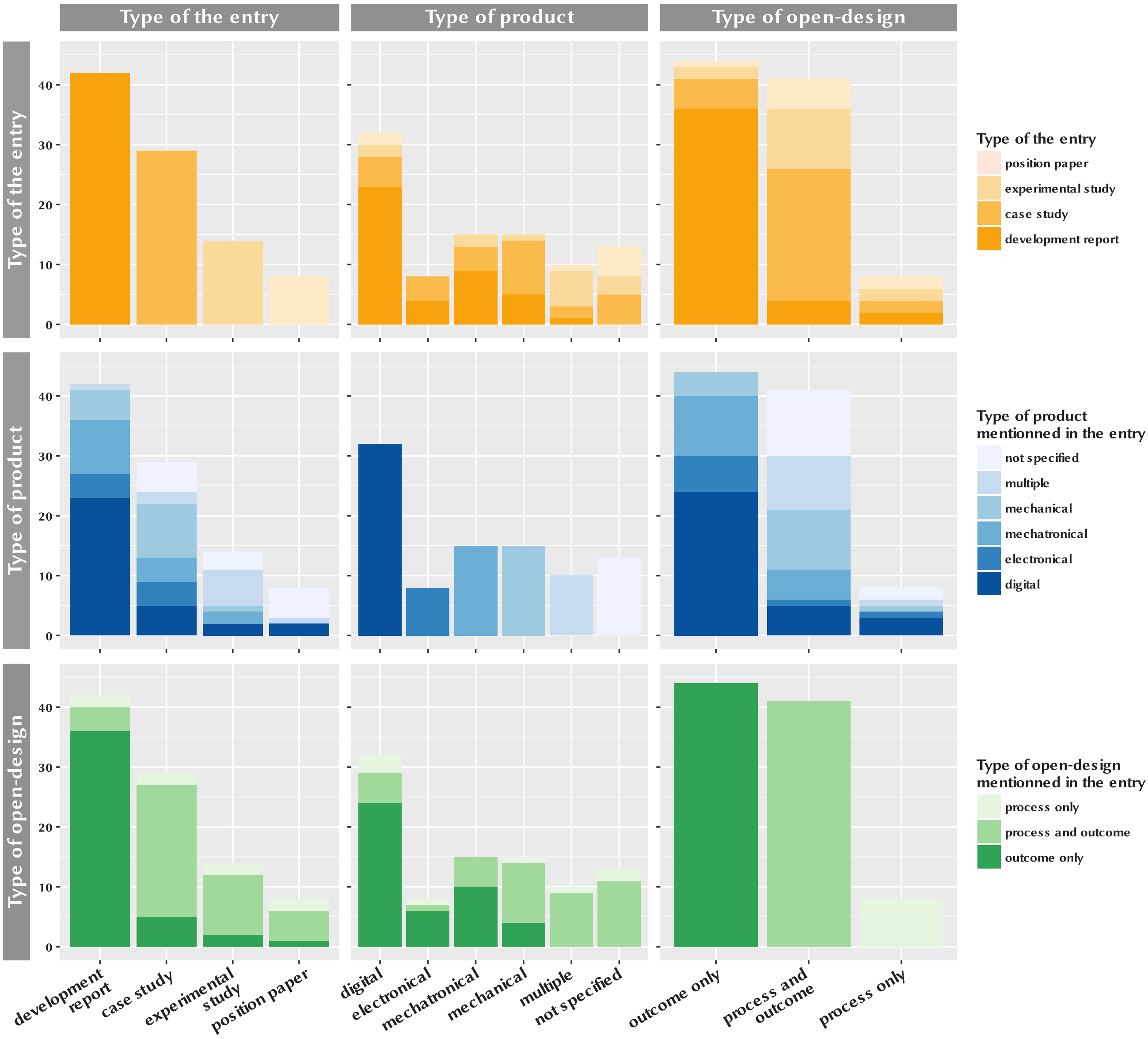


Figure 4.3
Nombre d'entrée, en fonction de leur type, du type de produit mentionné, et du type d'ouverture.

type de recherche auquel ils faisaient référence, au type de produit qu'ils évoquaient, ainsi qu'au type de conception ouverte utilisée.

Enfin, à l'aide de cette base de données enrichies, nous avons mené une analyse d'abord quantitative sur les métadonnées, puis quantitative pour formaliser notre typologie.

ii Résultats quantitatifs

Les différentes catégories utilisées pour classifier les articles à l'étape deux sont présentées dans le Tableau 4.2. La Figure 4.3 présente, elle, le nombre d'articles en fonction des trois critères évalués : le type de publication, le type de produit, et le type de conception ouverte.

iii Analyse

Ces résultats laissent apparaître la conception ouverte comme une thématique nouvelle mais émergente. Nous n'identifions pas de communauté scientifique globalement constituée sur ce sujet, mais quelques groupes de recherches se sont formés. La majorité des articles à propos de la conception ouverte de produits tangibles concernent des rapports d'expérience, où c'est essentiellement les plans qui sont ouverts, plus que le processus de conception.

iv Résultats qualitatifs

Le Tableau 4.3 présente l'impact de l'approche ouverte sur les cinq paramètres décrivant le processus de conception de produits.

v Analyse

Ces résultats nous permettent de proposer la typologie présentée dans le Tableau 4.1 où nous distinguons trois types de pratiques. Ces pratiques sont liées au statut (professionnel expert ou particulier amateur) des acteurs prenant part au processus et ceux à qui ces processus sont dédiés.

vi Conclusion

Cette expérimentation nous a permis d'approfondir notre connaissance des recherches scientifiques sur la conception ouverte. La recherche sur

1. See Buitenhuis et Pearce (2012)

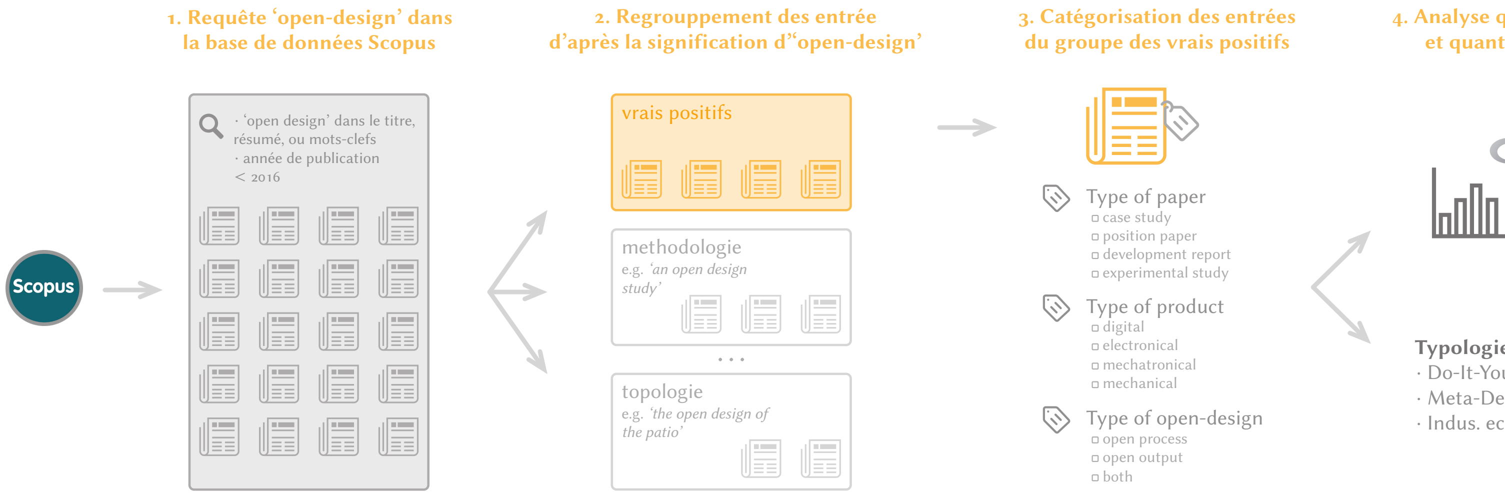


Figure 4.2
Protocole de la première expérimentation : une analyse systématique de l'état de l'art.

