



HAL
open science

Building Open Source Hardware Business Models

Karine Evrard-Samuel, Peter Troxler, Laetitia Thomas

► **To cite this version:**

Karine Evrard-Samuel, Peter Troxler, Laetitia Thomas. Building Open Source Hardware Business Models. Francisco José Monaco. Business Models and Strategies for Open Source Projects, IGI Global, pp.50 - 79, 2023, 9781668447857. 10.4018/978-1-6684-4785-7.ch003 . hal-04514641

HAL Id: hal-04514641

<https://hal.science/hal-04514641>

Submitted on 21 Mar 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Chapter 3

Building Open Source Hardware Business Models

Laetitia Marie Thomas

Université Grenoble Alpes, France

Karine Evrard-Samuel

Université Grenoble Alpes, France

Peter Troxler

Hogeschool Rotterdam, The Netherlands

ABSTRACT

Open source hardware (OSH) initiatives are collectively managed projects enabled by the internet and digital fabrication tools. They allow people to create products in a cheaper, faster, and more efficient manner. To date, there is no strategic and actionable framework using the commons theory for analyzing how these hardware initiatives develop economically effective and sustainable business models. Based on an analysis of the business models of 27 community-based and community-oriented OSH initiatives studied over a 3-year period, this chapter presents such a framework. The five-stages spiral framework offers to guide companies and startups involved in OSH to interact with their surrounding innovation ecosystems progressively, enrich their value propositions and grow in impact.

Over the past decade, despite research interest in Digital Commons (Fuster Morell, 2014; Acquier *et al.*, 2016; Benkler, 2017; Raworth, 2017; Litman, 2014), little information exists on how commons-based peer-production open source hardware (OSH) initiatives may monetize their innovations. The aim of this chapter is to investigate the business models used by open-source hardware entrepreneurs and

DOI: 10.4018/978-1-6684-4785-7.ch003

Building Open Source Hardware Business Models

explore the nature of the value created in such initiatives. Question which continue to baffle researchers are:

- How can value creation and capture be based on a collective resource?
- Can a resource arrangement that works in practice work in theory?
- How can design documentation be commercially exploitable, freely editable and available concurrently?

Open Design, identified as critical for spreading the impact of the circular economy, has become the *modus operandi* for social design. Therefore, understanding its growth patterns and deviations is important as this addresses the long-term viability in the context of the economic transformation needed to implement circular economy and the UN's SDG goals.

Open source hardware and peer production, both instances of Digital Commons applied to manufacturing, are believed to be the most radical, theoretical and organizational innovations to have emerged from the Internet (Raasch *et al.*, 2009; Van Abel *et al.*, 2010; Bonvoisin, *et al.* 2016; Moritz *et al.*, 2016; Benkler, 2016; Sanguinetti, 2019).

To date, Commons research has focused on how Open Source and Knowledge Commons need to be purposefully protected from enclosure and kept open as raw material for ideas (Hess & Ostrom, 2011; Litman, 2014). Fuster Morell and Espelt, (2018) devised a much-needed holistic framework to assess the knowledge, governance and technological openness of commons-based cooperative platforms. Raworth (2017) explained that distributed and regenerative designs are novel configurations of value creation and capture in Digital Commons. Troxler, (2019) has adapted Ostrom's governance principles (1990) to Open Design.

Yet, to our knowledge, how Digital Knowledge Commons can be monetized, and what growth patterns could be aligned with distributed and generative value, have yet to be developed in literature. Thus, it is interesting to look closely at business models for open source hardware as this concept represents the orchestration of activities surrounding value creation, delivery and capture (Teece, 2010; Zott & Amit, 2010). The purpose of this chapter therefore, is to provide an actionable, strategic framework to help open source entrepreneurs in developing their business models. The 5-stage spiral framework is a creativity tool for brainstorming "what is right for us" solutions. OSH projects may use the modular nature of business model patterns, combining them like building blocks according to an organization's strategic needs. As organizations iterate through the stages, they are enriched from slightly different perspectives.

This chapter is structured as follows: the first section details the implications of OSH, with Digital Knowledge and Innovation Commons, on entrepreneurship and

Building Open Source Hardware Business Models

business models. The following section explains how different model types may be strategically used as building blocks depending upon an organization's needs. The authors present a framework showcasing the most frequent to the most daring business model patterns used in OSH initiatives. Lastly, they explain how OSBMs have the potential of shifting away from linear and extractive production and consumption models to ones where value is generated, appropriated and preserved.

BACKGROUND

Digital Knowledge Commons

The Commons Theory is an intriguing boundary-spanning theory, expressing the transition from hierarchical and proprietary logic based on closed property, to a decentralized, contributive logic of structured openness managed by formal and informal institutional mechanisms. Choosing the Commons theory as a theoretical base offers a feasible construct from which to study how open source hardware initiatives grow while opening up their core innovation to a wider community.

The Theory contends that Digital Commons are a self-organized social system for the long-term stewardship of non-depletable and non-rivalrous resources preserving shared values and community identity, and are subject to social dilemmas. Unlike Natural Commons which are scarce, the particularity of Digital Commons is that the more they are used and shared, the more efficient, cheaper and transparent they become. They furnish raw material for ideas and need to be kept open in order that knowledge circulate (Bollier, 2014; Litman, 2014; Raworth, 2017; Hess & Ostrom, 2011).

In the case of free and libre open source hardware (FLOSH) because the building plans, assembly instructions, and bills of materials are published on a digital platform, such as GitHub, they are *Digital Knowledge Commons*. Eric Von Hippel (2005), in the concluding insights of his book *Democratizing Innovation* writes, "As innovation becomes more user-centered, the information needs to flow more freely and in a more democratic way, thereby creating "rich intellectual commons . . . [and] attacking a major structure of the social division of labor."

Kate Raworth (2017) explains that the Commons theory is powerfully disruptive, as it addresses novel configurations in value creation and capitalism through *distributive* and *regenerative* design. The notion of "distributive" means easy to replicate. Anyone with an Internet connection can entertain, inform, learn and teach worldwide.

Digital fabrication technologies are the essence of distributive design and manufacturing as they blur the line between producers and consumers. Applied to industry, the term distributive manufacturing means democratizing access to

Building Open Source Hardware Business Models

manufacturing. The idea is to make technology more robust, more modular and more freely available, globally empowering global citizens to break away from currently unsustainable supply chains (Rifkin, 2014, p.8; Kumar *et al.*, 2020; Rauch *et al.*, 2016).

The other disruption offered by Digital Commons is that of being regenerative by design. The concept of a circular economy is the intention of transforming industrial manufacturing from extractive to regenerative design by using renewable energy and eradicating waste by design. Diverging from the take-make-and-waste mentality, waste becomes “food” as biological and technical materials are never used up and thrown away but circulated again and again through cycles of reuse and renewal. (Raworth, 2017, p. 220). Sustainability as meeting the needs of the present without compromising the needs of future generations to meet their own needs, merely means achieving a neutral point of not doing any more damage to our ecosystem. Regenerative design goes further, restoring, renewing and revitalizing energy sources and materials. Regenerative design integrates the needs of society with those of nature (Orcajada, 2021).

To these novel configurations, generativity is added as the human capacity to problem-solve in a myriad of different ways adapted to a plethora of different contexts. Eglash (2016) refers to generativity as “the bottom-up circulation of unalienated value”. Zittrain defines generativity as unintended applications which spontaneously occur when “driven by large, varied, and uncoordinated audiences” (2006, p. 1980). Troxler, (2010) defines it as “fab-lab magic”: the satisfaction of going from an idea to a tangible reality and of showing others how to do it. In layman’s terms, this means making sure the “apple seed” of an innovation – design plans, bill of materials and assembly instructions – remains open, so as to generate countless new apple trees. Generativity is the basis of the Academany programs, developed by Neil Gershenfeld and Sherry Lassiter, sets the grounds for worldwide educational collaborations offering distributed education on demand, combining local manufacturing and global networking.

Table 1 provides a literature review on the Commons theory covering the history of the Commons (Ostrom 1990), the integration of Commons to growth (Hess & Ostrom, 2011; Benkler, 2017; Litman, 2014); the importance of open governance (Fuster Morell and Espelt, 2018; Troxler, 2019); and the novel configurations of value creation and capture offered through Digital Commons (Raworth, 2017).

