J. Eng. Technol. Manage. 37 (2015) 90–102

Contents lists available at ScienceDirect

Journal of Engineering and Technology Management

journal homepage: www.elsevier.com/locate/jengtecman

Co-creation and user innovation: The role of online 3D printing platforms

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ARTICLE INFO

Article history:
Received 3 February 2014
Received in revised form 16 July 2015
Accepted 24 July 2015
Available online 22 August 2015

Keywords:
Co-creation
User innovation
3D printing
Platforms
Mass customisation

ABSTRACT

The aim of this article is to investigate the changes brought about by online 3D printing platforms in co-creation and user innovation. As doing so requires a thorough understanding of the level of user involvement in productive processes and a clear view of the nature of co-creative processes, this article provides a 'prosumption' framework and a typology of co-creation activities. Then, based on case studies of 22 online 3D printing platforms, a service-based taxonomy of these platforms is constructed. The taxonomy and typology are then matched to investigate the role played by online 3D platforms in regard to the various types of co-creation activities and, consequently, how this impacts user innovation.

1. Introduction

Among the recent technological developments, 3D printing has been deemed as one of the most promising. For Rich Karlgraad (Forbes), 3D printing is the "transformative technology of the 2015–2025 period" (Karlgraad, 2011). For Chris Anderson (Wired), the "desktop manufacturing revolution [. . .] will change the world as much as the personal computer did" (Anderson, 2012). Finally, U.S. President Barack Obama, in his 2013 second term State of the Union address,[1] emphasised the critical role of 3D printing in strengthening manufacturing, scientific, defence and energy sectors.

One of the key reasons why 3D printing technologies are considered so promising is that they render very low volume production economical and, thereby, enable mass-customisation on a very large scale. They also create significant opportunities for co-creation between firms and their customers. Co-creation and mass-customisation are two very important vectors of user innovation, which is, itself, a critical source of radical innovation (Lettl, 2007).

Yet, while there is little doubt that 3D printing technologies will have, in the coming decades, a highly transformative effect, consumer adoption of these technologies still remains rather low. Indeed, while prices of 3D printers have considerably decreased over the past couple of years, advanced printers remain rather expensive and affordable personal 3D printers (in the $1000–2000 range) are only able to produce simple objects (one material/colour) of relatively low quality. Furthermore, 'making' an object requires more than just a 3D printer and advanced knowledge of 3D modelling (CAD) software is still often required.

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[1] http://www.whitehouse.gov/state-of-the-union-2013#webform.

http://dx.doi.org/10.1016/j.jengtecman.2015.07.002
0923-4748/

Aiming to bridge such gaps, several online 3D printing platforms have appeared over the past few years. The first of such platforms, Ponoko, was launched in 2007 and there are now over 20 of such platforms operating online, the best known of which are Shapeways and Thingiverse. Just like Web 2.0 and social media, these platforms enable firms and users to engage in co-creation activities – this time around physical objects – and have the potential to be significant vectors of user innovation.

While previous ICT revolutions have enabled consumers to take an ever increasing part in production processes, 3D printing is the 'last piece of the puzzle' that enables consumers to intervene at *any* stage in the production process, from the initial idea to the fully manufactured product, and even to carry out most (if not all) of this process.

Hence, understanding the changes that online 3D printing platforms can bring about to the innovative processes requires to fully understand the diverse nature of co-creation activities and the changing role of consumers in the production process. To do so, this article provides both a framework of consumer involvement in the production process and a typology of co-creation technologies. Then, based on case studies of 22 online 3D printing platforms, the core design and manufacturing services these platforms offer are investigated. The resulting classification of platforms is then used to discuss the role played by each type of platform in regard to co-creation activities and leveraging of user innovation.

The structure of this article is as follows. The first section reviews the relevant literature on co-creation, innovation and mass-customisation. The second section is devoted to the changes in consumer involvement in production processes. The third section reviews the different forms of co-creation and provides an integrated typology. The fourth section presents the case studies and reviews the core services offered by online 3D platforms. The two final sections are devoted respectively to the role played by 3D printing platforms in co-creation and in leveraging user innovation.