4.2 Expérimentation 1 : Analyse systématique de l'état de l'art

i Protocole

Notre expérimentation se découpe en quatre phases (voir Figure 4.2). Tout d'abord, nous avons lancé une requête dans la base de données *Scopus*, afin d'extraire l'ensemble des papiers correspondants au mot-clef « open design » (i.e. conception ouverte en anglais). Afin de rendre notre recherche reproductible, nous ne nous sommes intéressés qu'aux publications antérieures à 2016.

La seconde étape a cherché à identifier les « vrais positifs », c'est-à-dire les papiers faisant bien référence à la conception ouverte comme définie précédemment. En effet, le mot-clef open design est utilisé dans d'autres contextes avec une signification différente (par exemple pour des articles d'études médicales où open design fait référence à un type de protocole expérimental dans lequel à la fois le patient et le médecin savent si ce premier fait partie du groupe test ou du groupe témoin). Pour cela, nous avons catégorisé les articles en fonction de leur titre, leurs mots-clefs, et leur résumé. Le cas échéant, nous avons lu l'article dans son entier pour lever l'ambiguïté. Les différentes catégories ont été créées autant que de nécessaire : si nous découvrions une nouvelle signification d'open design, nous créions une nouvelle catégorie.

La troisième étape ne s'est concentrée que sur les vrais positifs. Nous avons lu l'ensemble de ces articles et les avons catégorisés en fonction du

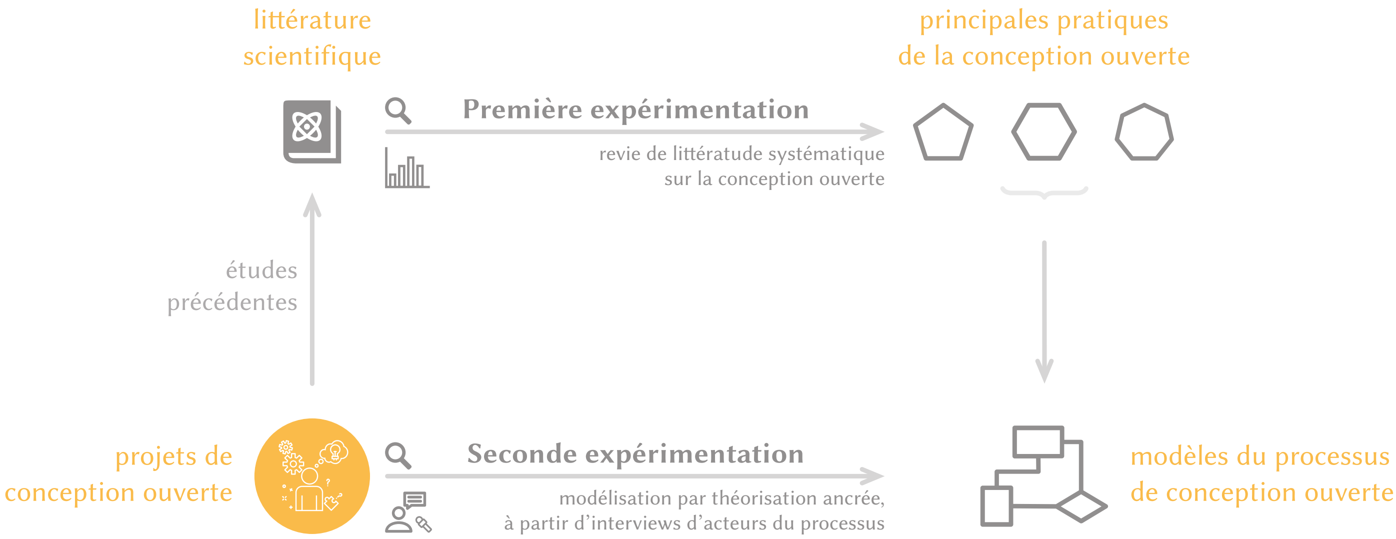


Figure 4.1
Aperçu des expérimentations.
Deux hypothèses liées vont être testé afin de répondre à la problématique.

Chapitre 4
Expérimentations

Nous venons de détailler la problématique de notre étude. Nous avons aussi proposé deux hypothèses comme réponses potentielles à cette problématique. Ces dernières doivent toutefois être validées par des expérimentations empiriques. Dans ce chapitre, nous présentons donc tout d'abord notre plan d'expérience, puis présentons chacune des deux expérimentations que nous avons menées. Pour cela, nous détaillons les protocoles mis en place, le résultat de leur mise en œuvre, et l'analyse de ces résultats qui nous permettent de statuer sur la validité de l'hypothèse testée.

4.1 Plan d'expérience

Notre problématique vise à définir comment modéliser le processus de conception ouverte. La première expérimentation cherche, à travers une revue systématique de l'état de l'art, à formaliser une typologie des pratiques de la conception ouverte, afin d'identifier des groupes de pratiques homogènes. La seconde expérimentation cherche, elle, à partir d'un ensemble homogène de projets, à modéliser le processus de conception ouverte pour l'un de ces groupes. La Figure 4.1 présente l'agencement de ces expérimentations.

3.3 Hypothèses

Pour répondre à la problématique, nous proposons deux hypothèses. Celles-ci sont des explications probables suggérées par notre revue de littérature. Elles doivent néanmoins encore être validée — c'est l'objectif de notre étude empirique.

i H1 : première hypothèse

Notre revue de l'état de l'art nous a permis de délimiter le cadre de notre recherche. Il apparaît que la conception ouverte regroupe un grand nombre de pratiques relativement hétérogènes. Néanmoins, nous ne pouvons modéliser avec précision qu'un ensemble homogène de pratiques. Notre premier objectif est donc de définir une typologie des pratiques existantes. Pour cela, une revue de littérature systématique semble adaptée (Grant et Booth, 2009).

Notre première hypothèse est donc :

> *Une revue de littérature systématique permet de formaliser une typologie des pratiques de la conception ouverte.*