Yet, to date and to our knowledge, how Digital Knowledge Commons can be monetized, what growth patterns could be aligned with distributed, regenerative and generative value, has not been treated in literature. Thus, it is interesting to look at business models for open source hardware as this concept has become the means of representing how value is created and captured.

Building Open Source Hardware Business Models

Table 1. Literature review of the commons theory

Themes covered	Topics	Subtopics
History of the commons	Natural Commons	Tragedy, Comedy and Triumph of Commons (Raworth, 2017; Benkler, 2016; Fuster Morell, 2014).
	Digital and Knowledge Commons	Definitions of Digital Commons (Hess & Ostrom, 2011; Raworth, 2017).
		Understanding Knowledge Commons (Hess & Ostrom, 2011).
		Scope of Digital Commons (Benkler, 2006; Benkler, 2016; Litman, 2014).
		Integration of commons to growth (Benkler, 2016)
Novel configurations of value creation and capture in Commons	Distributive Design	Networked information economy (Raworth, 2017)
		Peer Production/Open source hardware/ Open Design (Benkler 2016; Li, Seering and Wallace, 2018, Li and Seering, 2019; Troxler, 2019)
		Drivers and motivations for Digital Commons (Benkler 2016, Li, Seering and Wallace, 2018)
		Challenging the centrality of property to growth (Benkler 2016)
		Integration of open commons to growth (Benkler 2016)
	Regenerative Design	Beyond sustainability to appropriate participation and design as nature (Raworth, 2018, Orcajada, 2021)
	Generative Design	Generative Justice (Eglash, 2016; Troxler, 2010)
Wealth creation	Money creation and complementary currencies (Raworth, 2018)	
Principles for Commons	Principles for common-pool resources	Principles for natural common-pool resources (Hess & Ostrom, 2011)
		Principles for Open design governance (Troxler, 2019)
		Assessment of Commons collaborative platforms (Fuster Morell & Espelt, 2018)
		Digital and Digitally supported Commons and Open Data (Fuster, Carballa Schmikowski, Smorto <i>et al.</i> , 2017)
Business Models for OSH	Dimensions of OSHBM	Components (Fjelsted <i>et al.</i> , 2012; Bonvoisin <i>et al.</i> , 2017)
		Typologies (Thomas, 2019; Pierce, 2017; 2012; Decode, 2017; Moritz <i>et al.</i> , 2016; Stacey & Pearson, 2015; Tinck & Bénichou, 2014; Wolf & Troxler, 2016)

Open Source Hardware Innovation and Entrepreneurs

Open, collaborative hardware development is a new innovation paradigm. FLOSH – which would stand for Free and Libre Open Source Hardware – in Stallman’s terms, as in “free speech not free beer”, as an alternative to intellectual property restriction is capable of grounding sustainable innovation ecosystems which, as in the software industry, are also able to leverage scientific and technological development in other industrial sectors.

Open Source Hardware Innovation is a collaborative, product development process, in which building plan designs, assembly instructions and bills of material are made publicly available online for anyone to study, replicate, modify, distribute and sell, including hardware based on those designs (Raasch *et al.*, 2009; Bonvoisin *et al.*, 2016; Bonvoisin *et al.*, 2017). Thus, OSH is characterized by knowledge sharing and decentralization enabled by modern information and communication technologies (ICT) (Moritz *et al.*, 2016). Ideally, OSH uses readily-available components, materials and standard processes, maximizing possibilities of mass participation as well as the means of deviating from conventional business models and a market economy (Troxler, 2019). As such Open Design, and OSH as part of open design, transcend

Building Open Source Hardware Business Models

organizational boundaries, blending the traditional innovation categories of product, process, managerial or radical innovations (Sanguinetti, 2019, p.52). OSH, at the crossroads of different innovation categories, represents a disruptive innovation for organizations needing to reconfigure their own business models. OSH, is part of the Design Global Manufacture Local (DG-ML) model described by Kostakis *et al.*, (2015) as a proto-model of production which, for the moment cannot perpetrate itself independently of capitalism. Nonetheless, its complementary components represent a paradigm shift away from “the irrational exploitation of resources and the ecologically destructive magnification of production and consumption”.

The open source hardware and peer production phenomena as regards manufacturing force us to reevaluate the centrality of property to growth (Raasch *et al.*, 2009; Bonvoisin, *et al.*, 2016; Moritz *et al.*, 2016; Benkler, 2017). Changes here are disruptive as they lead to changes in the firm-centric business model understanding of how firms seek to create and capture value. They suggest that innovation and manufacturing processes are becoming democratized and that “anyone” may learn and teach each other how to attain energy, food and technological sovereignty, for example.

OSH entrepreneurs are a new entrepreneur type who forgo intellectual property ownership and license their products as open source to run their businesses. They wager that benefits gained from their communities will offset the risks of lowering entry barriers to competitors (Li and Seering, 2019). These entrepreneurs tend to follow the maker ethos and open-source culture of being an actor rather than a spectator in a technological world.

Research has revealed that OSH projects have strong potential for social innovation. Often, with value-driven around notions of making, freedom and collective innovation, they materialize ideals of degrowth imaginary, such as autonomy and conviviality central to the objectives of Transition Towns and the Fab City Collective (Kostakis *et al.*, 2015; Fab City Collective 2018; Hopkins, 2019). These values help in federating support within and beyond their internal communities to include stakeholders in broader, local and global ecosystems. These values also serve to catalyze global and local DG-ML pipelines, implementing objectives such as the Fab City’s locally production of 50% of city consumption within forty years, while inspiring citizens to become interested in achieving energy, food and technological sovereignty (Thomas, 2019; Unterfrauner *et al.*, 2017; Acquier *et al.*, 2016)

Business Model Research for Open Source Hardware

If OSH is a proto production model, OSHBM are a proto business models. As Gavras (2019) suggests, the question is whether an alternative, holistic emergent productive model is proposed or if existing corporate infrastructure is reorganized according

Building Open Source Hardware Business Models

to design principles primarily native to open source culture. Indeed, at this stage, existing literature on business models for open source hardware remains descriptive but neither strategic enough for either theoretical insight nor for practical application. Fjeldsted *et al.*, (2012), analyze the novel key elements required for commercial OSH initiatives, namely the platform, drive, community, product development process, and business model. Moritz *et al.*, (2016); Li and Seering, (2019) and Mies, *et al.*, (2019), observe the crucial importance of community building in the value creation and capture mechanisms. Menichinelli (2015) and Pearce (2012; 2017) observe that such business models blur the boundaries between consumers and producers, notably for scientific equipment. Troxler and Wolf (2017) analyze such agency in the form of formally appointed functional groups (division of labor), stabilized procedures (rules), and loose networks of people (community).

Tables 2-5 display our conceptual order of the different, current literature streams concerning OSH business models from both academic and practitioner perspectives, as related to four business model design aspects – financing, product and service mix, corporate competences, and the platform model.

While peer production and open source hardware transcend firm-based management theories – they are spreading in practice, but in theory they remain a puzzle. The Commons theory is an interesting lens through which to observe this. Based on the literature review, the research gap identified is that to date there is no strategic and actionable framework using the Commons theory to analyze how open source hardware initiatives monetize their innovations and capture value; how they grow in scope and scale while opening their innovations to a broader community. To fill this gap, we studied how open source hardware initiatives grow while opening their core innovation to a wider community. This study was conducted over a three-year period, from 2016 through 2019 as part of the Franco-German OPEN! Research

Table 2. OSHBM patterns related to financing

Pattern Title	Pattern Description
3rd party funding/Contribution from wide range of actors (Decode, 2017; Moritz <i>et al.</i> , 2016)	An institution funds the production/conservation/expansion of a common as part of its own mission, or to pursue its commercial interests.
Reciprocity based voluntary contributions/Direct Donations (Decode, 2017; Stacey & Pearson, 2015)	Where individuals and organizations make voluntary financial contributions to sustain the production of a common on the basis of reciprocity.
Disassociating revenue making strategies/Two-sided market logic (Decode, 2017)	Revenue models in which a positive externality created by the main output is produced and used to create revenue (selling of user data and publicity).
Advertising (Stacey & Pearson, 2015; Moritz <i>et al.</i> , 2016)	In this version of multi-sided platforms, advertisers pay for the opportunity to reach the audience of the content creators.

