3D printer builders' Open-hardware strategies

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ABSTRACT

This article studies open-source 3D printer manufacturers' business models, as well as the strategies into which these models fit. To do so, we use the concepts of business model innovation and specific capabilities. The analysis of the particularities of the projects and of the associated companies reveals two "pure" open-hardware strategies, the first one based on the temporary exploitation of the free/libre/open hardware community as a complementary resources, the second one based on the construction of a sustainable collaborative activity in order to maintain dynamic capabilities that are hard to imitate.

KEYWORDS

3D printing, FLOH, open-hardware, business models, makers

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1 INTRODUCTION

While the concept of maker is now relatively old, its recent popularity owes much to the COVID-19 pandemic. Shortages of equipment led to makers' mobilization to restore emergency supplies by relying on 3D printing machines made available by fablabs or that they owned at home [33]. To do so, they freely shared design files (plans and construction processes), facilitating reusability and adaptation. According to Von Hippel's analysis [34], this sharing is not very surprising: benefiting directly from the innovation they produce, these user-innovators are encouraged to undertake it and, as they can expect feedback or cumulative innovations on there innovative work, to disclose it.

But in order to do so, one must benefit from equipment and materials: printers. Digital manufacturing provides them with an agility and capacity to scale up to small to medium series that the user-innovators of yesterday did not necessarily have, exemplifying the capacity of 3D printing and makers to create "a mass market for niche products" [1, p. 95]. 3D printing, and in particular the technology of depositing molten wire, appeared at the end of the 1980s in a classic innovation model: research work leading to an invention, protected by a patent, that has been exploited by a company created for this purpose, and by incremental innovation (e.g. printing in several colors). The patent has been used to prevent competition, like the company XYZprinting which owns, among other the patent US20180211052A1 entitled "Protecting method for accessing material data of printer" (2020) on a device allowing to block the use of consumables proposed by competitors. These firms have deployed classic business models, such as the "razor-blade" model [25]. Operated by manufacturers of inkjet printers (cartridges), photographic equipment (films) or coffee machines (pods), its profitability is based on the recurrent purchases of consumables. It subsidizes access to the equipment (machines), in return for a higher variable production cost.

Arguably more original, and also more discreet, are Free/libre/open hardware (FLOH) projects such as RepRap [1], which have developed open sourced plans and processes to build printers. The projects has been built, on the one hand, on the development of scientific instruments [26], and on the other hand, on communities of users [18]. Makers have, somehow, applied their user-innovator habits to the tools they use. These projects have seen the creation of several companies. The facts that they emerged from community-base FLOH projects, that they have built solutions based on the assembly of different components (in this case hardware and software) suggest business models inspired by FLOSS based business models, or "open-source" business models [12]. The latter are service models, which make it possible to adapt FLOS software to the needs of users, but also to guarantee its proper functioning over time. The more dynamic FLOSS projects are, the more numerous the contributions, the more there is a need for maintenance, monitoring and guarantees of the software solution's evolution [20]. In other words (ibid), open-source business models are based on the management of the always necessary evolution of a software (or "software-flow"), more than on the access to a fixed software base (or "software-stock"), a management made possible by the development of what Teece named dynamic capabilities [27]. But it is always complicated to transpose models from one sector to another. Some practices seem endogenous, specific to the production of physical objects, such as the production quality control when companies address a clientele unable to reproduce the objects from the plans published online [30]. One may wonder, for example, if it is not more a question of the collective production of standards, which are then implemented by different manufacturers who compete with each other, like the personal computer industry that was structured around the IBM PC[1]. Before concluding on the analogies between these different industries, it seems necessary to us to study, in a more precise way, these business models that we will call, by semantic analogy only for now, "open-hardware". The article has

[1]See [16] for a presentation of this process of collectivization of the production of a standard, which escapes its initial creator, IBM.

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four parts. In the first part, we discuss the theoretical concepts that open-hardware models question, but that also allow us to study them: business models, the notion of dynamic capabilities. In the second part, we explain our research methodology based on longitudinal case studies. In the third part, we present the different companies and their business models, which we discuss through the lens of the literature on business models and innovation in the fourth part, identifying two open-hardware business models.