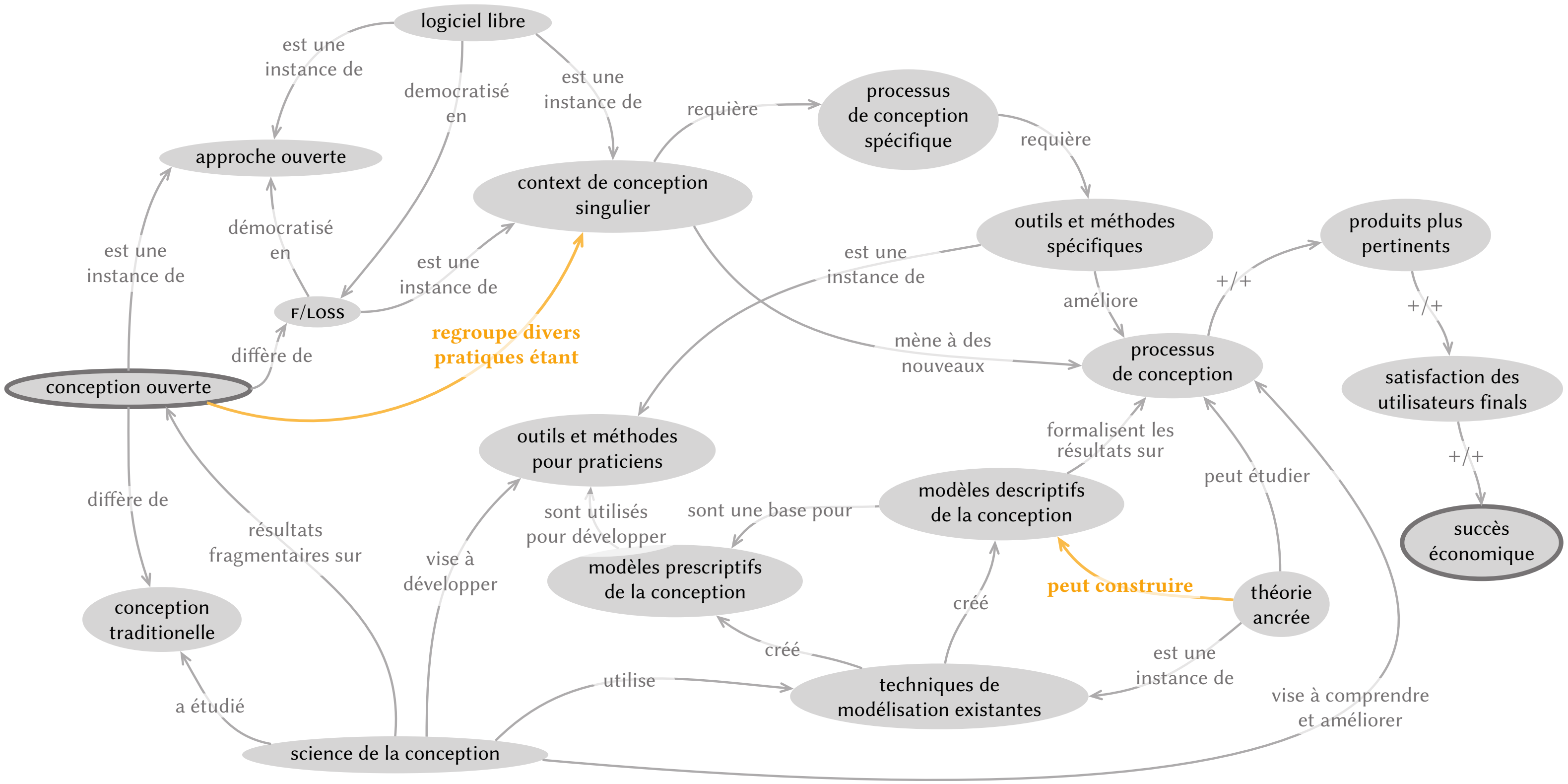
ii H2 : seconde hypothèse

Une fois des ensembles homogènes de pratiques définis, nous cherchons à modéliser le processus de conception ouverte dans l'un de ces contextes. L'approche par théorisation ancrée semble permettre de construire de tels modèles (Glaser et Strauss, 1967 ; Lingard et al., 2008 ; Paillé, 1994). Seulement, une telle méthodologie n'a pas encore été utilisée pour modéliser le processus de conception de produit.

Notre seconde hypothèse est donc :

> *L'utilisation d'une méthode reposant sur la théorisation ancrée permet de construire des modèles du processus de conception de produits pour l'un des types de conception ouverte préalablement identifiés.*

Figure 3.1
Modèle d'impact à partir de notre état de l'art.



Chapitre 3
Problématiques et hypothèses

Nous avons présenté l'intérêt et la singularité de la conception ouverte, ainsi que le peu de connaissances formalisées sur cette thématique. Nous avons également mis en avant l'intérêt de modéliser les différentes pratiques de conception de produits, afin de pouvoir, dans un second temps, développer des outils et méthodes à l'intention des praticiens. Ces thématiques sont l'objet de notre étude. Nous allons maintenant définir sa problématique ainsi que les hypothèses que nous chercherons à valider dans la partie empirique de nos recherches.

3.1 Analyse de l'état de l'art

La Figure 3.1 présente les points saillants de notre état de l'art. Ils relient la thématique de notre recherche, la conception ouverte, avec l'objectif final des sciences de la conception, le succès économique et industriel des nouveaux produits conçus. Deux suppositions, guidées par notre revue de littérature ont été mise en avant. Elles seront testées à travers nos expérimentations.

3.2 Problématique

Nous avons vu que des modèles du processus de conception de produits spécifiques à chaque approche de la conception sont nécessaires, afin de pouvoir développer des outils et méthodes adaptés. La conception ouverte n'a néanmoins été que peu étudiée jusque-là, ni formellement modélisée. La problématique que nous formulons est donc la suivante :

> *Comment modéliser le processus de conception ouverte dans le cadre du développement de produits physiques ?*

de modèles économiques pérennes (Almeida Meroz et Griffin, 2012). Les autres participants sont mus par des motivations diverses (Lakhani et Wolf, 2005 ; Lerner et Tirole, 2002).

Un point critique semble être le manque d'outils adaptés pour formaliser les représentations intermédiaires. En effet, Affonso et Amaral (2015) montrent que leur usage reste très limité. Bonvoisin et Boujut (2015) montrent qu'il y a notamment un manque de plateformes pour échanger ces représentations intermédiaires.

Quant au type de produits ainsi conçus, derrière la large palette de secteurs impactés (Balka et al., 2009), on observe que deux tendances se dessinent. La conception d'objets simples du quotidien, et celle de grands systèmes complexes (Cruickshank et Atkinson, 2014 ; Phillips et al., 2014). Le point épineux reste la très grande hétérogénéité des plans ainsi mis à disposition, ce qui freine l'identification d'une approche globale de la conception (Tamminen et Moilanen, 2016).

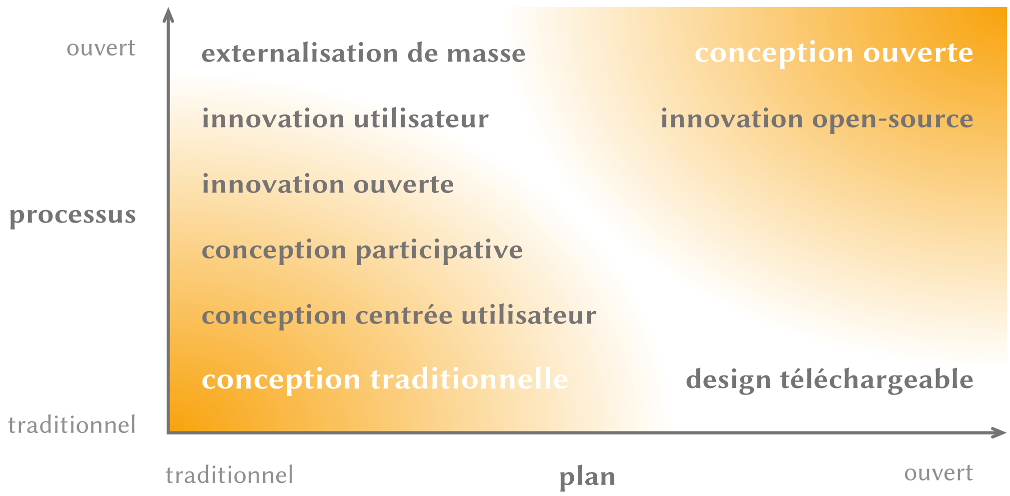


Figure 2.5
La conception ouverte, et les concepts liés.

elles n'arrivent à retranscrire la dualité de l'ouverture dans la conception ouverte : celles-ci se concentrent soit sur le processus, soit sur son résultat.