Building Open Source Hardware Business Models*Table 3. OSHBM patterns related to product and service mix*

Pattern Title	Pattern Description
Product as a service (Tinck & Bénichou, 2014; Moritz <i>et al.</i> , 2016)	Rose to prominence in 1959, when Xerox introduced the "pay per copy" printing model. Now spreading throughout industries via trends such as the sharing economy and the circular economy.
Freemium (Decode, 2017)	The selling of an extended/more performant version of the original digital common.
Shifting revenue making strategies (Decode, 2017)	In order not to charge for the common produced, revenue making is shifted towards the selling of something else.
Digital to Physical (Stacey & Pearson, 2015)	Giving away the bits and selling the atoms (where bits refer to digital content and atoms refer to a physical object).
Novelty (Wolf & Troxler, 2016)	Drawing on the current state of a new technology, such as 3D printing.
Direct sale of objects via web shops (Wolf & Troxler, 2016; Moritz <i>et al.</i> , 2016)	Selling designs directly via a web shop of their own, peripheral to the main business of selling

Table 4. OSHBM patterns related to corporate competences

Pattern Title	Pattern Description
Design Centric (Tinck & Bénichou, 2014)	Most common in OSHW. Organization focused on product design and R&D, while manufacturing is handled by another party. In this model brand and community are key strategic assets.
Expertise and Experience base (Tinck & Bénichou, 2014)	Model directly inspired from FLOSS, where most common BM consists in monetizing expertise and services.
Research and educational activities (Wolf & Troxler, 2016)	3D printing courses. Creating physical objects for educational purposes, or improving 3D printing technology. Excluded sharing of knowledge.
Manufacturing Centric (Tinck & Bénichou 2014)	The organization's core value proposition is to manufacture and distribute OSHW for an affordable price.
Customized prototyping for industry or private clients (Wolf & Troxler, 2016; Moritz <i>et al.</i> , 2016)	To repair broken objects or to create personal things. May include closed parts and dual licensing.
Standardize and Leverage (Tinck & Bénichou 2014)	Opening up one key product, which can be profitable in itself, but the openness serves to make the associated technology a de facto standard in the industry.

project, and studied 27 different open source mechatronic hardware initiatives. Table 6 displays the research design of the study in which the authors use open source hardware initiatives as a case study to explore how Digital Knowledge Commons can be both monetized and shared with a broader community.

Building Open Source Hardware Business Models

Table 5. OSHBM patterns related to the platform model

Pattern Title	Pattern Description
Membership fees (Stacey & Pearson, 2015)	A traditional nonprofit funding model. In the Made with Creative Commons context, they are directly tied to the reciprocal relationship that is cultivated with the beneficiaries of their work.
Brokerage/ Matchmaking (Decode, 2017; Stacey & Pearson, 2015)	Based on matchmaking two parties such as a driver and rider or host and guest.
Online Brokerage and sales platform (Wolf & Troxler, 2016)	Consists of internet-based infrastructure allowing suppliers to expose themselves to a potential clientele and helping customers to find services and products from a range of suppliers.

Table 6. Research design of study

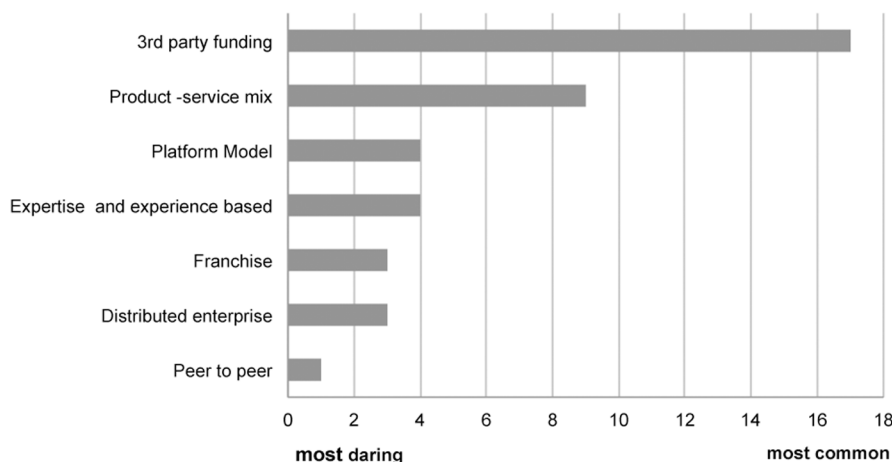
	Conceptual framework	References
Research gap	"Puzzle" of OSHBMs	(Chesbrough, 2003; Soloviev <i>et al.</i> , 2010; Menichinelli, 2015; Wolf & Troxler, 2016; De Filippi, 2018)
Theoretical sampling	tangible, complex, open OSH initiatives	(Bonvoisin <i>et al.</i> , 2017; Bonvoisin <i>et al.</i> , 2018)
Theoretical foundation	Digital Commons (raw material for ideas)	(Hess & Ostrom, 2011; Benkler, 2013; Raworth, 2017; Fuster-Morell <i>et al.</i> , 2017; Fuster-Morell & Espelt, 2018)
Methodology	Qualitative transversal case study analysis of 22 community-based OSH initiatives and 5 community-oriented OSH initiatives	(Eisenhardt and Graebner, 2007; Mantere & Ketokivi, 2013; Gavard-Perret <i>et al.</i> , 2012; Ketokivi & Choi, 2014; Avenier & Thomas, 2015, Timmermans & Tavory, 2012; Goffin <i>et al.</i> , 2019)
Outcome	Framework for Digital Commons to grow in scope	(Saebi & Foss, 2018)

BUILDING OPEN SOURCE HARDWARE BUSINESS MODELS**Business Models as Building Blocks**

The study revealed a large spectrum of activated revenue streams. Their range correlated with the community joining process. In essence, the “fat end of value capture” lies in the long tail of products and services around the hardware products (Thomas, 2017, 2019). The heart of value creation, however, lies in the ability to access, replicate, modify and use design files. Such openness factors, together with the potential impact of innovation achieved through network effects, are what fuel the momentum for design collaboration, making the product become better, faster, cheaper and more efficient.

Building Open Source Hardware Business Models

Figure 1. Business models clusters identified in study



The authors organized the following business model patterns, as idealized examples of business models from the most common to the most daring or unusual (see Figure 1).

The most commonly activated pattern was “3rd party funding” (16 projects), in which projects relied on forms of crowdsourcing, direct donations, or on corporate sponsorships. More mature projects (7 years +) had evolved into a hybrid model where a corporate structure funded the operations of the non-profit. The next cluster of patterns was the “Product-service mix” (9 projects), taking the form of a freemium offer to which kit sales, training, workshops or maintenance packages could be added. The following cluster, “Expertise and experience-based” (4 projects), included corporate competencies relating to design-centric or manufacturing-centric activities such as consulting or customizing offers. The Franchise pattern (3 projects) appeared as a means of ensuring quality and safety standards.

The “Platform model” (4 projects), included more elaborate interaction modes with co-creator communities through subscription, or matchmaking. The OSH initiative thus becomes a platform where customers can browse for designs, download them for a fee and produce them at their local Fab Lab, or be directed (through matchmaking) to the manufacturer most apt to fabricate them. Platforms are mainly about lock-in, monitoring, controlling and monetizing exchanges, “knowing” what people are doing to stimulate behavior that is easy to monetize.

The least used patterns appearing in our findings are the “distributed enterprise” model (3 projects) and the “Peer-to-peer” model (1 project), in which the point is

Building Open Source Hardware Business Models

Table 7. Distribution of business model patterns per initiative

Project	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	SUM
3rd party funding																												15
Sales																												13
Self-funded																												9
Crowdfunding																												7
Kits																												6
Workshops																												5
Consulting																												3
Subscription																												2
Renting platform																												1
N/A																												1
License																												1

Building Open Source Hardware Business Models

not only is to give other people the opportunity to reproduce the product itself, but also to train people to build a business around it in order for the initiative to scale.

When analyzing which OSH initiative used which business model pattern, what appears noteworthy in all projects is their use of business model pattern combination, also observed by Wolf and Troxler (2016). Table 7 shows the distribution of these patterns. The top row numbers the 27 different OSH projects studied. The left column details the list of business model patterns activated in each initiative. The right column indicates the number of projects using each business model pattern.

Three different clusters of business model pattern bricks can be identified. The 3rd-party-funding cluster builds on the product service mix + corporate competence models. Expertise is either design-centric or manufacturing-centric. This business model pattern directly derived from free and libre open source software (FLOSS) consists in shifting revenue-making strategies from product sales to expertise and services. Offers will take the form of DIY workshops wherein people purchase “the experience of building it yourself”. Consulting services may be offered to customize or to build derivatives, such as an aquaponic greenhouse to grow fresh, aromatic plants for a restaurant; or learning to use your processes; or, for instance, the rental of the OSH initiative’s collaborative platform for decentralized problem solving.