2 LITERATURE REVIEW

The classic literature on business models [23], and specifically the one studying innovation based business models [3] studies the actors' capacity of turning the assets they own into value (created for the users and captured by the company). In that sense, technological creations are seen as intellectual property assets. This is also the case here. In FLOS, as in FLOH, an actor develops intellectual property, source code or specification text, of which it is the owner (has a copyright, or if it is an industrial process, a patent). It then imposes on its adopters, thanks to particular licenses of use, the disclosure of the source code of the concerned elements and of any later improvement if they diffuse them. The opened source approach does not represent a denial of intellectual property but a new way of managing it. Authors do not give up their rights but only the monopoly rent that these rights would allow in a classic intellectual property rights regime and this article proposes to study their reasons.

In von Hippel's analysis (ibid), value creation and value capture are linked: users participate in the free development they use because it allows them to adapt it to their needs, while benefiting from the contributions of others. But if companies are willing to pay to be able to use free developments, whether they are software or printer components, which is what we are dealing with here, this means that they either need help to access these elements, or that they pay for other things, complementary values. The literature on technical innovation, proposes three main concept to study this question: 1) the fact that it is about developing a technological platform, a dynamic assembly of pieces of innovation and of their valorization, 2) which can be done more or less openly, cooperatively, and 3) where actors develop specific capabilities to produce these pieces of innovation and benefit (extract value) from them.

These projects are about building "technology platforms", meaning organizations or meta-organizations that [14]: (1) federate and coordinate agents capable of innovating and competing around the creation of a technology or technology system; (2) create value by generating and exploiting economies of scale on the supply or/and demand side; and (3) involve a modular technology architecture composed of a core and a periphery. Their challenge [28, p. 6] is to be simultaneously stable and flexible, and to offer both control and autonomy: stable in order to ensure the possibility of using the technology, over time, flexible in order to allow for innovation; control in order to organize this stability at a reasonable cost, and autonomy (of the actors and of their business model) because this is indispensable for innovation.

Looking at the technical structure of such an industry, allows to better its challenges and the type of value the companies can create [38]. In these industries, it is first a question of articulating elementary technologies into products (what he calls architecturation skills), and second of being able to identify which product best meets needs (use skills). The architecturation part constitutes the core of the platform's activity (coordination of modules) and innovation can come from a new module, which must remain compatible with the others, or from an innovative architecture of existing modules (requiring the development of specific technologies, "architecturation technologies"). However, this innovation must serve needs. It is also important for the value creation, to link an architecture to needs, possibly with additional support or technological developments (the "technologies of use"). A functioning platform needs to allow for openness to contributors from outside (to the company that controls it), while maintaining control over the coordination of the whole system [2]. But in the classic, company-owned technology platform, one of the key resource controlled it the technological infrastructure, thanks to intellectual property ownership, but also capacity to maintain and make evolve the technology. This allows the company to choose the degree of access openness, and to the possibilities of interfacing with the technology [2, 15]. The example of the IBM-PC illustrates that this control can be more or less decentralized, but that the companies which control the key components for the articulation of elementary technologies into products (Microsoft, Intel), capture the best part of the value created. But the open-source models have shown that it is not necessary for an actor to own the infrastructure or the basis of the innovation (intellectual property) in order to capture value, or even to control this infrastructure. Actors deploy different strategies (e.g. deployment of resources, sponsorship of core developers, and ownership of the project name as a brand) to control projects that constitute complementary resources needed to build their own value proposition [9]. To do so, the actors have to build dynamic capabilities [27], built on specific resources, human, technological, organizational, reputational and commercial [10]. The literature on resources [8, 29, 37] would say that, in order to absorb a resource, it is necessary to have absorptive capacities, which depend, among other things, on the skills of the firm (and its employees), or/and its ability to access intermediaries to compensate for this lack of internal skills, but also to choose between making, or having made (the machines, their maintenance). This what makes open-source strategies extreme cases of open-innovation [7], where the control is as much on the IP element as on the flux of innovation.