Ainsi, nous proposons la définition suivante de la conception ouverte :

> *La conception ouverte est l'état pour un projet de conception, où à la fois le processus de conception et les sources de son aboutissement sont accessible et (ré)utilisable par tout à chacun et dans n'importe quel but.*

V Premiers résultats à propos de la conception ouverte

On observe des cas de conception ouverte dans de nombreux secteurs (Raasch, Herstatt et Balka, 2009). Cependant, tout comme les logiciels libres voient leurs participants contribuer notamment pour faire avancer un problème qui les tracasse (Shirky, 2005), ce sont les produits grand public qui sont les plus à même d'être impactés par l'approche ouverte.

Concernant le processus de conception, peu de modèles sont proposés dans la littérature. Fjeldsted et al. (2012) proposent un modèle peu détaillé et tenant plus des sciences de gestion. Macul et Rozenfeld (2015) rapportent le processus de conception utilisé dans la communauté *Open Source Ecology*. Celui-ci est relativement sommaire, mais néanmoins très semblable aux processus classiques de conception de produits.

Les acteurs de tels processus s'organisent de manière similaire aux projets de développement de logiciels libres, où les utilisateurs finals jouent un grand rôle (Panchal et Fathianathan, 2008). Cela bouleverse les pratiques actuelles (van der Beek, 2012). Les concepteurs professionnels semblent peu enclins à prendre part à de telles pratiques, notamment à cause du manque

ii À l'intersection de l'approche ouverte et du tangible : le matériel libre

Le matériel libre est la première étape vers la conception ouverte. Cette approche consiste à partager les plans d'un objet afin qu'il puisse être étudié et reproduit par chacun (Mellis et Buechley, 2012). Au rang des matériels libres, on trouve des micro-processeurs, des machines-outils, des voitures, des téléphones intelligents, un satellite, des meubles, etc.

Avoir accès aux plans d'un objet permet de le réparer de l'améliorer, de le reconcevoir : ce sont des proto-formes de conception ouverte.

iii Concepts liés à la conception ouverte

On peut évaluer « l'ouverture » d'un projet de conception à travers deux dimensions : nous avons vu qu'un processus de conception est caractérisé par trois aspects : le besoin, le processus de conception lui-même, et le plan (voir Figure 2.4). Or il apparaît que le besoin est indépendant du projet de conception : les praticiens n'ont pas d'influence sur lui (ils peuvent chercher à mieux le comprendre ou le définir, mais ils ne peuvent pas le modifier). Ainsi, on évaluera l'ouverture d'un projet en fonction de deux dimensions indépendantes : le processus et son aboutissement (Huizingh, 2011). Ces deux axes s'évaluent selon une échelle continue (un processus est plus ou moins ouvert ; ce n'est pas une notion binaire).

On place la conception ouverte comme une forme de conception où et le processus et le plan sont ouverts. À l'inverse, les processus traditionnels ont ces deux aspects non ouverts. Sur l'espace ainsi défini, nous pouvons placer plusieurs notions étudiées dans la littérature (voir Figure 2.5) : la conception centrée utilisateurs (Norman et Draper, 1986 ; Abras et al., 2004 ; iso 9241-210), la conception participative (Schuler et Namioka, 1993 ; Ehn, 1993 ; Kensing et Blomberg, 1998), l'innovation ouverte (Chesbrough, 2003 ; Marais et Schutte, 2009), l'innovation utilisateur (Hippel, 2005, 2014 ; Füller et al., 2007 ; Bogers et West, 2010), l'externalisation de masse (Brabham, 2008 ; Nickerson et al., 2011), le design téléchargeable (Atkinson, 2011), ou encore l'innovation open-source (Gläser, 2007 ; Raasch, Herstatt, Blecker et al., 2008 ; Raasch, Herstatt et Balka, 2009).

iv Élaboration d'une définition de la conception ouverte

Quelques définitions de la conception ouverte ont été proposée dans la littérature (Vallance et al., 2001 ; Raasch, Herstatt et Balka, 2009 ; Aitamurto et al., 2013 ; van der Beek, 2012 ; Tooze et al., 2014). Néanmoins,

2.4 Conception ouverte

Nous avons montré l'importance du processus de conception dans le développement de nouveaux produits, ainsi que la nécessité de créer des modèles de ce processus de conception afin de formaliser la singularité de chaque approche de la conception, afin de pouvoir bénéficier de ses caractéristiques propres. Nous avons ensuite présenté différentes approches de la conception, et montré en quoi elles diffèrent. Notre objectif est maintenant de détailler ce qu'est la conception ouverte, son caractère singulier, et son lien avec d'autres formes de conception.

i Que signifie « ouvert » dans conception ouverte ?

Nous avons vu que la définition de l'open-source permettait d'envisager ce paradigme en dehors du secteur informatique. Ce qu'il y a de commun aux différentes instances de l'approche ouverte, c'est la notion d'ouverture. L'*Open Knowledge Foundation* la définit comme il suit : « Être ouvert signifie que chacun peut librement accéder, utiliser, modifier et partager dans n'importe quel but. Cela peut tout au plus être sujet à des restrictions visant à préserver la traçabilité et le caractère ouvert » (OKF, 2015). Ainsi les principes fondamentaux sont le libre accès, la libre utilisation, et une potentielle limitation. Ces principes induisent deux conséquences : le caractère digital du contenu partagé (afin d'assurer le libre accès dans la pratique), des collaborations de pair à pair.

Le Tableau 2.2 met en avant les implications de l'approche ouverte.

Table 2.2
Aspects principaux de l'ouverture, et leurs impacts sur les logiciels et les produits tangibles.

Principes de l'approche ouverte	**Libre accès**	**Libre (ré)utilisation**	**Restrictions potentielles**
Conséquences pour les logiciels	– sources disponibles en ligne – nouveaux modèles d'affaire	– sources diffusées en langage humain – multiplications de version alternatives et modifiées – les utilisateurs finals prennent part à la conception	– utilisation de licences spécifiques (Apache, GPL, etc.)
Conséquences pour les produits tangibles	– numérisation des sources	– développement de travaux dérivatifs – utilisateurs finaux comme concepteurs bénévoles – nouveau processus de développement	– apparition de nouveaux cadres légaux (e.g. licences Creative Commons)

Table 2.1
Comparaison des approches de la conception

Approche	**Linéaire**	**Cyclique**	**Agile**	**Externalisée**
Pour concevoir	Biens tangibles	Biens tangibles et numériques	Biens numériques	Biens ouverts
Besoin	Besoin défini au début du projet. Généralement pas lié aux concepteurs.	Besoin défini au début du projet. Généralement pas lié aux concepteurs.	Besoin défini au début du projet. Peut être redéfini après chaque itération.	Besoin évolue en fonction des acteurs du projet et de leurs priorités
Activités	Processus linéaire d'action-validation	Execution itératif d'un certain nombre d'activités	Itération fréquente de phases de conception, pour amélioration incrémentale	Certaines activités seulement peuvent être externalisées
Acteurs	Spécialisés et organisés en silos	Équipes multidisciplinaires avec interactions informelles	Équipes multidisciplinaires avec interactions informelles	Équipe restreinte entourée de nombreux participants pour certaines activités
Représentations intermédiaires	Formalisées après chaque étape	Informelles durant le processus de conception	Formalisées à la fin des sprints de conception	Totalement numérisées et accessibles en ligne
Plan	Formalisé à la fin du processus	Formalisé à la fin du processus	Les fonctionnalités et la qualité s'accroît après chaque itération	Numérisé et évoluant continuellement

2.3 Modèles de processus de conception existants

Nous avons vu pourquoi et comment on modélise les processus de conception de produit. L'objectif de cette section n'est pas de présenter une liste exhaustive des modèles (voir Tomiyama et al., 2009 ; Howard et al., 2008 ; Cross et Roozenburg, 1992 ; Finger et Dixon, 1989a,b pour cela), mais de mettre en avant ce qui diffère entre ces modèles.

i Classification des modèles de conception

On peut classer les modèles en fonction de leur apparence (linéaire, cyclique) (Blessing, 1994). On peut également s'intéresser à leur stratégie : plutôt orientée vers la recherche de solution ou l'analyse de problèmes (Wynn et Clarkson, 2005). Enfin, on peut évaluer leur niveau d'abstraction (Tomiyama et al., 2009).