2. Consumers as a source of innovation

The importance of external sources of innovation started to be emphasised by researchers back in the 1980s (von Hippel, 1988) and gained even more attention since 2003, when Chesbrough coined the term 'open innovation' (Chesbrough, 2003).

Traditionally, open innovation with consumers was mainly 'outside-in', i.e. consumers were used as a source of ideas for new products or improvements of existing products (Christensen, 1997; von Hippel, 1988). However, nowadays consumers are involved in generating ideas for new products, co-creating products with firms, testing finished products and in providing end user product support (Nambisan, 2002). Consumers are no longer simply external sources of ideas (outside-in) (Berthon et al., 2007; Bogers et al., 2010; Poetz and Schreier, 2012), but can also become external paths to market (inside-out) (Baldwin and von Hippel, 2006; Shah and Tripsas, 2007).

Co-creation corresponds to the customer-related part of open innovation: 'open innovating' with consumers necessarily implies co-creating with them. However, not all co-creation activities carried out with consumers lead to open innovation, as innovation requires successful commercialisation. Hence, suggestions submitted by consumers that are not acted upon, or a collaborative design that does not go beyond the prototype stage are examples of co-creation activities that do not result in innovation.

Co-creation can either be autonomous or sponsored (Zwass, 2010). When autonomous, consumers co-create independently (even though tools and platforms provided by the company may be used), without any incentive provided by the company. In contrast, sponsored co-creation takes place at the initiative of a company or any other established organisation.

Co-creation can occur at different stages of the production process: design stage (co-design), manufacturing stage (co-manufacturing) and distribution stage. Furthermore, co-creation can also take place between individual customer, giving raise to "communities of creation" (Sawhney and Prandelli, 2000) or "communities of co-design" (Piller et al., 2004).

Co-creation is also often associated with mass-customisation. Mass customisation relates to the production of personalised or custom/tailored goods or services on a large scale (i.e. customisation is the rule and not the exception). Although, co-creation activities increasingly result in mass-customised products, mass-customisation does not necessarily involve co-creation activities (Prahalad and Ramaswamy, 2004) or even lead to open innovation (Piller and Tseng, 2010; Chesbrough and Piller, 2012). For instance, when mass-customisation implies choosing from a set of predetermined options (e.g. colour, size, add-ons), this is not co-creation, as consumers do not provide actual input, besides choosing amongst options that were set by the firm (possibly without any customer input). Furthermore, selecting from predetermined options does not lead to innovation, as this does not provide any element of novelty (Piller and Tseng, 2010).

Fig. 1 summarises the relationship between open-innovation, co-creation and mass-customisation.

3. From consumer to 'prosumer': levels of consumer involvement

One of the most obvious consequences for businesses of the advent of Internet is the increased participation of users in the production process. This increased participation has been particularly visible since the birth of Web 2.0 technologies and for some of the most successful Web 2.0 outlets (e.g. Facebook, Instagram, Flickr, Twitter), the content provided by users accounts for most of the value of the service. This increased user participation blurs the line between consumption and production activities (Berthon et al., 2008), since users both consume and produce content. No longer 'pure' consumers, users have become 'prosumers'.

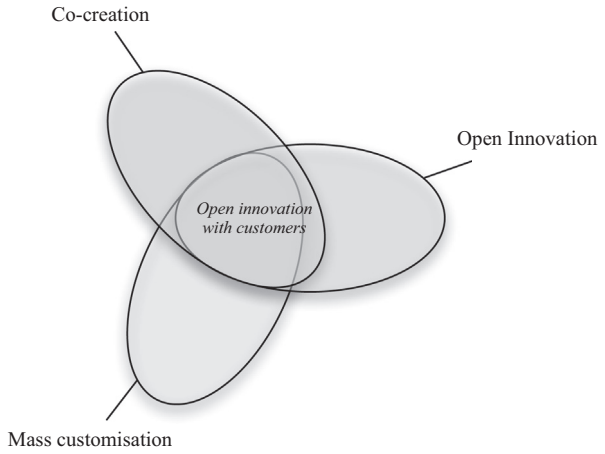

Fig. 1. Relationship between Open Innovation, co-creation and mass-customisation.