In other words, open-hardware business models depend on the structure of the technological platform coordinating the production of the different components of a 3D printer and their interfacing which is partly, but only partly, organized by the management of intellectual property rights. The other elements are the other capabilities the actors create that allow them to capture a part of the value created by the ecosystem, but also to create complementary value (and to capture enough of this created value). The question that arises is whether open-hardware companies have developed open-hardware architecturation strategies, or peripheral strategies (on the development of the technologies of use, for which FLOH solutions are used to build the offer, but where the open character of the material is not central).

In the longer term, because the structure of the FLOH project changes, or because the specific assets built enable the company to pursue new strategies for creating and/or capturing value, its business model may also evolve [4, 13]. Some authors [21] have even spoken of a life cycle for business model. This means that studying open-hardware business model requires a longitudinal approach.

3 CASES STUDIED

Classically for an exploratory and longitudinal approach [36], we conducted a case study, of the RepRap project, and of four companies that have emerged from it: Makerbot, Prusa Research, Ultimaker and Dagoma. These companies were selected for their popularity in the French market as measured by trends provided by the Google search engine (see Figure 1).

In terms of data, the analysis of the RepRap and Makerbot projects is based primarily on the research of [11]. It is supplemented, for the last years of Makerbot's activities, by collecting studies and consulting the manufacturer's website. This same type of data was used for Prusa Research, Ultimaker and Dagoma. The public data were completed, in this first case, by one interview with one of Prusa's employee, and, in this last case, by two interviews with one of Dagoma's founders, about the involvement of the company in the production of face shields during the first wave of the COVID-19 pandemic, and about its actual business model and its long-term strategy, and one interview of Prusa. These data were structured thanks to the Bussiness Model Canvas[25]), in order to easily summarize the three dimensions of business models (value creation, value capture and capacities to do so). Before presenting the business models, we provide a summary of RepRap.

3.1 The RepRap project: the matrix of FLOH

The RepRap project started in 2005, a few years before the end of patents on FDM technology. It resulted in FLOH work on a self-replicating 3D printer based on FDM technology renamed FFF (Fused Filament Fabrication). This project has played a pioneering role in the development of low-cost 3D printing. As a FLOH project, it served as an inspiration or technical basis for many open-hardware and proprietary 3D printers (e.g. Makerbot and Ultimaker, cf. the RepRap Family Tree). Today, as the project's Github repository shows, the activity has decreased significantly. The 3D printers designated by RepRap are published under the GPL. The rights and duties of this license are further complemented by standards for commercialization. Commercialization may be acceptable if the company contributes [11]:

- directly by sharing the details of the commercialized machine, the improvements made, including publishing the Bill of Materials (BOM) with the list of parts used, the list of suppliers, and the list of prices; providing resources, including hosting forums, hosting sharing platforms, and supporting the project;
- indirectly through the development of skills and knowledge (e.g. customer support), access to cheaper resources (e.g. volume effects and economies of scale on parts), contribution to market growth, and diffusion of innovation.

Commercialization, on the other hand, is never acceptable for the entire machine (and not extensions or specific parts). Neither it is accepted that a company does proprietary development previously published under a free license, or patents an innovation co-developed with the project.

4 OPEN-HARDWARE BUSINESS MODELS

The four companies are presented in the chronological order of their creation.

4.1 Makerbot

Makerbot was incorporated in 2009 to commercialize open designs derived from the RepRap, after FDM process patents expiration. The first design, the Makerbot Cupcake, was closely derived from RepRap Mendel, particularly in terms of electronics. The machine was presented as original because "designed by a community, built by people whose names you know and whose ideas you admire, and endowed with a personality" [1, p. 116]. The company has quickly moved away from this model, however, even if it has continued to open-source some components' code, mainly software. In September 2012, Makerbot announced the release of the Replicator 2 (under a proprietary license). In parallel with the adoption of a proprietary development mode, Makerbot has filed patents since 2010 (with agreement between 2012 and 2013). It has also changed its model-sharing platform's term of used, imposing a transfer of ownership from the object creators to Makerbot. This reversal has led to various sanctions from the RepRap project participants: the call for a boycott, the cessation of contributions to projects and the call for the reverse engineering of proprietary machines. Makerbot's decisions were motivated by the existence of "clones", and, according to Bre Pettis, one of the company's co-founders, its vulnerability to "unwritten and unspoken rules" proclaimed by the community, while licenses are supposed to "clarify rights and duties". The main reason seems to be a value capture problem, with significant losses of market share on low-cost desktop 3D printing machines to Chinese manufacturers, in a more slowly growing than expected market for home printers. As a result, the company has gradually reoriented itself towards the professional market, with machines and a wide range of associated materials. In particular, it relies on its patented modular extruder technology, offered to the professional market, compatible with different materials (including, for example, stainless steel). Makerbot has developed an essentially proprietary model (except for the older models' software and firmware still open sourced) based on the intellectual property on technological assets responding to specific business needs, in a classic razor-blade type business model.