Notre grille de lecture s'intéresse, elle, au type de produit conçu (tangible, digital, ou immatériel), ainsi qu'au niveau d'ouverture de la conception (ouvert ou traditionnel) — voir Figure 2.4.

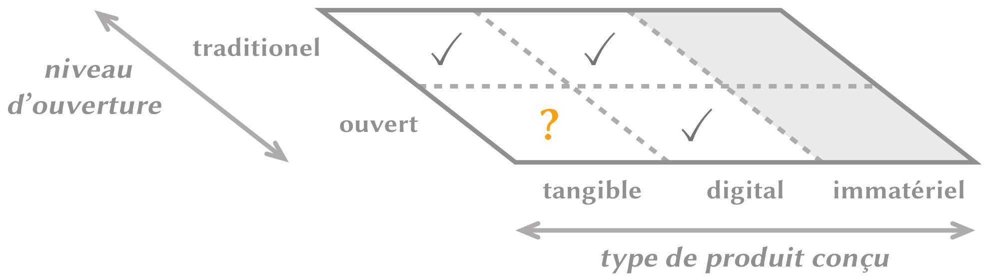


Figure 2.4
Les différents types de modèles de conception.

Nous pouvons observer qu'il existe des modèles de conception traditionnels pour tous les types de produits. Cependant, pour dans le cadre de conception ouverte, nous n'avons trouvé que des modèles pour le développement de logiciels (produit digital). (La conception de service ne rentre pas dans le cadre de notre recherche.)

ii Analyse des différents processus de conception

Le Tableau 2.1 présente une comparaison des différentes approches de la conception en fonction des cinq paramètres de descriptions d'un processus de conception (voir Figure 2.3).

indiquant quelles sont les activités (ou étapes) de ce processus, quels sont les acteurs y prenant part, ainsi que les représentations intermédiaires utilisées pour véhiculer de l'information sur le produit entre étapes et entre acteurs.

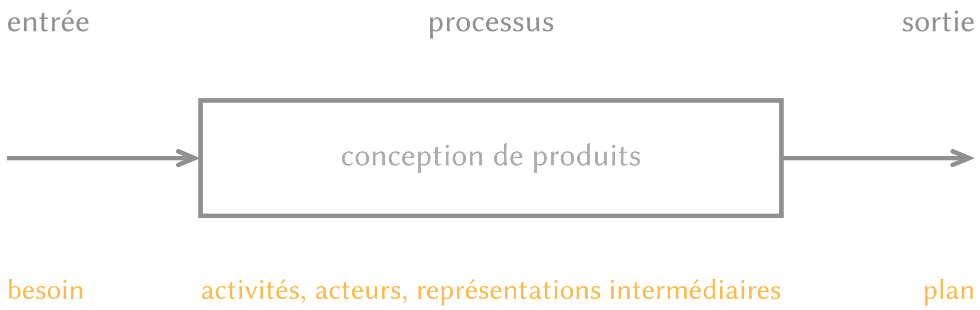


Figure 2.3
Les cinq paramètres utilisés pour décrire le processus de conception.

iv Développer des modèles de processus de conception

De nouveaux modèles de conceptions sont créés d'abord dans une approche descriptive, afin de formaliser et donc mieux comprendre les pratiques actuelles. Cela a pour objectif dans un second temps de développer des modèles normatif afin d'améliorer l'efficacité de ces pratiques, ainsi que leurs outils et méthodes adéquats. Ce mouvement illustre le caractère appliqué des sciences de la conception qui a notamment pour objectif final l'amélioration des pratiques de conception.

Plusieurs méthodologies existent pour modéliser des processus humains, notamment dans le cadre des processus d'entreprise (Kettinger et al., 1997 ; Aguilar-Savén, 2004 ; Giaglis, 2001). Certains d'entre eux sont dédiés aux processus de conception (Smith et Morrow, 1999). Ils diffèrent en fonction de leur objectif, et de leur objet. Amigo et al. (2013) étudie une large palette de méthodes de modélisation et émet des recommandations en fonction des objectifs de celle-ci. Dans notre cas, nous souhaitons définir des séquences d'activités, mettre en avant les flux d'informations, les différents livrables pour mieux comprendre le processus de conception. Mais aucune technique ne semble adaptée.

Nous avons donc cherché des techniques de modélisation hors du champ des sciences de la conception. L'une d'entre elle est la théorisation ancrée (Strauss et Corbin, 1994, 1998). Cette approche permet la structuration systématique et par étape d'un corpus de données brutes. Elle est adaptée pour révéler des processus sociaux implicites (Lingard et al., 2008), et correspond donc à nos critères.

de la conception est donc « la description finale du produit conçu » (Cross, 2000, p. 4). Il est composé de plans, nomenclatures, fichiers 3D, instructions de montage, etc.

ii Un processus cognitif et de multiples processus industriels

La conception de produits est un processus complexe. Elle met en jeu de nombreux acteurs avec de nombreuses contingences, est influencé par une multitude de facteurs et s'attaque à des problèmes très divers. C'est une instance de résolution de « problèmes mal définis » (Rittel et Webber, 1973 ; Cross, 1982 ; Willem, 1990 ; Buchanan, 1992). Le problème initial ne contient pas toutes les informations nécessaires à sa résolution (et contient souvent des attentes contradictoires). En effet, « les informations nécessaires pour comprendre le problème dépendent de l'idée que l'on se fait de sa solution » (Rittel et Webber, 1973, p. 161).

Ainsi, si le processus cognitif ayant lieu durant la conception est commun à tous les processus de conception (ce processus est composé de quatre phases, dont deux étapes abductives principales, permettant la transition d'un espace problème à un espace solution), son application en méthode est-elle fortement influencée — notamment par le type de produit à concevoir. Ainsi, de nombreux modèles de processus de conception sont décrits dans la littérature pour rendre compte de cette multitude de pratiques.

iii Décrire le processus de conceptions

Un processus peut, de manière générale, être décrit par ses données d'entrées, le processus lui-même, et les données de sorties. Dans le cas de la conception, les données d'entrée sont le besoin, et celles de sortie, le plan (voir Figure 2.3). On peut détailler la description du processus lui-même en