Although the 'prosumer' phenomenon has now reached an unprecedented scale, the concept itself is not entirely new (it was coined in Toffler, 1981). Early works mainly focused on the increased role of consumers in Do-It-Yourself (DIY) activities (whether self-manufacturing, self-service, or self-help) (Toffler, 1981) or in providing input for customisation, either in the form of measurements (Toffler, 1981), or by choosing and combining different available options (Kotler, 1986). In these early works, however, prosumers are only thought as providing 'labour force' as a part of the production process and (understandably at the time) situations where consumers are creating entirely new products (and provide the whole design) of manufacture the whole product at home (using machines) are not considered.

More recently, the advent of Web 2.0 technologies and the significant opportunities for user participation and involvement that they entail lead to a surge of interest in the prosumer phenomenon. As noted in Ritzer and Jurgenson (2010):

> Prosumption was clearly not invented on Web 2.0, but given the massive involvement in, and popularity of, many of these developments (e.g. social networking sites), it can be argued that it is currently both the most prevalent location of prosumption and its most important facilitator as a "means of prosumption".

In the recent years, the question of consumers becoming prosumers has been particularly thoroughly discussed in Tapscott and Williams (2006) and Ritzer and Jurgenson (2010). With regard to the concept itself, however, Ritzer and Jurgenson (2010) remain very close to the definition of the earlier works of Toffler (1981) and Kotler (1986). Indeed, their vision of prosumption is that of consumers 'replacing' workers for some of the tasks in the production process. In contrast, Tapscott and Williams (2006) depart from this rather narrow view of prosumption and extend it to situations where consumers take part in the production process in a far more creative way, for instance when consumers 'hack' or remix existing products.

Yet, looking at the recent developments, it is clear that consumers are doing more than that. To better understand the radical changes brought about over the past years in the production process by the developments of ICTs, it can be useful to use the economic concepts related to division of labour. Classical economic theories, which appeared in the wake of the first industrial revolution, make the difference between 'capitalists' (i.e. investors) who own the means of production (tools, machines, factories) and 'workers' who only own their labour force. Later theories further differentiated between workers depending on whether their work implied the possession and use of intellectual capital (white collar) or not (blue collar).

Using these concepts enables to differentiate different levels of prosumption (Table 1). What is particularly striking is that the highest level of involvement, consumers as 'investors', has so far been given very little attention in the literature (it is only mentioned, partially, in Tapscott and Williams, 2006). Yet, it is definitely one of the key defining features of modern prosumption.

Indeed, nowadays, when consumers take part in the production process they increasingly do so using their own means of production. Obviously, their computers, mobile devices, etc. are used to produce content for Web 2.0 platforms. Beyond that, their cameras, camcorders, etc. are used to produce multimedia content. They may even invest in software enabling them to

Table 1
'Division of labour' and level or prosumption.

Type of activity	Literature	Examples
'Blue collar'	Toffler (1981)	DIY
'White collar'	Kotler (1986) Ritzer and Jurgenson (2010)	Custom order/choice of options
'Investor'	Tapscott and Williams (2006)	Home printing

be more creative and produce higher quality content (e.g. digital photography post processing software, 3D modelling software, spelling and grammar checker). All of this increases, *de facto*, the means of production available to firms engaging in co-creation with consumers. Consumers and their equipment thus become a part of the complementary assets that are critical to firms' success (Teece, 1986; Stieglitz and Heine, 2007; Rayna and Striukova, 2009).

This role of consumers as investors is even more noticeable when one considers their involvement in the production of physical objects. Consumer-owned printers, for instance, are one of the many means of production that firms can use within a co-creation activity. Consequently, 'print-at-home' tickets have enabled the transport industry to radically decrease their own printing costs.

This last aspect is, of course, critical and will undoubtedly, gain importance as the rate of adoption of 3D printers increases. Indeed, with 3D printing technologies, the role of consumers in the production process of physical objects ceases to be peripheral and limited to minor contributions, but becomes central in the production process.