The distributed enterprise cluster builds upon the above, with the difference that it adds “train the trainer” workshops in order, to not only use OSH for the benefits of decentralized problem solving, but to further diffuse the concept by creating entrepreneurs who will replicate the model. The Peer-to-peer pattern, for transactions between private individuals, is organized by an intermediary responsible for their safe and efficient handling. Eventually this function can be monetized by charging transaction fees or through advertising and donations.

The platform cluster (4 projects) includes the subscription and matchmaking models. These create value via their capacity to orchestrate an ecosystem of industry players (designers, manufacturers, resellers, customers, prosumers) around one key technology or design platform.

The last two clusters, Distributive enterprise and Platform, stand out as the most elaborate in the sense that they articulate the most varied streams of revenues and value offerings.

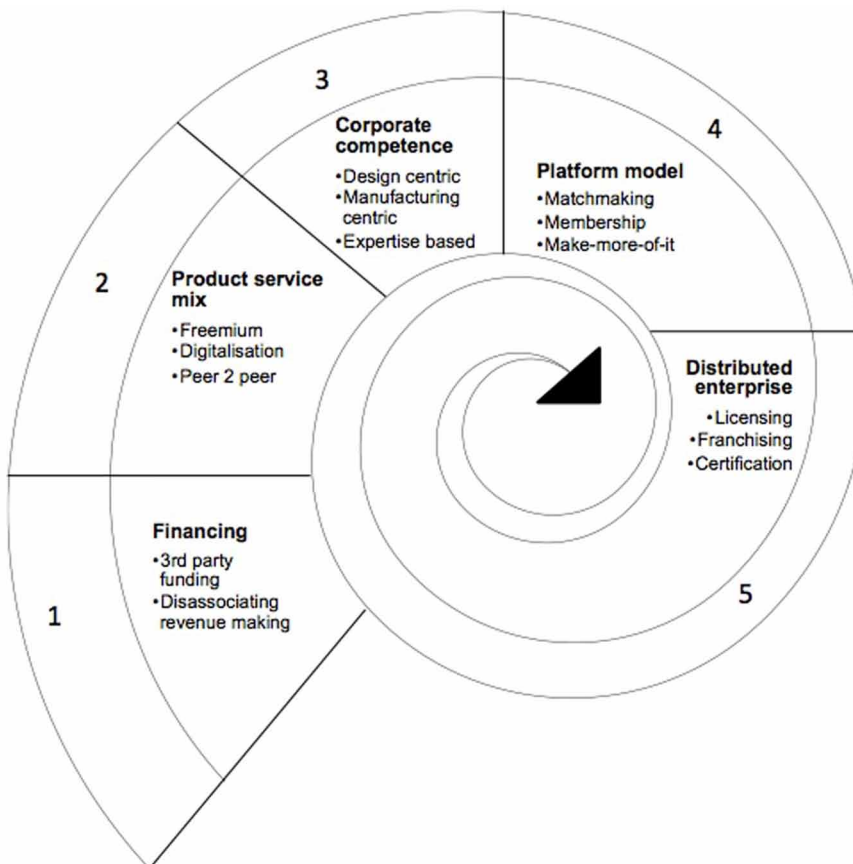
The modular nature of business model patterns reveals that, depending on an organization’s specific context and resources, the patterns can be combined to provide multiple revenue streams. These appear to be used individually, to be regrouped in different categories, and/or to serve as building blocks. The patterns identified build upon one another, compiling “all of the above” solutions. The modular nature of the “bricks” creates both a level of complexity and a facility of use, as the projects can begin from wherever they stand.

Proposal for an Open Source Hardware Business Growth Model

Figure 2 illustrates how OSH initiatives progressively interact with their surrounding innovation ecosystems, enrich their value propositions and grow in impact. This framework is the fruit of many rounds of abductive iterations using data, literature, sessions with entrepreneurs interested in opening up their business models, and experts in OSH with academic and practitioner backgrounds. Through loops of presentations and feedback received, a categorizing began to emerge based on what Gassman *et al.*, (2014) would call a *similarity principle*.

Patterns were organized into a 5-stage framework – from the most commonly used business models to those least commonly used.

Figure 2. Five-stage framework of most commonly to least commonly found OSHBMs



Building Open Source Hardware Business Models

The spiral sense of the framework represents the iterative process projects go through in designing their progressively harder and riskier architecture of activities: first, finding funding sources; next fine-tuning the value proposition; third, leveraging the organization's corporate competence; then orchestrating and monetizing exchanges among actors; and finally, franchising the model to develop its impact. OSH project holders may constantly have to fine-tune the manner in which they create and share value with their stakeholders. These stages reveal the creative concessions observed for revenue making while the core aspects of value propositions remain open. Briefly, like climbing a mountain stages 1 through 3 are easier. Stage 4 represents a struggle for businesses seeking to open their business models. Stages 1 through 4 are in line with what has previously been described in literature. Stage 5, the distributed enterprise, emerged inductively from our empirical findings. This stage would represent the arduous mountain top – hard to reach but fulfilling “the promise of open source”, that is, open source enterprises creating open source enterprises, allowing the DNA of an innovation to circulate so that others may creatively adapt it to their own local contexts.

Stage 1: Financing (N=16/27)

The first Stage pertains to external financing modes. OSH initiatives require capital to fund their activities. The cultural difference between an open source approach and the traditional closed model is that OSH initiatives need to be more creative to do so.

This stage also serves to build a consortium, accrue legitimacy, get a feel for what external stakeholders are willing to support and a sense of what public entities are striving for. Two main options are available: 3rd party funding and disassociating revenue-making strategies.

3rd party funding refers to sourcing money from institutions, corporate actors or the general public. The goal being to find institutions willing to fund the production/conservation/expansion of a common, because they have an interest in it. This support may include public funding, grants, or corporate sponsorship. The drawback, of course, is risking a lack of independence as regards the governance or economic model. General public support can take the form of reciprocity-based revenue-making strategies, such as crowdfunding campaigns or direct individual donations. Voluntary financial contributions sustain the production of a common based on reciprocity. The novelty here is the ability to limit influence or professional investors. This category includes memberships, donations, pay now, buy later, becoming a patron or pay-what-you-want, where customers are given a range of price options for a product or service.

The disassociating revenue making strategy is the second mode of tapping into external funding. Here, a positive externality created by the main output is

Building Open Source Hardware Business Models

produced to create revenue. For instance, once the community is large enough, the organization may charge third parties for advertising on the community forum, earn income through sponsorships or sell personal data.

Stage 2: Product Service Mix (N=9/27)

Through this Stage, OSH initiatives can experiment with tailoring their value proposition design and their go-to market strategies. Indeed, in the initial stage of a project, most proponents had a vague idea of who their target customers were, and what value proposition would adequately match their needs. The idea here is to move progressively from a product mindset to a service mindset. As one of the OSH entrepreneurs explained, “if we were just interested in selling a final product we might as well sell bidets”.

Propositions for this Stage include freemium options, whereby what was collectively developed can be offered for free to establish a large initial customer base but custom add-ons and premium offers are developed for specific needs, or for a more efficient version of the original digital common. The common produced is not charged but revenue making is ‘shifted’ to the selling of something else related to the common. In the case of OSH, both ‘digital-to-physical’ and ‘experience-selling’ make sense. For instance, in the case of the Danish furniture brand, Stykka, (which intends to become the OSH equivalent to furniture design that Spotify is to music), Fab Market or Open Desk, designers are compensated if customers select their designs, and if they choose to manufacture the designs in their local Fab Lab or woodshop. Experience selling comes through selling DIY workshops where users learn how to build, weld and assemble their own machinery, brick press, tractor, or solar power generator. Peer-to-peer refers to transactions between private individuals, such as the case for E-nable: where 3D printing machine owners build prosthetic limbs for children born with agnesia.