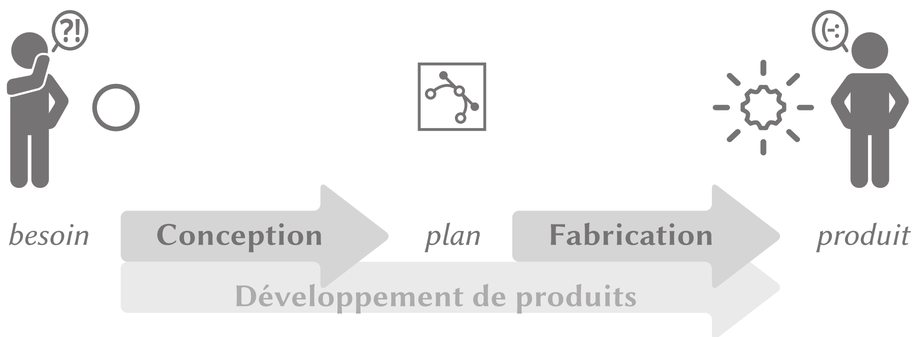
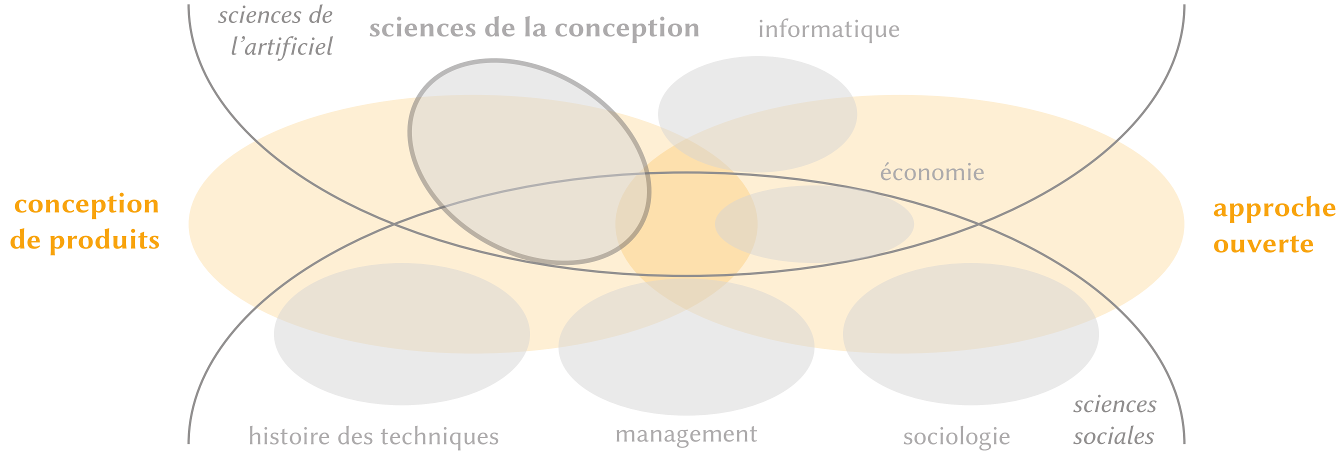


Figure 2.2
Développement de produits et ses deux sous-composantes : la conception et la fabrication, *adapté de* Ulrich *(2011, Exhibit 1-9, p. 6)*



iii Environnement scientifique

Figure 2.1 Domaines d'étude et d'apports : nos recherches s'inscrivent dans le cadre des sciences de la conception.

Ces recherches ont été menées au sein du Laboratoire Conception de Produits et Innovation d'Arts et Métiers ParisTech. Ce laboratoire étudie l'optimisation du processus de conception de produits à travers trois approches : l'intégration de savoirs métiers, la modélisation des processus individuels et collectifs aux différentes étapes de la conception, ainsi que le développement d'outils et technologies supports. C'est dans la seconde optique que nous nous plaçons.

Nos travaux sont aussi liés à des communautés scientifiques internationales qui se sont intéressées à des problématiques similaires. On peut ainsi lister une école allemande (Balka et al., 2010), une école américaine (Hippel et Krogh, 2003 ; Lakhani et Wolf, 2005), une école brésilienne (Macul et Rozenfeld, 2015), une école néerlandaise (Van Abel, Evers et Klaassen, 2011 ; Troxler, 2011b), ainsi qu'une école franco-allemande (Bonvoisin et Boujut, 2015).

2.2 Modélisation des processus de conceptions

i Définition de la conception de produits

La développement de produit est la « transformation d'une opportunité de marché en un produit sur les étales » (Krishnan et Ulrich, 2001, p. 1), c'est à dire partir d'un besoin et arriver à un produit. La conception de produit est la première étape de ce processus (voir Figure 2.2). Elle part du besoin et vise à définir de manière univoque un futur produit (tangible, digital, ou même immatériel), répondant au besoin, et qui doit être produit. Le résultat

Chapitre 2
État de l'art

Nous avons décrit un champ de recherche qui nous apparaît intéressant d'étudier : la conception ouverte et sa modélisation. Nous présentons maintenant un état de l'art sur cette thématique afin de retracer les recherches précédentes menées sur ce sujet, clarifier les limites actuelles de notre compréhension de cette nouvelle approche, ainsi que définir les termes et méthodes utilisée dans la suite de notre recherche. Nous présentons tout d'abord notre positionnement scientifique, puis nous passons en revue les travaux concernant la modélisation des processus de conception, les modèles de processus existants, et enfin, la conception ouverte.

2.1 Positionnement

i Paradigme épistémologique

Nous plaçons nos travaux dans le paradigme post-positiviste. Nous utiliserons donc la méthodologie *modified manipulative*. Ainsi, nous utiliserons tant des méthodes qualitatives que quantitatives.

ii Domaines d'étude et d'apports

Nos recherches s'enracinent à la fois dans les sciences de l'artificiel qui s'intéressent aux objets et phénomènes conçus par l'humain (Simon, 1996), ainsi qu'aux sciences sociales qui étudient les hommes et leurs interactions. Nous bénéficierons d'apports venant de l'informatique, de l'histoire des techniques, du management, de l'économie, de la sociologie (voir Figure 2.1). Mais c'est essentiellement des sciences de la conception dont nous nous enrichirons. C'est aussi à cette discipline que nous contribuerons.

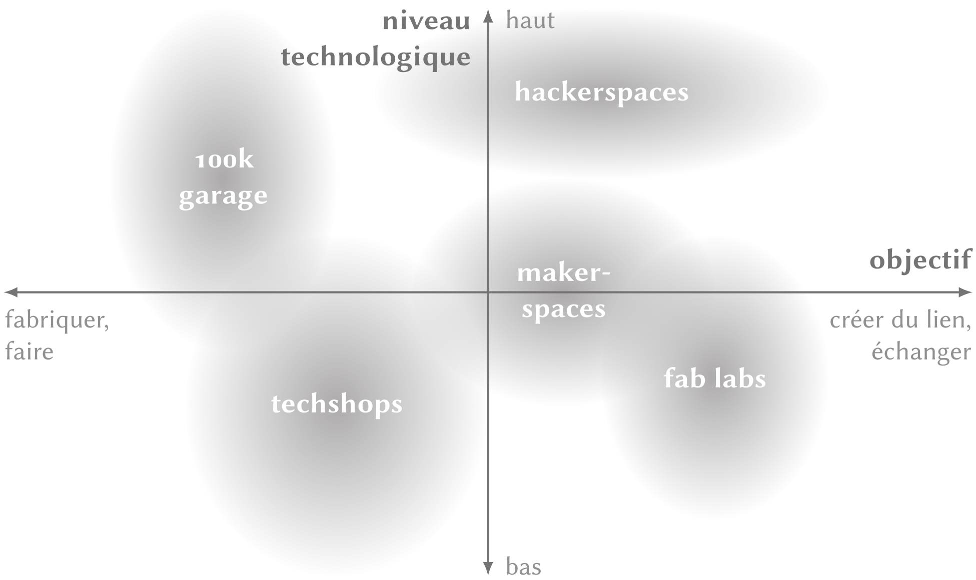


Figure 1.2
Des tiers-lieux pour la conception, *adapté de* Troxler *(2011a, p. 92)*.

donné lieux à de nombreux succès industriels. Il semble donc pertinent d'espérer les mêmes bénéfices dans le domaine du tangible. Ces démarches reposent sur deux aspects : l'externalisation et répartition à grande échelle des tâches de conceptions, ainsi que la réutilisation de savoirs préexistants.

iii De l'importance de modéliser la conception ouverte

Les projets de conception ouverte partagent certaines caractéristiques avec les logiciels libres : accès aux sources, développement modulaire, contributions de participants volontaires externes au projet, etc. Cependant, les bonnes pratiques de la conception de logiciels libres ne sont pas directement transposables pour la conception des produits tangibles. En effet, à la différence des octets, les atomes sont des biens rivaux à coût marginal de duplication non-nul : reproduire un objet demande du temps et des ressources. De même, partager un objet à travers le globe ne peut se faire instantanément.