4.2 Ultimaker

The company was created in 2011 after a first year of experimenting with the RepRap in the Utrecht (NL) fablab ProtoSpace. Its first product was an FLOH printer, sold as a kit, the Ultimaker Original, reputed easier to handle than the RepRap. The company has successfully scaled up without clashing with its community, although it has gradually closed its hardware development process. The designs are available up to version 3 under a CC-BY-NC license, and closed since. It has started filing of patents from 2015 and the launch of SaaS services to easily manage a fleet of machines – 3D printer farm –, which is the core of its offer (in addition to the selling of

Figure 1: 3D Printers Estimated Popularity (using Google Trends, France)

the machines). The company occasionally sells 3D printer farm installation services.

On the software aspect of the 3D printer farm management, it has preserved the FLOS nature of Cura, its slicing software[2], commonly used by FLOH 3D printers. The company has kept a central position in its development, as the lead developer (David Brahm) was hired by the company. Cura is integrated with Ultimaker's paid software offering.

Among the companies analyzed, Ultimaker is the one that has pushed the furthest the development of added services, aimed at companies, often relying on commercial partners, but without totally cutting itself off from FLOH projects: free online training, diversity of recognized materials from different suppliers (the "Material Alliance"), openness to software add-ons developers, development of farm management services...

4.3 Prusa Research

Joseph Prusa founded the Czech startup Prusa Research in 2012, which designed its first printer, the Prusa i3, the same year. It was also an evolution of earlier designs developed within the RepRap project. This Original Prusa 3i Mk2 clocked in at nearly 5% market share in 2017, far ahead of the Makerbot Replicator 2x.

Prusa Research seems to have maintained a much stronger open-hardware strategy than Makerbot. The source code of the machines is still available, under an open license, on a dedicated GitHub, in which users contribute. The company has also organized the sharing of designs (printing program using its printers) between users, where it also proposes its own open design, such as a visor, widely reused during the first wave of the COVID-19 pandemic [31]. Indeed, although it is hardware, software remains important to control the evolution and quality of the 3D printing solution. As Ultimaker, Prusa Research has developed its own open-source licensed slicer, PrusaSlicer, based on the FLOS slicer Slic3r, which was started in 2011 inside the RepRap community.

While Prusa Research appears as the focal point of an ecosystem of actors collaborating around the FLOS projects it has initiated, it also collaborates with other ecosystems, in particular RepRap's and E3D-Online's. E3D-Online is a company active in the design and marketing of hardware dedicated to 3D printing. It initially specialized in nozzles[3] for RepRap.

The range of machines offered by Prusa Research has gradually expanded. The company makes extensive use of its printer farm (500 printers in 2018). This has allowed it to develop strong expertise in small and medium series 3D product printing. This is a kind of "eating your own dog food" [17], which allows a high level of control over the quality of its productions (the machines), which are tested in real production conditions. This has also allowed the company to evolve towards installation, customization and maintenance services for companies' 3D printer farms. Finally, Prusa Research has diversified its sources of income via its online shop, selling its printers but also derivative products, notably filaments (recurrent purchases). Prusa Research has therefore developed a model very open to both contributors and advanced 3D printing users, and also to other free projects (RepRap, E3D-Online, etc.), with strong brand control, significant diversification of revenue sources.