Indeed, the production process of an object typically involves three stages: design, manufacturing, distribution. Traditionally, consumers have been mainly involved in all three stages, albeit to a limited extent (e.g. choice of colour or sizes, assembly of pre-manufactured parts, going to the store and back). However, the recent progresses in ICTs and 3D printing technologies have the potential to completely turn this model around. Indeed, home 3D printers enable consumers to be solely in charge of the manufacturing and distribution stages. Even if some of the parts are manufactured at a local printshop (because they need to be made out of a special material), the consumer remains in charge. Furthermore, the rise of co-creation platforms, such as those presented in the following sections, also empowers consumers to take an active, and even leading, role in the design process.

Fig. 2 summarises the different levels of consumer involvement in the production process according to their level of participation in design, manufacturing and distribution. It shows that, indeed, the concept of prosumers corresponds to very different levels of actual involvement. Over the years, consumers have been increasingly involved in all three dimensions, for instance the 1950s saw the birth of self-service fast-food and the 1970s the birth of DIY and factory outlets. However, while significant, consumers' input was never leading (aside from some rare cases, such as bespoke tailoring). Digital technologies have accelerated the 'prosumer trend' and, online, consumers have been playing a leading role in design, 'manufacturing' and distribution for a couple of years now. The advent of 3D printing will enable consumer to take a leading role 'offline' as well. Thus, for businesses, consumers are no longer 'just clients'. They have taken an ever-increasing part in the production process and, as such, as prosumers, they have become legitimate partners for businesses.

4. Categorising co-creation activities

Although it is clear that consumers' involvement in the production processes has increased, this does not make their participation homogeneous. The previous section discussed the extent of consumers' participation in the production process. This section is devoted to categorising the different types of co-creation activities consumers can engage in with businesses. This classification of co-creation activities is used in the following sections to discuss the roles of online 3D printing platforms.

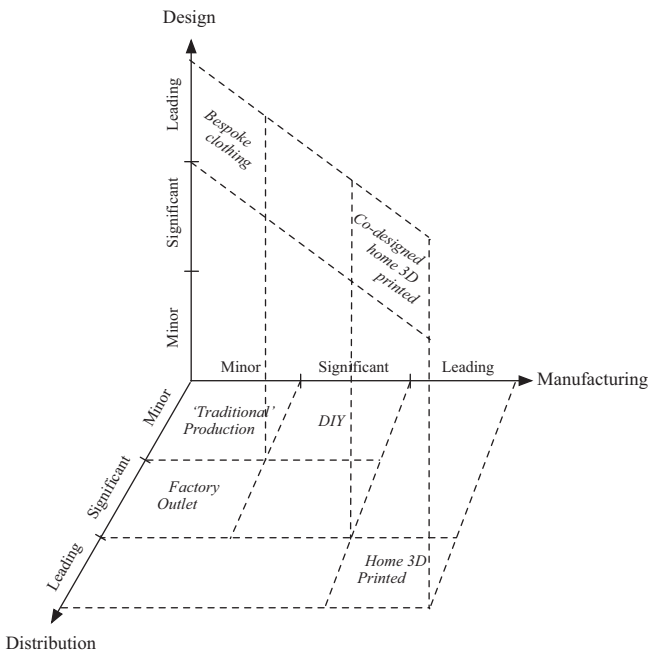

Fig. 2. Level of involvement of consumers in the production process.

Table 2
Typology of co-creation activities.

	Mass-production	Mass-customisation
Differentiated	*Crowdsourcing* *Social media*	*Customised objects* *Crowd-customisation*
Integrated	*Open Innovation platforms* *Open source*	*Co-design platforms*

Co-creation activities may have different forms. Indeed, there is a significant difference, for instance, between one consumer printing at home an object entirely designed by a firm and several consumers engaging in a crowdsourcing activity. In order to categorise co-creation activities, two critical aspects need to be considered: whether the roles of the consumers and firms are differentiated or integrated and whether the resulting product is aimed at the mass-market or is customised.

The first aspect relates to the complementarity of the activities of consumers and firms as a part of the co-creation process. In some cases, consumers and firms provide different and complementary resources, for instance, one designs the product and the other manufactures it (and vice versa). A well-known example of differentiation of activities between firm's and consumers' activities is DIY furniture, when firms supply flat-packed furniture and consumers assemble the object themselves. In contrast, other co-creation activities involve firms and consumers working together on the same aspect of the production process, for instance, when a customer is ordering a custom made piece of jewellery or when firms and customers work together writing a computer programme (e.g. Open Source software).