Pour autant, les méthodes de conception traditionnelle ne prennent pas en compte les spécificités de l'approche ouverte. Cela empêche le développement d'outils spécialisés afin que les praticiens puissent pleinement exploiter les avantages de la conception ouverte.

iii L’approche ouverte : l’open-source au-delà de l’informatique

L’open-source peut être défini comme « une approche de la conception de logiciels et de la propriété intellectuelle dans laquelle le code source du logiciel est disponible pour tous les participants et peut être modifié par chacun d’entre eux » (Warger, 2002, p. 18). On voit que ce qui est « ouvert » c’est le code-source et non le logiciel lui-même. Cela rend possible l’interprétation de cette approche en dehors du secteur informatique : données ouvertes (Bonnet et Lalanne, 2014), open-art et culture (Maurel, 2014), éducation ouverte avec les moocs, science ouverte (Gruson-Daniel, 2014), licences ouvertes (FSF, 2007).

1.3 La conception ouverte

Le troisième thème est la conception ouverte qui est à la rencontre de la conception de produits et de l’approche ouverte.

i L’émergence de la conception ouverte

La conception ouverte a été rendue possible grâce à trois facteurs. Tout d’abord, la démocratisation de la production. En effet, par l’apparition de machines-outils grand public et à moindre coût (impression 3D, mais aussi découpe laser, etc.), de nombreux utilisateurs ce sont mis à fabriquer eux-mêmes leurs produits. Cela est un premier pas vers la conception par eux-mêmes de ces produits.

Deuxièmement, la numérisation du processus de conception. Les outils de modélisation 3D deviennent notamment grand public et permettent au plus grand nombre de dessiner soi-même ses objets. De plus, la digitalisation de l’ensemble de la chaîne de développement de produit fait que l’importance d’un savoir-faire est moindre, et qu’il devient facile d’externaliser à grande échelle certaines étapes du développement.

Enfin, de nouvelles structures de conceptions comme les fab labs ou les makerspaces (voir Figure 1.2) se sont développées, démocratisant un peu plus la conception de produits.

ii L’intérêt de la conception ouverte

L’intérêt des logiciels libres sont reconnus depuis longtemps : flexibilité, liberté, fiabilité, contrôlabilité, stabilité, facilité de maintenance, etc. Ils ont dédiés) à une structure horizontale (une marque pouvait vendre ses logiciels à plusieurs types d'ordinateurs) (Ong, 2004). Les éditeurs logiciels ont donc cherché à protéger leur propriété intellectuelle en ne distribuant des logiciels que sous forme binaire (i.e. en langage compréhensible par une machine, mais pas un humain). Ce n'était alors pas le cas, ce qui permettait aux utilisateurs qui le voulaient d'améliorer leurs logiciels, voire de corriger eux-mêmes des bugs (Stallman et Williams, 2010). Ainsi, la *Free Software Fundation* s'est formée pour promouvoir quatre libertés caractérisant un logiciel libre (FSF, 2014 ; Weber, 2004) :

— liberté d'utiliser un logiciel sans restriction,
— liberté d'étudier et de modifier son fonctionnement,
— liberté de distribuer des copies de ce logiciel,
— liberté de distribuer des copies d'une version modifiée de ce logiciel.

Certains acteurs du secteur logiciels n'ont pas partagé l'approche militante (ou « politique » — Stallman, 2008) de promotion du logiciel libre. Ils ont créé l'Open-Source Initiative qui promeut les avantages concrets de l'open-source avant toute considération idéologique (Open Source Initiative, 2006) Cette approche apolitique c'est ensuite répandue dans d'autre secteurs industriels.

La Figure 1.1 présente les différentes notions liées au logiciel libre.

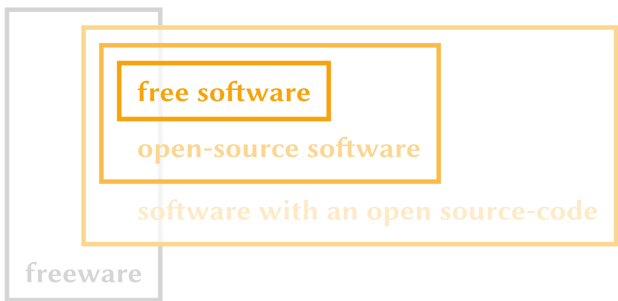


Figure 1.1
Terminologie autour du logiciel open-source : logiciel libre, logiciel open-source, logiciel avec code-source ouvert, et logiciel gratuit.

ii Spécificité des modèles de conceptions de logiciels libres et open-source

Les caractéristiques des logiciels libres ou open-source ont bousculé les processus de conceptions dans le secteur informatique. De nouveaux acteurs (notamment des utilisateurs amateurs) ont pris part au processus de conception, on a vu des nouvelles formes de collaboration décentralisée, asynchrone et non coordonnée (Raymond, 2001 ; Kogut et Metiu, 2001).

ii Les sciences de la conception

Depuis les années 1950, les sciences de la conception visent à étudier ce processus pour mieux comprendre les pratiques existantes, proposer des processus plus efficaces et développer les outils et méthodes adéquats (Simon, 1996 ; Heymann, 2005 ; Papalambros, 2015 ; Blessing et Chakrabarti, 2009). Plusieurs approches discutent de la nature de ce processus : singulier ? scientifique ? (Cross, 2001) Nous considérerons que, peu importe la nature du processus, celui-ci peut être l'objet de la science, c'est-à-dire qu'il peut être étudié selon la méthode scientifique.

iii De multiples modèles de processus de conception

De nombreux modèles de processus de conception sont décrits dans la littérature scientifique. En effet, le caractère singulier de chaque besoin et du contexte dans lequel il s'exprime ainsi que de la manière dont il est traité, font qu'il n'y a pas de « méthode miracle » qui pourrait s'appliquer dans chaque cas (Wynn et Clarkson, 2005).

Les modèles de conception servent à formaliser les pratiques et mieux les comprendre. Ces modèles sont nécessaires (Ullman et al., 1988) pour développer des outils supports pour les praticiens. De grandes familles de modèles se dessinent : des modèles généraux qui donnent un point de vue global sur le processus de conception mais sont de peu d'utilité pour le praticien, et des méthodes plus appliquées, mais valides dans un nombre restreint de contextes (Wynn et Clarkson, 2005). Ces différentes méthodes servent notamment à prendre en considération les particularités du produit conçu (produit tangible, digital, ou service).

1.2 L'approche ouverte

Le deuxième thème sur lequel repose notre recherche est l'approche ouverte. Celle-ci prend racine dans les mouvements du logiciel libre, et de l'open-source qui se sont ensuite répandus dans d'autres secteurs.

i Logiciels libres et open-source : les origines de l'approche ouverte

Le mouvement du logiciel libre est né à la fin des années 1970, en réaction à un changement de structure du secteur informatique. Celui-ci est passé d'une structure verticale (la même marque produisait ordinateurs et logiciels

Chapitre 1
Contexte et enjeux

L'objectif de ce premier chapitre est d'introduire la question de recherche qui a motivé notre étude. Nous utilisons notamment une approche historique pour présenter les grands thèmes de notre thèse : la conception de produits, l'approche ouverte, et l'émergence de la conception ouverte.

1.1 La conception de produits

Nos travaux s'inscrivent dans le domaine des sciences de la conception. Nous présentons brièvement ce cadre, et montrons pourquoi il est nécessaire de développer de multiples modèles de processus de conceptions

i Définitions préliminaires

De nouveaux produits sont conçus pour répondre à des besoins actuellement insatisfaits. Le développement de produits est ainsi le processus qui part d'un besoin et tend à fournir un produit qui répond à ce besoin. Ce processus se décompose en deux parties : la conception, et la production (Ulrich, 2011). La conception a pour objectif d'imaginer et de décrire le système allant répondre au besoin, tandis que la production a, elle, pour objectif de réaliser — ou de fabriquer — ce système. À la jonction de ces deux processus se trouve le « plan » du produit, c'est-à-dire sa description univoque, aboutissement de la conception, et servant de donnée d'entrée à la production.