4.4 Dagoma

The Roubaix (north of France) based company Dagoma started marketing machines in 2014 with ease of use as a differentiating

[2] "The slicer, also called slicing software, is computer software used in the majority of 3D printing processes for the conversion of a 3D object model to specific instructions for the printer. In particular, the conversion from a model in STL format to printer commands in g-code format in fused filament fabrication and other similar processes." Wikipedia Article Slicer (3D printing)

[3] The element in a 3D printer that applies the molten filament to the bed.

element (“click and print” concept). Dagoma’s origins are less connected to the RepRap project, as its initiators initially created a company to sell 3D printed object (bikes), and turned toward selling the printers they have created to do so. Their first models were as much inspired by RepRap’s designs as by Prusa’s. Several models have followed: Discovery 200 (2014), Disco Easy 200 (2016), Neva (2017), Magis (2018) and Disco Ultimate (2018). The Discovery 200 presented itself as the cheapest 3D printer on the market, which, as with Makerbot, has found its limits with the rise of Chinese competition and the lesser-than-hoped development of the home printer market. Dagoma underwent a financial insolvency agreement in 2020 and reoriented itself towards the professional market, with the Pro 430, a small and medium-size series printer. The company is thus seeking to position itself as an alternative to Ultimaker in the segment of machines priced above €2,500. It has also developed a 3D printer farm and a strong competence in on-demand manufacturing of 3D printed pieces small and medium series (30% of its revenues in 2021). During the first wave of the COVID-19 pandemic it produced 250,000 face shields (in May 2021).

Dagoma seems to follow a “partly open” IP management approach, as described by West [35], since its GitHub sees coexisting elements under different free licenses, among which Creative Commons with Non Commercial clause (NC) license. In terms of co-creation, the company initially opened the extension catalog to community contributions. It also opened an online club to promote user creations and to produce them.

4.5 Synthesis

These companies all come from a Free/Libre technology ecosystem, RepPrap, on which they have relied to build printer offerings that are easier to use and more durable for users than those that have to be built from shared plans. It is thus not surprising then that they all share some capabilities, such as experts capable of architecturing machines.

However, we see that strategies have shifted on the relationship with open projects in particular, and on the way innovation is managed in general. This is what we propose to analyze now.

5 ANALYSIS

We propose to analyze two aspects: the way in which specific capabilities have been constructed, to allow for the building of a sustainable business model, offering a value that is difficult to contest; the fact that this construction leads to models that illustrate those proposed by Gawer [14].

5.1 The building of a business model: developing capabilities on specific technologies

First, all companies have had, and still have, the same strategy for the development of the technologies of use, at least for the standard elements, embodied in software: to favor the production, by the users, of Free/Open propositions. This is, for example, the case for the printing model libraries that develop the use cases. These elements are complementary assets to the value proposition centered on the provision of printing capacities. In other words, they have tried to support the creation of technology of use, seen as complementary assets, at the lower cost for them, by externalizing them to the users, as they were not seem as core for their value capture.

They also have had a fairly similar path in the construction of the offer and the capacities that have enabled them to develop their architecturation skills. All these companies were created to market more or less modified FLOH machines, offered in kit form. The cost of entry was relatively low because it required little investment: the key capabilities were the designers, and their knowledge of the components and their ability to assemble them from models. This business model is close to custom development, or “Craftsmanship”. But it only lasted as long as the industrial production of machines, which was mainly in Asia (low cost industrialization).

First the companies proceeded to the industrialization of a standard machine, by making it more reliable and by resorting to process innovation, which corresponds to a business model described as “Industrialization”. This is also what the Asian companies did, but our studied companies relied on FLOH components to do so. However they have had to abandon the low cost series, where economies of scale were not important enough to compete with the Asian offers, to concentrate on the medium-high range, in terms of quality or production capacity. To do so, they had to evolve and specialize, to increase the quality and reliability of the products they develop, in order to increase the value created but also captured, from a public that is sensitive to these elements, the companies. The challenge is then to find the right balance between standardization of the offer, which allows economies of scale, and flexibility, which allows to serve different needs. Of course, this brings us back to the central question of platform, the control of the innovations and of the technologies to create and capture value.