Stage 3: Corporate Competence (N=4/27)

During Stage 3, the OSH initiative needs to carefully assess its core strengths in order to build its competitive advantage. If the founders are design-centric, they are most often focused on product design and R&D, and they outsource the manufacturing. In this model, the brand and the community are key strategic assets. If they are manufacturing–centric, the organization’s core value proposition is to manufacture and distribute open hardware products for an affordable price. In addition to the brand and customer community, industrial efficiency is a key asset. One noteworthy example is Seed Studios, the “IOT Hardware enabler” which manufactures electronic products for makers and engineers. Indeed, many parts required for hardware are

Building Open Source Hardware Business Models

manufactured in Shenzhen, China, “the factory of factories” which, based on its manufacturing might, has developed a synergy with all manufacturers in the world and has become a “hardware accelerator”.

Another business model pattern associated with this stage of corporate competence, is customized prototyping for industry or private clients. As the design skills for creating and developing a 3D printed prototype are scarce, therefore still novel, customers can be “locked-in” to a vendor’s world, which will make switching to another provider more difficult.

Through the pattern of the integrator model the organization will gain economies of range and efficiency by controlling most or all parts of the supply chain from sourcing to manufacture to distribution. In the case of Baidu and Tesla, this approach fosters innovation and improves efficiency. Tesla, for instance, is using this model to consolidate its position and modify market boundaries from the inside by creating both the demand and the supply of associated products and services, such as electrical batteries, charging stations and Powerwalls.

If the organization chooses to focus on expertise and experience, their revenue models will come from monetizing expertise and services. Consulting services may be offered to customize or build derivatives of a given product (ex: Arduino) or to learn about the processes used. For instance, Local motors and Wikispeed offer the service of renting out their collaborative design platform. Similar to the “make more of it” pattern, knowhow and resources are sold to the third party as a service. Accumulated specialist knowledge and spare capacities are monetized and new expertise built up, all of which can be used to further improve internal processes and revitalize the core business (Gassman *et al.*, 2014).

These design, manufacturing or expertise-based design types, offer the opportunity to “standardize and leverage”. The idea being to open-up one key product in order to make the associated technology a de facto standard in the industry as is the case with Tesla’s strategy.

Stage 4: The Platform Model (N=4/27)

Inspired by the digital economy, the core of the value proposition in this model is to organize an ecosystem of industry players around one key technology or design platform.

The goal, regrouping a variety of different players: makers, designers, manufacturers, buyers, is to form a multi-sided market. This model opens-up core assets, in order to enable new roles in a firm’s organization. Revenue generation, beyond just selling a product, can come from subscription fees, training sessions corresponding to the experience, selling, and make- more-of-it patterns identified by Gassman *et al.*, (2014).

Building Open Source Hardware Business Models

This category includes deriving revenues from brokering strategies. Here revenue is based on matchmaking between two parties such as driver or a rider or a host and a guest. This method is widely used by platform cooperatives and can take the forms of a transaction fee or a subscription. In the case of Kreatize, the value proposition is based on an algorithm matching a manufacturer's requirements with a supplier capable of producing and improving the design. Make Works is another example specific to manufacturing, enabling the sourcing of local manufacturing and materials. This type of competence will become increasingly important through distributed manufacturing, wherein key assets are the ability to map manufacturers and their competencies to reconfigure supply chains. One respondent explained: "what we are trying to do is to create supply chains on the fly, in the sense that depending on the products and the local actors, you organize the supply chain locally".

Stage 5: Distributed Enterprise (N=3/27)

Stage 5, emerged from our empirical data and is the most challenging to implement. Three of our cases were experimenting with either a franchise or a distributed enterprise model. These patterns together form the "distributed enterprise" stage (3/27) which is placed at the end of the process, because although it may not be the starting goal of many OSH initiatives, it is a logical progression.

One OSH entrepreneur explained:

We're training them either to produce the machines you can make in a fabrication shop, or to actually produce them by taking the blueprints to a fabricator and then selling, having them fabricating the product for you. We prefer the idea of the immersion-training workshop in manufacturing, where you organize the workshop. We have twelve people or so, they pay you to build it, they get immersion training and you sell the product. It's a dual revenue model, where you're catching revenue for manufacturing as well as education.

In this schema, revenues can also come from labels and certifications from the host organization, certifying that, after having gone through a certain number of workshops, the resulting product is sufficiently safe. The patterns of licensing or franchising, or of matchmaking are other options if the initial project has developed a superior knowledge of supply chain logistics that makes buying in bulk easier. Another OSH entrepreneur explained: "I'm saving them the trouble of having to find all the materials they need from 25 different places". Franchising is a perfect means of allowing for geographical expansion without having to muster up all the resources and carry all the risk, which is handled by franchised, independent entrepreneurs (Gassman *et al.*, 2014).

Building Open Source Hardware Business Models

SOLUTIONS AND RECOMMENDATIONS

Prerequisites for Building Open Source Hardware Business Models

The main recommendation offered is a mindset shift from a “me” perspective focused on personal interest and scarcity to the “we”/ common good perspective of abundance found in Commons-based peer production. This shift is understood as a means of accelerating a circular economy and empowering individuals and organizations to address problems, such as climate change, that a single entity or company cannot solve alone.

The OSH initiatives studied were value driven. Indeed, the projects carrying a strong social or environmental vision were more likely to receive contributions from community members as well as stakeholder support. Similar values were used to federate a community of contributors. Conversely, when interacting with and within organizations which do not have an organizational culture endorsing these values, at best there is a stasis state, and at worst the values are undermined. These findings are congruent with previous research by Zott *et al.*, (2011) and Breuer & Lüdeke-Freund (2018) attest to the importance of values-based innovation for addressing complex societal problems.

The crux of the matter at this point seems to be the ability to establish participatory governance ensuring the transparency and effectiveness of the initiatives on multiple global and local levels. Here, governance needs to be value-driven in order to promote generative, decentralized, bottom-up innovation processes. This point coincides with the principle of “nested enterprises” with multiple activity layers identified by Ostrom (1990).

Implementing Open Source Hardware Business Models

To date, OSH just has not had the same impact and spread as OSS. Perhaps the simple reason is that hardware is hard. While the marginal cost of producing one unit in software certainly nears zero, the reality in hardware of materials and space will always cost money (Tinck & Bénichou, 2014). While even the development phase of industrially produced goods itself may generate relatively low costs, they bear about 70% the responsibility for the costs in downstream areas through production and sales. Recent work on Open Source Economy and “Open Source Product Life Cycle”, integrates the externalities previously borne by society such as waste disposal and or costs due to environmental toxins and pollution, which should be made visible, and ultimately be included in the product price (Rabis, 2019).

Building Open Source Hardware Business Models

Additionally, the sustainability of distributed manufacturing, particularly in constraint-based innovation, relies largely on continued access to affordable materials either imported or, preferably, locally sourced. Indeed, off-the-shelf components can limit the design and customization potential which are inherent to the concept of user-developed hardware and digital fabrication (Erhun, 2018, Gavras, 2019).

Moreover, globally, there are different standards for raw material and parts, electrical wiring, imperial and metric measures. One of the authors experienced this while building an HILO weaving machine and running to the hardware store a number of times because parts specifications in Germany are not the same as in France.

Our findings offer a practical sense for understanding what revenues OSH projects can activate in answer to the “what’s right for us?” question. They suggest ways that OSH projects can raise money to get traction for their ideas, and even design the ideas themselves to produce their own revenue. Just as Gassman *et al.*, (2014) suggest with the Business Model Navigator, the idea is to assess the current means of revenue of an OSH initiative, while activating and brainstorming other possibilities. Each stage of our spiral framework (see Figure 2) suggests consecutive steps that may assist in understanding how to create an OSH business model project for an innovation, how to market it and how to position oneself in the market.

The framework displays progressively more challenging steps to implement. OSH initiatives and companies should not be deterred by these sequential steps. Together, they form a logical progression of OSH potential and can be taken separately or grouped, like building blocks. If an OSH initiative explores and applies each of these patterns, together they may have a compounding effect, generating even more value. Most businesses operate on the 1 to 3-stage basis. Stage 4 allows exploring the new roles and revenues created if a given organization opens up its tangible assets, such as fabrication space or its machinery, or its intangible assets, such as building plans, to a wider community (Zimmerman, 2014; Danish Design Center, 2018). This platform stage is difficult to implement in sectors and in industries accustomed to revenue from closed intellectual property. Stage 5, the “Distributed Enterprise”, is the most risk-embedded step for enterprises. It enables OSH initiatives to think about how to become the “Mc Donald’s” of their own industries and to grow in geographical scale. The distributed enterprise is a means of riding “piggyback” on something that is already in place. In line with FLOSS’s philosophy, it permits standing on the shoulders of giants, and is where a real potential for OSH lies.