Cette thèse se concentre sur la conception de produits. En effet cette étape est cruciale dans le coût final d'un produit, et donc son succès industriel (Ulrich et Pearson, 1998 ; Ullman, 2010 ; Ulrich et Eppinger, 2012). Améliorer la conception permet donc de développer plus efficacement des produits plus pertinents et répondant mieux à nos besoins.

Table des matières

Résumé

L’open-source a révolutionné le secteur informatique par une nouvelle approche publique, décentralisée, et asynchrone de la conception qui encourage la collaboration entre pairs. De nouveaux acteurs et pratiques ont bouleversé le processus de conception, mais aussi donné lieu à des succès industriels. Cette approche se répand aujourd’hui à la conception de produits tangibles, à cause de la numérisation et la démocratisation de ce processus — c’est la conception ouverte.

Nombre de pratiques hétérogènes sont cependant regroupées sous ce terme. Les liens avec les pratiques existantes ne sont pas non plus clairement identifiés. Enfin, peu d’informations à propos du processus de conception ont été formalisées dans la littérature scientifique. Cela freine le développement d’outils pertinents qui permettraient aux concepteurs d’exploiter pleinement les spécificités de la conception ouverte.

Ainsi, nous nous sommes intéressés à la modélisation du processus de conception ouverte, dans le cadre du développement de produits tangibles. Nous avons d’abord élaboré une typologie des pratiques via une revue systématique de la littérature. Ensuite, via une approche par théorisation ancrée, nous avons construit des modèles mettant en lumière les différentes facettes du processus de conception : phases, acteurs, représentations intermédiaires.

À travers notre état de l’art, nous avons défini et cartographié la conception ouverte et les notions connexes. Par l’étude de 624 entrées de la base de données *Scopus*, nous avons identifié trois types de pratiques : *do-it-yourself*, *meta-design*, and *industrial ecosystem*. Elles sont liées au statut (amateur ou professionnel) des concepteurs et destinataires du processus. Nous avons aussi construit deux modèles du “do-it-yourself open-design” à partir d’interviews semi-directifs de 11 participants à des projets de conception ouverte. Cette approche apparaît influencée à la fois par le logiciel libre et la conception amateur. La qualité de nos modèles et de notre modélisation a été validée par l’outil statistique.

Cette étude ambitionne d’être une référence pour de futures recherches sur la conception ouverte, en proposant un panorama détaillé des pratiques liées à ce phénomène. Nos modèles descriptifs doivent servir de point de départ pour développer des outils pertinents à l’intention des praticiens. Notre méthode de modélisation peut également être répliquée dans d’autres contextes pour formaliser des processus encore non cartographiés.

Boisseau, Étienne (2017) *Open-Design. Modeling the open-design process in the development of tangible products.* PhD thesis, Arts et Métiers ParisTech. Paris, France.

Open-Design

Modélisation du processus de conception ouverte, dans le cadre du développement de produits tangibles

Étienne Boisseau · Abrégé en langue française

OPEN-DESIGN. MODELISATION DU PROCESSUS DE CONCEPTION OUVERTE, DANS LE CADRE DU DEVELOPPEMENT DE PRODUITS TANGIBLES

RESUME : L'open-source a révolutionné le secteur informatique par une nouvelle approche publique, décentralisée, et asynchrone de la conception qui encourage la collaboration entre pairs. De nouveaux acteurs et pratiques ont bouleversé le processus de conception, mais aussi donné lieu à des succès industriels. Cette approche se répand aujourd'hui à la conception de produits tangibles, à cause de la numérisation et la démocratisation de ce processus – c'est la conception ouverte.
Nombre de pratiques hétérogènes sont cependant regroupées sous ce terme. Les liens avec les pratiques existantes ne sont pas non plus clairement identifiés. Enfin, peu d'informations à propos du processus de conception ont été formalisées dans la littérature scientifique. Cela freine le développement d'outils pertinents qui permettraient aux concepteurs d'exploiter pleinement les spécificités de la conception ouverte.
Ainsi, nous nous sommes intéressés à la modélisation du processus de conception ouverte, dans le cadre du développement de produits tangibles. Nous avons d'abord élaboré une typologie des pratiques via une revue systématique de la littérature. Ensuite, via une approche par théorisation ancrée, nous avons construit des modèles mettant en lumière les différentes facettes du processus de conception : phases, acteurs, représentations intermédiaires.
À travers notre état de l'art, nous avons défini et cartographié la conception ouverte et les notions connexes. Par l'étude de 624 entrées de la base de données *Scopus*, nous avons identifié trois types de pratiques : *do-it-yourself*, *meta-design*, et *industrial ecosystem*. Elles sont liées au statut (amateur ou professionnel) des concepteurs et destinataires du processus. Nous avons aussi construit deux modèles du « do-it-yourself open-design » à partir d'interviews semi-directifs de 11 participants à des projets de conception ouverte. Cette approche apparaît influencée à la fois par le logiciel libre et la conception amateur. La qualité de nos modèles et de notre modélisation a été validée par l'outil statistique.
Cette étude ambitionne d'être une référence pour de futures recherches sur la conception ouverte, en proposant un panorama détaillé des pratiques liées à ce phénomène. Nos modèles descriptifs doivent servir de point de départ pour développer des outils pertinents à l'intention des praticiens. Notre méthode de modélisation peut également être répliquée dans d'autres contextes pour formaliser des processus encore non cartographiés.

Mots-clefs : open-design, open-source, conception de produits

OPEN-DESIGN. MODELING THE OPEN-DESIGN PROCESS IN THE DEVELOPMENT OF TANGIBLE PRODUCTS.

ABSTRACT: Open-source revolutionized the software industry through a public, decentralized, and asynchronous development paradigm that fosters collaboration among peers. New practices and stakeholders disrupted the designing process, yet led to industrial successes. Due to the digitalization and democratization of the designing process, this approach now spreads to the development of tangible artifacts. This is open-design.
However, open-design currently appears as an umbrella term that encompasses from amateur do-it-yourself projects to sector-scale industrial collaborations. It is not clear either, how these practices relate to existing designing approaches. Finally, little knowledge about the open-design process is formalized. This impedes the development of adequate tools for helping practitioners to make the most of it.
Therefore, we investigated how to model the open-design process in the development of tangible products. First, we developed a typology of open-design practices based on a systematic search and review of the scientific literature. Then, we selected one of the types identified and modeled the different facets of the designing process (activities carried out, stakeholders involved, and boundary objects used) in this context, using a grounded theory-based approach.
Through our literature review, we mapped open-design in relation to existing designing approaches, and coined a new definition thereof. Based on 624 papers indexed in the *Scopus* database, we identified three types of practices – *do-it-yourself*, *meta-design*, and *industrial ecosystem* – which are related to the status (professional or amateurs) of the processes' stakeholders and addressees. We also constructed two models of the "do-it-yourself open-design" process using semi-directive interviews of 11 project leaders who took part in the *PoC21* innovation camp. They depict open-design as a designing process influenced by both open-source software development and amateur design. We tested the quality of our models and our modeling method via statistical analysis.
This study aims to be a cornerstone for future research on open-design by providing an overview of practices linked to this phenomenon. Our descriptive models should serve researchers for providing practitioners of open-design projects with relevant tools and methods. Our modeling method could also be applied in other contexts to formalize uninvestigated designing practices.

Keywords : open-design, open-source, product design

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