As said in the review of literature, firms may develop capabilities (organizational assets, technologies and human expertise) on the product side (the building of machines), or on the service side (user support). All companies has sought to satisfy a diversity of needs by developing the flexibility of its standard machines (e.g. diversity of materials and associated software/hardware modules), which leads to the “Platformization” type business model. but two companies have chosen to focus on the building and machines and have developed capabilities related to the elementary technologies ↔ product articulation, Makerbot and Prusa, and two have specialized in the use capabilities (product ↔ needs), Ultimaker and Dagoma.

Makerbot has specialized in the production of specific equipment, printing materials, which may have been improved beforehand when the kits were commercialized. It is a matter of integrating the upstream part of the chain, by developing elementary technologies, and to create recurring revenues. It has also internalized the assembly of these components into a product. Doing so, and at the image of what Apple may do in the computer market, the company master the whole architecturation technology and thus the quality of its products. However, their model is more a classic proprietary than an open-hardware business model.

Prusa, on the other hand, has maintained an open strategy for the architecturation technologies, both for the elementary technologies and their integration into 3D printers. The preservation of a strong link with the communities seems to have made it possible to subcontract part of the R&D on those technologies to the user-innovators, which are valued (in terms of value capture) on the professional market, in the development of complete machines, which are built thanks to the company's ability to go out and find the best technologies and to architect them in an efficient way. The farm is then a key asset, because it allows for testing these architectures, while offering a service (printing on demand), test that allows to guarantee the quality of the assemblies made. The investment in R&D is not on the mere development of technologies, but on the capacities to absorb those produced by an innovation ecosystem that is maintained and animated.

The same difference in terms of innovation management/open strategy exists for the companies which specialized on technologies of use. Regarding the architecturation technologies, both Dagoma and Ultimaker have stopped the open-hardware strategy (even if their older –FLOH– models of printer are still available). They haven't developed specific architecturation technologies. Ultimaker, however, has developed an open-source strategy on the slicing software Cura beside other elements, because it is a key component to insure the quality of the printing, and has integrated it into a SaaS printing control service toward professional companies. This service comes with other, privately own software, such as printer farm facility management software. As for Prusa on the hardware part, Ultimaker acts as a technology innovation editor to deliver the best service in "(private) 3D Printing as a Service business model". It is interesting to note that Prusa has recently imitated Ultimaker in the development of its own open-source slicing software project. This illustrate that the core capacities are close: absorptive technological capacities on innovative technologies developed by users-innovators, i.e. capacities to assess, select the best proposition and incorporate them into a guaranteed offer to professional clients. Dagoma has gone a step further in the technology of use, as its differentiating offer is to be able to print pieces at the best cost. Their core competency in thus in the management of a farm of 3D printers, in a "(public) 3D printing as a service", meaning software and teams to manage their internal 3D printer farms. It makes it possible to satisfy the demand of smaller clients, which are their original clients (for their low-end machine) albeit at the cost of a significant investment (e.g. a farm of machines). For the time being, the companies continues to use its own machines, which allow some testing of the products it sells, but with a strategy of technology taker on the architecturation part.

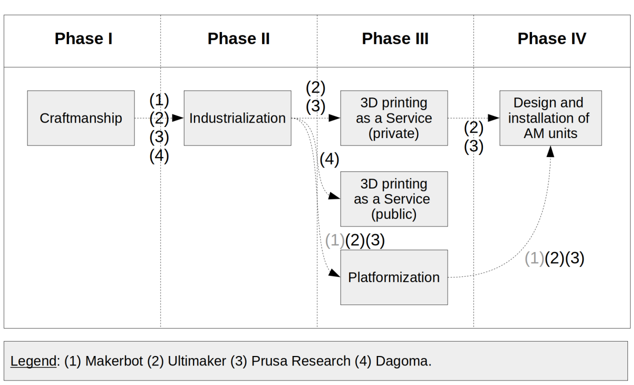

Figure 2: Open-hardware Business Model Evolution

Figure 2 summarizes the companies' business model evolution. All have started with the same capabilities: their creators' skills to edit (select and assemble) the FLOH elementary technologies to build low-cost 3D printing production. But the market pressure has made this strategy unsustainable. They have had to focus on quality to meet professional needs, and thus to develop specific capabilities to create this quality differentiation and build offers that address a specific type of needs.