The second aspect relates to whether the output of the co-creation activity is meant for the mass market or is tailored for a specific individual. This aspect is particularly important as it is connected with the created value and incentives to participate in the co-creation activity. Some co-creation activities result in a product 'valuable to one' (mass-customisation), while other lead to products that are 'valuable to the many' (mass-production).

Based on these two key aspects, it is possible to build a typology of co-creation activities (Table 2). Nowadays, the most common type of co-creation activity is 'differentiated/mass-production'. Most crowdsourcing activities belong to this type, as crowdsourcing typically implies that the 'crowd' is in charge of one type of activity (usually design), while the company takes care of the rest and mass-manufactures the product. This is for instance the case for Threadless, as the crowd of users is both in charge of suggesting new designs and selecting the best designs, which are then mass-manufactured by the company. In the purely digital realm, Web 2.0 outlets and social media are another example of co-creation that is both differentiated and mass-produced (posts, photos, etc. are generally meant for more than one person).

The second category corresponds to co-creation activities that are also targeted at the mass-market, but that involve activities of firms and consumers that are integrated with one another. 'Open Innovation platforms', such as Nokia Concept Lounge and Fiat Mio, fall within this category (in both cases objects were co-designed by the firms and consumers) and so does Open Source software (since it generally implies that the developers of a firm engage in a co-development exercise with users outside of the firm). In both cases, activities are integrated and the resulting output is indeed mass-produced (or 'mass-distributed').

The other two categories of co-creation relate to activities that lead to the production of mass-customised products. These two forms of co-creation, while originally relatively rare, are now gaining momentum with the raise of technologies that make mass-customisation economically worthwhile. In some cases, mass-customised products require a true collaboration between firms and users. This is particularly the case when co-design takes place (in the 'low tech' world, bridal cakes and bouquets could fall within this category). In other cases, roles are clearly differentiated. This particularly applies to all 'user manufacturing' co-creation activities, for instance the Ikea co-creation model, which includes transportation and assembly (Kambil et al., 1996; Payne et al., 2009), 'print-at-home' tickets or stamps, or, more recently, digital downloads (in which case, the 'custom' aspect relates to the bundling of the content).

In the future, the democratisation of 3D printing technologies is likely to enable more advanced types of co-creation. In fact, this is where two apparent opposites, crowdsourcing and mass-customisation, could meet: the crowd would be solely in charge of design and firms of manufacturing and the resulting product would be meant for one customer only and not for the mass market.

5. A study of online 3D printing platforms

The study of online 3D printing platforms will be presented in the following subsections. Beforehand, however, it might be useful to provide a brief overview of 3D printing technologies in general.

3D printing is a form of "additive" manufacturing, where a three-dimensional object is 'printed' (built) by adding layer after layer of a particular material, which differs from the more usual "subtractive" (when an object is cut out from the raw material) or moulding/die-casting (when liquefied material is placed into a mould) forms of manufacturing. The first stage of 3D printing involves creating a digital model of the object to be printed. This is usually done with generic 3D modelling software (some of which are available for free) or using dedicated software provided by 3D printing services (e.g. Thingiverse, Shapeways or Sculpteo). 3D scanners can also be used to automatically create a model of an existing object (just like 2D scanners are used to digitise photos, drawings or documents). When an object is printed, the 3D model of the object is discomposed into successive layers that are printed one at a time.

The most frequently used material for 3D printing is plastic, but wood, metal alloy, salt, ceramics and even sugar and chocolate can be used to print. Currently, most printers can only print with one material at a time, but it is only a matter of time before several materials can be used simultaneously. The Objet500 Connex (sold for USD 250,000) can already print from more than 100 materials (up to 14 simultaneously) and manufacture items which are at the same time both rubber and rigid, opaque and transparent. The range of objects that can be manufactured with 3D printers is very wide and is constantly growing: robots, body parts (organs), prosthetics, art, food items, musical instruments, furniture, clothes. 3D printers can be even used to print other 3D printers.