This phased approach to business model design allows initiatives to progressively reach out for ecosystem support, to gain a broader customer-user base, strengthen their core competencies and to scale for impact. Indeed, business model design is a continual weaving together of activities as organizations gradually discover their ecosystem, find new partners, accumulate experience, and identify new customer

Building Open Source Hardware Business Models

needs (Frankenberger *et al.*, 2014; Zott & Amit, 2010, Magretta, 2002). Our framework illustrates the blurring of boundaries between partners and customers as OSHBMs tend to have “fuzzier systems and more units” (Menichinelli, 2015). This occurs at various entry points. One is access to the innovation’s blueprints. Another is through crowdfunding, as customers now become investors and partners. The platform stage gives additional ways of blurring lines. Matchmaking provides clear, open-innovation opportunities with key suppliers, who can become partners. Finally, in the last stage, the distributed enterprise further blurs lines, as not only the blueprint for the innovation is shared, but how to build a business as well.

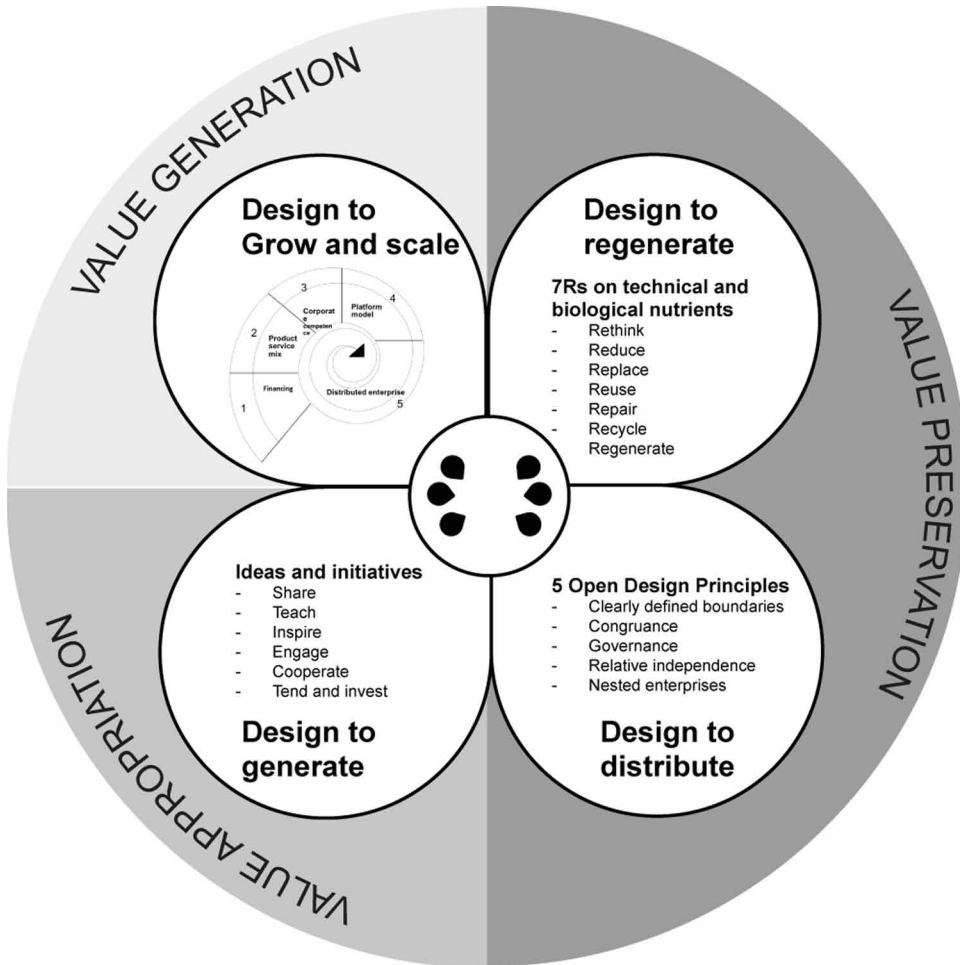
Value Generation, Appropriation, and Preservation

Our findings indicate that the terms value creation and capture may need to be replaced in light of Open Source Economics. The novelty of OSHBM, explained in Figure 3, is that through distributive, regenerative and generative design OSH has the potential to generate, appropriate and preserve value, even to alter positively the current unsustainable and traditional centralized economies of scale and associated extraction of material and labor.

The upper left quadrant represents value generation. The notion of value generation is central to OSH initiatives. The objective is to raise funds giving traction to OSH ideas, or even better to design the ideas themselves to produce their own revenue and outperform existing extractive models. However, value creation is no longer only about bargaining relationships between buyers and sellers; rather, value generation and appropriation, bottom left quadrant has become a function of how often an innovation is downloaded and whether or not it has been appropriated massively, and whether or not it has impacted patterns of consumption or production. Through OSH, value creation becomes a function of how a given technology has been developed to actually meet customer and user needs (Thomson and Jakubowski, 2012; Pearce, 2017; Joyce and Paquin, 2016). In this sense, the most modular and circular designs that are easy to copy and can be applied like Lego parts in a remix of recurring solutions can generate the most value creation (Zimmerman, 2019). Use value goes from being the specific qualities of the product perceived by customers in relation to their needs (Bowman and Ambrosini, 2000), to notions of dignity, mutual support, and social inclusion (Unterfrauner *et al.*, 2017). This occurs, as Li and Seering, (2019) note, because the existence of an active community of developers, mentors and consumers increase the perceived and functional value of OSH products and services through 1) instant feedback on market information; 2) justification of the product’s performance; 3) emotional value related to users learning and exploration experiences. Thus, open source can increase customers’ perceived value and decrease the cost of running a company.

Building Open Source Hardware Business Models

Figure 3. Building an open source hardware business model



The notion of value appropriation means that peer-to-peer networks of distributive design (Raworth, 2017, p.192) and the capacity to “inform, learn and teach worldwide” enable copying and implementing innovations globally. The concept of OSH to learn globally and make locally enables individuals to share, teach, inspire, engage, cooperate, tend and invest in ideas and initiatives that make a difference. In this sense, the value created by OSH potentially transcends financial value, as well as the 7Rs of rethinking, reducing, replacing, reusing, repairing, recycling and regenerating biological and technical materials, (upper right quadrant in the figure). This unalienated circulation of Digital Knowledge Commons ignites human skill and competence to co-create and adapt local solutions to global problems.

Building Open Source Hardware Business Models

What makes OSH value appropriation crucial to the entrepreneurship potential of achieving circular and generative economy goals, is letting the DNA, or the “seed” of an innovation circulate, enabling others to do the same, or something different, based on the hardware. Just as distributive value is an inside-out process of making an innovation available worldwide, value appropriation is an outside-in process, whereby an individual learns to experiment with OSH technology and adapt it to his or her needs. Just as seeds naturally are fertile, and unnaturally are not, OSHBM have the potential to be built around the generation, appropriation and preservation of Digital Innovation Commons.

The accepted and collective responsibility for the preservation of Digital Innovation Commons is at the crux of Ostrom’s legacy, going from Natural to Digital Commons: a self-organized social system for the long-term stewardship of non-depletable and non-rivalrous resources preserving shared values and community identity, which are subject to social dilemmas. Of course, the natural and technical elements of an OSH initiative need to be preserved and tended, but as (bottom right quadrant), any OSH initiative is enriched if it heeds the open design principles of clearly defined boundaries; congruence, open governance, relative independence and nested enterprises (Troxler, 2019; Fuster Morell & Espelt, 2018; Hess and Ostrom, 2011; Ostrom, 1990).

Through distributed manufacturing and distributed enterprises, OSH, in the desire to solve complex problems, helps shift from an ethos focused on personal gain, to one focused on the Common good. As one OSH entrepreneur stated, OSH allows moving “from massively producing average products at a high global cost, to locally producing products that better fit our needs, at a lower cost”. This would support the growth and development of regional economic cycles and achieve sustainable production through digitalization, personalization and localization (Rauch *et al.*, 2016; Kumar *et al.*, 2020). This remains an ideal in many cases, for instance OSH scientific equipment (Pearce, 2012, 2017) or other equipment such as aquaponics kits remain too expensive to be appropriated by the general public. However, our research shows the ways that OSH initiatives can craft their business models around these issues.