The strategies have diverged between the companies which have focused on the architecturation technologies (Makerbot and Prusa), and those which have focused on technologies of use (Ultimaker and Dagoma). But in both cases, open or closer IP valorization remain possible to create a differentiating market position, and, ultimately, open or closed hardware business models.

5.2 Open-hardware, Open-source Business Models

It seems to us that two types of strategies can be identified, which illustrate two ways of managing a technological platform.

5.2.1 Closed Supply-chain Platform: Makerbot. Makerbot seeks to control all the components in order to master its architectures, as part of a quality strategy, and therefore favors a closed approach to innovation in order to guarantee the technological consistency of its platform, This is consistent with the company's strategy of moving upmarket to reach the professional market and the structuring of a razor-blade type business model that relies heavily on the sale of raw materials, but which requires strong control over the overall quality of the proposed solutions (the assembly of components), and also over the compatibility between the different elements of the hardware (again to guarantee overall quality, but also to control the appearance of cheaper clones of the "blade" part, the raw materials). The distribution of software, allowing the machines to function, or of creations are complementary assets to the core business (machine production), because they reinforce the attractiveness of Makerbot's solutions, and therefore the creation of value, without threatening the capture of value for the company.

As a result, the community is excluded from hardware developments, while a community activity remains for software and, under a different brand, for creations. One can even underline, according to a scheme that closely follows the Hirschmanian model of "exit, voice, loyalty" [19] already adapted to the open-source context [32], that this strategy of exclusion is self-perpetuating: the closure of certain elements inevitably generates conflicts with FLO –H or S– projects and participants, who become less involved, reinforcing the company's need to do things by itself, and thus diminishing the interest of collaborations with FLO projects. This strategy broadly follows the classic pattern identified in the open-source sector [24], or the more general framework of open innovation [5], where the community is exploited temporarily at the launch of the activity, to compensate for the lack of resources of the company, with a gradual closure of the development process, because the company is no longer able to capture the value created by the community. The company then develops (contractual) collaborations with suppliers or its own unitary technologies that guarantee it total control over the innovative solutions it proposes. This is what Gawer (ibid) has called the "in-house" platform strategy.

5.2.2 *Open Industry platform: Prusa Research & Ultimaker.*

Prusa Research and Ultimaker seem, instead, to want to generate innovations around their platform, via proposals from users or technology providers that it then selects to build more or less custom machines for particular customers. In practice, this results in the development of a particular form of innovation ambidexterity [22], as the companies have developed their capacities to make both incremental innovation (on their offer, especially the machines) and to explore new offers (radical innovation), such as the farm facility management. It must be pointed out that the Github space dedicated to software (e.g. firmware and slicer) are significantly more active than the parts more specifically dedicated to hardware, even for Prusa. Ultimaker has even abandoned the open-hardware strategy. It is perhaps within the platforms made available to stimulate the uses of 3D printing machines that the value exchanged (in the sense of [5]) is most significant. However, Prusa's open-hardware strategy remains important for it to maintain exploratory capacities. The publication of machine specifications under a free license is necessary to generate contributions, but also to allow users to test configurations and thus report bugs. In this sense, the two value propositions seem to be complementary: on the one hand the machine farm that allows the industrialization of configurations, on the other hand the professional customers, who can either acquire these standard configurations or ask for more specific services for which this library of propositions provides resources. Finally, and contrary to Makerbot, this strategy does not harm value capture, because the main source of revenue does not come from selling machines to its user-developers, but from printing solutions (machine, but also guarantee of operation, help with use), for which the company possesses other specific human assets (business experts or experts in 3D technology), which are also expensive to replicate.

Ultimaker has focused the open community management on the technology of use, notably through the control of Cura. It allows the company to develop technological partnerships (for example by ensuring compatibility with extensions connecting third-party software, but also third party elementary technology). In a sense, Ultimaker is developing a FLOS 3D printer operating system, which allows the company to sell a 3D printer farm operating system.