While 3D printing technologies were, originally, intended exclusively for (heavy) industrial use, the constant decrease in cost has put them within reach of SMEs and individual entrepreneurs. With home 3D printers now being available for less than USD 1000 (the cheapest printer, the Buccaneer, costs USD 350), 3D printing is progressively becoming a technology any business, small or large, can afford and a number of companies have already started to integrate 3D printing into their business model.

Beyond being used by firms, there is a growing trend of using 3D printing in consumer markets. While originally home 3D printing was often dismissed as a hobbyist activity, the entry of major players in this market tends to demonstrate otherwise. In May 2013, Staples became the first major U.S. retailer to sell 3D printers. Amazon followed the trend in June 2013, when it opened a 3D printing section, selling printers, plastic filament, books, software, parts and supplies. In July 2013, two major players joined the 3D printing market. High Street consumer electronic retailer Maplin started to sell 3D printers, consumables and accessories in its 205 stores throughout the UK and eBay announced its new iOS application, "eBay Exact", a storefront to existing 3D printing platforms.

5.1. Overview of online 3D printing platforms

3D printing is a relatively young technology and the number of online 3D printing platforms is still rather small (the first one was launched in 2007). Because of this, an inductive approach, based on qualitative case study was adopted (Eisenhardt, 1989; Yin, 2003). Since the aim of this study was to get insights into services offered by 3D printing platforms, explorative case studies were the most suitable for this kind of research (Yin, 2003).

Because the focus of this study was on consumer innovation and co-creation, only platforms that offer services that could integrate end-users were considered. Platforms specifically dedicated to larger businesses (e.g. rapid prototyping, tooling services) and that do not involve any (direct) interactions with users were not considered. Identification of the relevant platforms was conducted on three separate occasions: January, June and December 2013. The first set of platforms was established based on the first large-scale community survey of online 3D printing platform usage (Moilanen and Vadén, 2012). Out of the 12 platforms listed in Moilanen and Vadén (2012), eight matched the user interaction criteria and were retained for this study: 3D Creation Lab, 3DPrintUK, Cubify Cloud Print, i.Materialise, Kraftwürx, Ponoko, Sculpteo, Shapeways. This first set of case studies based on these platforms enabled to identify the different services offered by online 3D platforms and to classify them accordingly.

The subsequent two stages of investigation, in June and December 2013, were carried out using Google and Bing search engines[2] and the following platforms were added to the study: 3D Burrito, 3DLT, Additer, iMakr, Makerbot Store/Thingiverse and MakeXYZ (in June 2013); 3Dagogo, 3D Hubs, FastProtos, Maker6, Materialise Onsite, The 3D Printer Experience, Trinckle and White Clouds (in December 2013). Theses platforms did not reveal any significant departure, in terms of services and classification, from the first round of platforms.

Thus, this study is based on the analysis of 22 online 3D printing platforms. At the time of this writing, there does not appear to be any other of such platforms online. Although, more platforms are likely to appear in the coming years, this study relies on a fairly exhaustive sample.

The platforms investigated in this study are presented in Table 3. Among these 22 platforms, 10 originate from North America, three from the UK, seven from continental Europe and two from Australasia. Three of the companies located in continental Europe (Ponoko, Sculpteo, Shapeways) also have offices in the U.S. Finally, it is to be noted that four of the platforms in the study (iMakr, Makerbot/Thingiverse, The 3D Printer Experience, White Clouds) also operate physical stores.

The first mover on the market, Ponoko, launched its service back in 2007. A few other companies followed in the next two years (six of the platforms were launched between 2007 and 2009). Probably because of the lack of maturity and adoption of the technology at the time, there was a pause in 2010 and no online 3D printing platforms were launched that year. Starting in 2011, however, the growth resumed, with eight platforms launched between 2011 and 2013 and more than half of these 22 platforms were launched in 2013. There are, thus, signs that the rate of market entry is increasing.