FUTURE RESEARCH DIRECTIONS

This research opens a number of future avenues, feeding into previous discussions on whether OSH proposes an alternative, holistic emergent and productive model; or if it reorganize existing corporate infrastructure (Gavras, 2019). One example could be to study the decentralized financing forms of monetization available to distributed manufacture in the prism of knowledge, governance and technological and openness.

Building Open Source Hardware Business Models

As extensive research continues to explore emerging sustainable business models (Massa, Breuer and Lüdeke-Freund, 2022; Kopnina and Poldner, 2022); another possible stream of research could entail investigating whether organizations which have experimented with open source hardware initiatives do, or do not, find their business models transformed in the long run. Such research would seek to track the continual adaptation, responsiveness - and resilience-with-variation' 'value' of OSH. Following Røvik's (2011) theory on virus spread and contamination, do OSH initiatives "infect" the host and change operational processes? This theory could be used as a framework for describing 'emergence' as a continual, collaborative, commons-based business model pattern.

However, does such research go deep enough in tackling the cultural entropy underlying humans and organizations' unsustainable current modes of production and consumption? Based on evidence from 27 OSH entrepreneurs we have highlighted how OSHBM's have the potential to positively alter current unsustainable centralized economies of scale and associated material and labor extraction, to generate, appropriate and preserve value. Future research, building on the Transition Town movement could look at how that potential could be imagined, modeled and applied as commons are fundamentally a social process relying on relationships and shared knowledge (Kostakis *et al.*, 2015; Bregman, 2021; Hopkins, 2019, Elworthy, 2020).

CONCLUSION

This chapter explores the implications of FLOSH as a new innovation paradigm introducing novel forms of value creation and capture through distributive, regenerative and generative design.

We propose a 5-stage framework for helping OSH practitioners develop their business models using the full scope of OSH, which is based on three-year of research conducted in the scope of the OPEN! Research project, studying 27 open source hardware initiatives. Apart from providing actionable, strategic steps, the objective of the framework is to reimagine a market economy, and to live in what Kate Raworth calls Doughnut Economics, that is in equilibrium between our social foundations and the ecological ceiling of the planet.

Solving our greatest challenges is not only a matter of smart solutions. These are being developed, and they are amazing. The challenges in today's confusing world are that we need to start working together, better and faster. To this end a number of solutions are being developed using open source hardware to make faster, better, and cheaper innovations that can be deployed worldwide to tackle beehive colony collapse disorder, and oil spills, grow food, and build quicker.

Building Open Source Hardware Business Models

To achieve this intention, the authors provide recommendations for a mindset shift from the “me” perspective focused on personal gain and scarcity to the common good perspective defined by Ostrom as equity, efficiency and sustainability offered by peer-production.

The chapter concludes with suggested avenues for future research to explore to what degree does OSH transform the operational processes of host organizations, and how the disruptive potential of OSH may be further imagined, modeled and applied.

ACKNOWLEDGMENT

This research was jointly funded by the French and German national science agencies ANR (Agence Nationale de la Recherche, grant ANR-15-CE26-0012) and DFG (Deutsche Forschungsgemeinschaft, grants JO 827/8-1 and STA 1112/13-1).

REFERENCES

- Acquier, A., Carbone, V., & Massé, D. (2016). *L' Economie Collaborative: Fondements théoriques et agenda de recherche*. In *2nd International Workshop on the Sharing Economy*. Paris: ESCP Europe.
- Benkler, Y. (2017). Peer production, the commons, and the future of the firm. *Strategic Organization*, 15(2), 264–274. doi:10.1177/1476127016652606
- Bollier, D. (2014). *Think like a Commoner. A Short Introduction to the Life of the Commons*. Gabriola Island. New Society Publishers.
- Bonvoisin, J., Buchert, T., Preidel, M., & Stark, R. (2018). How participative is open source hardware? Insights from online repository mining. *Design Science*, 4(4), 1–31. doi:10.1017/dsj.2018.15
- Bonvoisin, J., Mies, R., Boujut, J.-F., & Stark, R. (2017). What is the “Source” of Open Source Hardware? *Journal of Open Hardware*, 1(1), 1–18. doi:10.5334/joh.7
- Bonvoisin, J., Thomas, L., Mies, R., Gros, C., Stark, R., Samuel, K., Jochem, R., & Boujut, J.-F. (2017). Current state of practices in open source product development. DS 87-2. In *21st International Conference on Engineering Design (Vol 2)*. Design Processes, Design Organisation and Management.

Building Open Source Hardware Business Models

- Bowman, C., & Ambrosini, V. (2000). Value Creation Versus Value Capture: Towards a Coherent Definition of Value in Strategy. *British Journal of Management*, 11(11), 1–15. doi:10.1111/1467-8551.00147
- Bregman, R. (2021). *Human Kind a Hopeful History*. Bloomsbury Publishing PLC.
- Breuer, H., & Lüdeke-Freund, F. (2018). Values-Based Business Model Innovation: A Toolkit. In Sustainable business models: Principles, Promise, and Practice. Springer. doi:10.1007/978-3-319-73503-0_18
- Danish Design Center. (2018). *Remodel, A toolkit for Open Design Business Models*. <https://remodel.dk>
- De Filippi, P. (2018). Blockchain: A global infrastructure for distributed governance and local manufacturing. In *Fab City the mass distribution of (almost) anything*. Barcelona: IAAC Fab Lab Barcelona.
- Dias, S. (2021). *Fabricademy 2021-22 Workshop HILO Machine Part 1*. <https://vimeo.com/649695293/ddd9f225d>
- Eglash, R., Babbitt, W., Bennett, A., & Callahan, B. (2016). *Culturally Situated Design Tools: Generative justice as a foundation for stem diversity (Issue December)*. IGI Global.
- Elworthy, S. (2020). *The Mighty Heart. How to transform conflict*. Pureprint Group. E-nable project. <https://e-nable.fr/fr/>
- Erhun, D. (2018). *An ICT4D initiative: FabLabs as a potential catalyst for constraint-based innovation in Rwanda* [Master Thesis]. University of Amsterdam.
- Fab City Collective. (2018). *Fabcity white paper*. In *Fab City the mass distribution of (almost) anything*. Barcelona: IAAC Fablab Barcelona.
- Fab Market. (n.d.). <https://distributeddesign.eu/talent/>
- Fjeldsted, A. S., Adalsteinsdottir, G., Howard, T. J., & McAloone, T. (2012). Open Source Development of Tangible Products - from a business perspective. In NordDesign 2012. Creative Commons Netherlands, Premesla: the Netherlands Institute for Design and Fashion and Waag Society.
- Foss, N. J., & Saebi, T. (2018). Business models and business model innovation: Between wicked and paradigmatic problems. *Long Range Planning*, 51(1), 9–21. doi:10.1016/j.lrp.2017.07.006

Building Open Source Hardware Business Models

Frankenberger, K., Weiblen, T., & Gassmann, O. (2014). The antecedents of open business models: An exploratory study of incumbent firms. *R & D Management*, 44(2), 173–188. doi:10.1111/radm.12040

Fuster Morell, M. (2014). Governance of online creation communities for the building of digital commons: Viewed through the framework of the institutional analysis and development. In *Governing Knowledge Commons*. Oxford University Press.

Fuster Morell, M., Carballa Schichowski, B., Smorto, G., Espelt, R., Imperatore, P., Rebordosa, M., Rodriguez, N., Senabre, E., & Ciurcina, M. (2017). Decode. *Decentralised Citizens Owned Data Ecosystem.*, 1(3), 1–144.

Fuster Morell, M., & Espelt, R. (2018). A Framework for Assessing Democratic Qualities in Collaborative Economy Platforms: Analysis of 10 Cases in Barcelona. *Urban Science (Basel, Switzerland)*, 2(3), 1–13. doi:10.3390/urbansci2030061

Gassmann, O., Frankenberger, K., & Csik, M. (2014). *The business model navigator*. Pearson Education.

Gavras, K. (2019). Open source beyond software: Re-invent open design on the Common's ground. *Journal of Peer Production*, 13, 1–25.

Goffin, K., Åhlström, P., Bianchi, M., & Richtnér, A. (2019). Perspective: State-of-the-Art: The Quality of Case Study Research in Innovation Management. *Journal of Product Innovation Management*, 36(5), 586–615. doi:10.1111/jpim.12492

Hess, C., & Ostrom, E. (2011). *Understanding Knowledge as Commons. From Theory to Practice*. MIT Press.