If these companies have developed capabilities around technologies, they are about controlling a dynamic asset [27]: it is because they are within a rich ecosystem and are able to transfer innovation proposals from user-innovators to their customers that they are capable of creating new, better offer and extract value from them. This is an original model of industrial platform (in the sense of [14]), where control is not essentially, solely, through intellectual property, but through the ability to attract innovators into an ecosystem in which the firm maintains a central position, thanks to the brand and the platform that refer to its proposals, but also thanks to those human (expert) and material (farm) assets that are difficult to imitate. It is worth pointing that Prusa has recently moved toward proposing its own 3D printer farm operating system and service (called Automated Farm System), as the capabilities to do so are close to the one its already has (technology edition skills and 3D printer farm to test them), illustrating its innovative ambidexterity.

5.2.3 *3D Printing as a Service: Dagoma.*

Dagoma appears to be more focused on needs than on technology, and increasingly technologically agnostic. Its core capabilities seems to be on the industrialization of usage capabilities, where the community plays a role in exploring the capabilities of the machines. This is why we do not speak of a platform model for this company, as its goal is to propose an online printing services (3D printing as a service).

Figure 3 summarizes the companies' positioning in terms of innovation management: the type of technology they invest in, and their strategy in terms of intellectual property management.

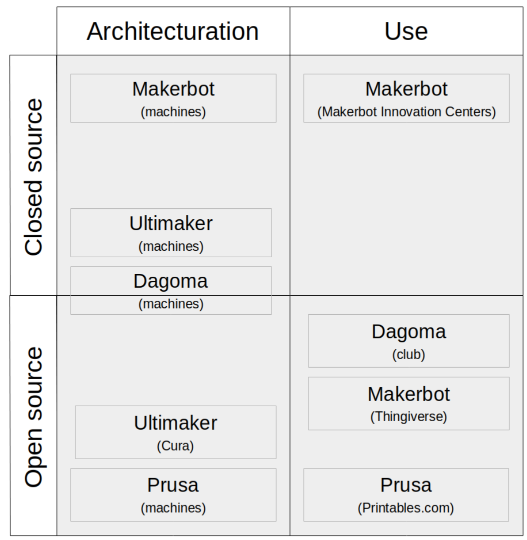

Figure 3: Business models summary

6 CONCLUSION

Companies collaborate with FLOH communities according to their contributions to the companies' value proposition and to the articulation with the capacities these companies have developed.

We identified two models, which echo existing technology platform models [14]: one close to Apple's, called "supply-chain type platform", Makerbot's, one to the PC ecosystem's, or RedHat's, called "industrial platform", Prusa Research and Ultimaker's. Makerbot seeks to control all the components to master its architectures to guarantee the technological coherence of its platform. Prusa Research, on the contrary, wants to generate innovations around its platform, via proposals from users or technology suppliers that it selects for its customers, tested in its farm (to meet standard needs), or in the construction of more or less custom machines for particular customers. Ultimaker is less open on the architecture part, because the core of the innovation dynamics for its business model lays on the technology of use, what we have called the 3D printer operating system, or which it also has an open-source strategy.

These two models stress the difference of perspective regarding innovation.

Makerbot has had closed innovation strategy based on intellectual property ownership to control (and sell) the access to its own specific asset. The collaboration with an open community was just a transitory situation for the company, allowing the technology to evolve more rapidly in a context of uncertainty, which is abandoned when the company has developed its own skill and portfolio (this is a rather classic situation for innovation [24]).

Prusa Research sees the machine specification free licensing as necessary to generate contributions, and to allows users to test configurations (bug reporting, testing externalization). The company's key asset is its dynamic capability to monitor this innovation dynamic, which creates a need for constant evaluation of the innovations, can lead to more quickly improving solutions, but furthermore generates a demand for innovation assessment and warranty. This strategy doesn't harm value capture, as the revenues are derived from the sale of printing solutions (innovative machines with operating warranty and training), for which the company owns specific human assets (business experts or 3D technology experts), which are also costly to replicate.

Whether for Ultimaker the open-source strategy is transitory to develop more quickly its innovative offer on 3D printer management system as for Makerbot or a more sustainable strategy of focusing on dynamic capabilities remains an open question today.

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