Hopkins, R. (2019). *From what is to what if: unleashing the power of imagination to create the future we want*. Somerset House.

Joyce, A., & Paquin, R. L. (2016). The triple layered business model canvas: A tool to design more sustainable business models. *Journal of Cleaner Production*, 135, 1474–1486. doi:10.1016/j.jclepro.2016.06.067

Kopnina, H., & Poldner, K. (2022). *Circular Economy. Challenges and opportunities for Ethical and Sustainable Business*. Routledge.

Kostakis, V., Niaros, V., Dafermos, G., & Bauwens, M. (2015). Design global, manufacture local: Exploring the contours of an emerging productive model. *Futures*, 73, 126–135. doi:10.1016/j.futures.2015.09.001

Building Open Source Hardware Business Models

- Kumar, M., Tsolakakis, N., Agarwal, A., & Srari, J. S. (2020). Developing distributed manufacturing strategies from the perspective of a product-process matrix. *International Journal of Production Economics*, 219, 1–17. doi:10.1016/j.ijpe.2019.05.005
- Li, Z., & Seering, W. (2019). Does open source hardware have a sustainable business model? An analysis of value creation and capture mechanisms in open source hardware companies. *The International Conference on Engineering Design, ICED*. 10.1017/dsi.2019.230
- Litman, J. (2014). The public domain. *Emory Law Journal*, 39(4), 965–1022.
- Lüdeke-Freund, F., Breuer, H., & Massa, L. (2022). *Sustainable Business Model Design. 45 Patterns*. Academic Press.
- Make Works. (n.d.). <https://make.works/companies>
- Menichinelli, M. (2015). Open Meta-Design. In D. Bihanic (Ed.), *Empowering Users through Design* (pp. 193–212). Springer. doi:10.1007/978-3-319-13018-7_11
- Mies, R., Bonvoisin, J., & Jochem, R. (2019). Harnessing the Synergy Potential of Open Source Hardware Communities. In *Co-Creation. Management for Professionals* (pp. 129–145). Springer Nature Switzerland. doi:10.1007/978-3-319-97788-1_11
- Moritz, M., Redlich, T., Grames, P. P., & Wulfsberg, J. P. (2016). Value creation in open-source hardware communities: Case study of Open Source Ecology. In *PICMET 2016 - Portland International Conference on Management of Engineering and Technology: Technology Management For Social Innovation*. Open Desk. <https://www.opendesk.cc/>
- Orcajada, A. (2021). *Material Driven. Fabricademy 2021 Recitation*. <https://class.textile-academy.org/classes/2021-22/week06/>
- Ostrom, E. (1990). *Governing the Commons. The Evolution of Institutions for Collective Action*. Cambridge University Press. doi:10.1017/CBO9780511807763
- Pearce, J. M. (2012). Building research equipment with free, open-source hardware. *Science*, 337(6100), 1303–1304. doi:10.1126/science.1228183 PMID:22984059
- Pearce, J. M. (2017). Emerging Business Models for Open Source Hardware. *Journal of Open Hardware*, 1(1), 1–14. doi:10.5334/joh.4
- Raasch, C., Herstatt, C., & Balka, K. (2009). On the open design of tangible goods. *R & D Management*, 39(4), 382–393. doi:10.1111/j.1467-9310.2009.00567.x

Building Open Source Hardware Business Models

Rabis, F. (2019). *Open Source Ökonomie Diplomarbeit Ehrenwörtliche Erklärung* [PhD]. Technische Universität Dresden.

Rauch, E., Dallasega, P., & Matt, D. T. (2016). Sustainable production in emerging markets through Distributed Manufacturing Systems (DMS). *Journal of Cleaner Production*, 135, 127–138. doi:10.1016/j.jclepro.2016.06.106

Raworth, K. (2017). *Doughnut Economics: Seven ways to think like a 21st century economist*. Random House Business Books.

Rifkin, J. (2014). *Ushering In A Smart Green Digital Global Economy To Address Climate Change And Create A More Ecological And Humane Society*. https://www.troisiemerevolutionindustrielle.lu/wp-content/uploads/2016/01/6-9-2015_Digital-Europe_Ushering-In-A-Smart-Green-Digital-Global-Economy-To-Address-Climate-Change-And-Create-A-More-Ecological-And-Humane-Society-2.pdf

Røvik, K. A. (2011). From Fashion to Virus: An Alternative Theory of Organizations' Handling of Management Ideas. *Organization Studies*, 32(5), 631–653. doi:10.1177/0170840611405426

Sanguinetti, V. (2019). *Adoption de l'Open Source par les organisations: Articuler business model ouvert et implication dans les communautés*. Université Jean Moulin Lyon III.

Stacey, P., & Hinchliff Pearson, S. (2017). *Made with creative commons*. Ctrl-Alt-Delete Books. <https://creativecommons.org/use-remix/made-with-cc/>

Stykka. (n.d.). <https://www.stykka.com/>

Teece, D. J. (2010). Business models, business strategy and innovation. *Long Range Planning*, 43(2–3), 172–194. doi:10.1016/j.lrp.2009.07.003

The academy of (almost) anything. (n.d.). <https://academany.org/about/>

Thomas, L. (2019). *Business models for Open Source Hardware*. Université Grenoble Alpes.

Thomas, L., & Samuel, K. (2017). Characteristics of Open Source Business Models. *XXVIII ISPIM Innovation Conference*.

Thomson, C. C., & Jakubowski, M. (2012). Toward an open source civilization: innovations case narrative: open source ecology. *Innovations: Technology, Governance, Globalization*, 7(3), 53–70. doi:10.1162/INOV_a_00139

Building Open Source Hardware Business Models

Tincq, B., & Bénichou, L. (2014). *Open Hardware Business Models*. Workshop at Open Hardware Summit. https://fr.slideshare.net/btincq/business-models-for-open-source-hardware?fbclid=IwAR1LzRMjs0fHn-0BjeP46G_tD9VyT9nKHZ1saDVJ4Le44h7R7GoTNxGdaEk

Troxler, P. (2010) Commons-based Peer-Production of Physical Goods. Is There Room for a Hybrid Innovation Ecology? *Third Free Culture Research Conference*.

Troxler, P. (2019). Building Open Design as a Commons. In *The Critical Makers Reader: (Un) learning Technology*. Academic Press.

Unterfrauner, E., Schrammel, M., Voigt, C., & Menichinelli, M. (2017). The Maker Movement and the Disruption of the Producer-Consumer Relation. *Internet Science*, 342(November), 1–51.

Van Abel, B., Evers, L., Klaassen, R., & Troxler, P. (2010). *Open Design Now. Why Design Cannot Remain Exclusive*. Bis publishers.

Von Hippel, E. (2005). *Democratizing Innovation*. The MIT Press. doi:10.7551/mitpress/2333.001.0001

Wolf, P., & Troxler, P. (2016). Community-based business models Insights from an emerging maker economy. *Interaction Design and Architectures*, 30(30), 75–94. doi:10.55612-5002-030-005

Zimmerman, L. (2014). *Open Design Platform*. <https://larszimmermann.de/Open-platform-design-flowchart-vs-0-2-released>

Zimmerman, L. (2019). *Mifactori, what is Open Circular Design*. <https://mifactori.de>

Zittrain, J. (2006). The Generative Internet. *Harvard Law Review*, 119, 1974. <https://ssrn.com/abstract=847124>

Zott, C., & Amit, R. (2010). Business model design: An activity system perspective. *Long Range Planning*, 43(2–3), 216–226. doi:10.1016/j.lrp.2009.07.004

KEY TERMS AND DEFINITIONS

Business Models: The architecture of activities through which a firm creates, captures and delivers value.

Commons: A shareable resource of nature or society that people choose to use or govern through self-organizing that is vulnerable to social dilemmas.

Building Open Source Hardware Business Models

Digital Commons: Digital Commons are non-depletable and non-rivalrous. The more they are used and shared, the more efficient, cheaper, and transparent they become. They serve as the raw material for ideas, and need to be kept open to allow knowledge to circulate.

FLOSH: Free and libre open source hardware.

FLOSS: Free and libre open source software.

FOSS: Free open source software.

OSH: Open Source Hardware is a collaborative product development process in which building plan designs, assembly instructions and bills of material are made publicly available for anyone to study, replicate, modify, distribute and sell, including hardware created, based on those designs.