5.2. Services offered by online 3D printing platforms

The 3D printing platforms have emerged to serve particular needs. At the moment there are only few consumers who are equipped with a 3D printer, and those who do have a 3D printer usually can only print with plastic (whereas they might want

[2] The results for the following queries were exhaustively reviewed individually by each investigator: "3D Printing", "3D Printing Service", "3D Printing Online", "3D Printing platform". For practical reasons, only platforms providing a service in English language were considered.

Table 3
3D printing platforms included in the study.

Company name	Est.	Location
3D Burrito	2013	Sweden
3D Creation Lab	2009	United Kingdom
3D Hubs	2013	The Netherlands
3Dagogo	2013	USA
3DLT	2012	USA
3DPrintUK	2011	United Kingdom
Additer	2013	Australia
Cubify Cloud	2012	USA
FastProtos	2013	USA
i.Materialise	2009	Belgium
iMakr	2013	United Kingdom
Kraftwürx	2011	USA
Maker6	2013	Canada
Makerbot/Thingiverse	2008 (store 2012)	USA
MakeXYZ	2013	USA
Materialise Onsite	2013	Belgium
Ponoko	2007	New Zealand (U.S. office)
Sculpteo	2009	France (U.S. office)
Shapeways	2008	Netherlands (U.S. office)
The 3D Printer Experience	2013	USA
Trinckle	2013	Germany
White Clouds	2013	USA

or need objects made of other materials). Hence, there are two main types of consumer needs that these platforms are aimed to fill. Some consumers want designs that they can print using their 3D printers. Others have designs, but do not own a printer (or, at least, not the one that prints with the material they want). There are also consumers who want to acquire designs and have them printed.

Because of these heterogeneous needs, there is room for specialisation in the market, which is reflected by the variety of combinations of services offered by the 22 online 3D printing platforms. These services, summarised in Table 4, relate either to design or to manufacturing activities. To this respect, it is important to note that while most platforms are specialised mainly either in design or in manufacturing, very few of them only engage in one type of activity. Indeed, aside from three platforms that only offer design related services (3D Burrito, 3Dagogo and 3DLT) and four other (3D Hubs, 3DPrintUK, MakeXYZ and Materialise Onsite) that only deal with manufacturing, all remaining platforms engage, at least at some level, in both types of activity. The different (both design and manufacturing) services offered by the platforms in the study are detailed in Table 4.

Fig. 3 displays the relationship between these services and how they relate to the flow of designs (digital objects) and manufactured (physical objects). Furthermore, this figure also displays the input provided, respectively, by individual users and the crowd. In this context, a user is defined as someone using a 3D printing platform with the aim to acquire a digital or a physical object. Some of the services offered by the platforms (e.g. design customisation, co-design) involve significant input from the user. Furthermore, some of these services (typically any that involves crowdsourcing) entail contribution from a particular user and from other users from the crowd. To keep the diagram clearer, interactions with third-parties (e.g. companies supplying designs or printing facilities) are not displayed.

Thus, online 3D printing platforms enable a wide range of user involvement in the production process, from the lowest degree of participation (e.g. user buys a set design that is printed and delivered by the platform) to the highest one (user co-designs the object and prints it at home). Likewise, in some cases, the crowd does not play any role, whereas in other cases, the crowd can be involved both in the creation of an object and its manufacture.

Table 4
Main services (design and manufacturing) offered by 3D platforms.

Service	Description
Design supply	Designs (3D models of objects) created by the platform are offered (for free or for a fee) to customers.
Design hosting	Platform hosts third-party designs that are sold (marketplace) or offered free of charge (repository).
Design customisation	Designs (own or third-party) can be customised (e.g. shape, size, layout) by users.
Co-design service	Assistance offered to consumers when designing a 3D object, generally by transforming two-dimensional sketches or pictures into a 3D object.
Design crowdsourcing	Users can crowdsource a design by posting a detailed project that is then developed further by the crowd.
Printing	3D models are printed into objects and are shipped to customers or delivered in store.
Printer sales	Platforms supply home 3D printers (in store or through mail order) to customers so they can print 3D objects on their own.
Printing crowdsourcing	Intermediary service between users wanting to print 3D objects and users (or companies) owning 3D printers and willing to print out 3D objects for a fee.

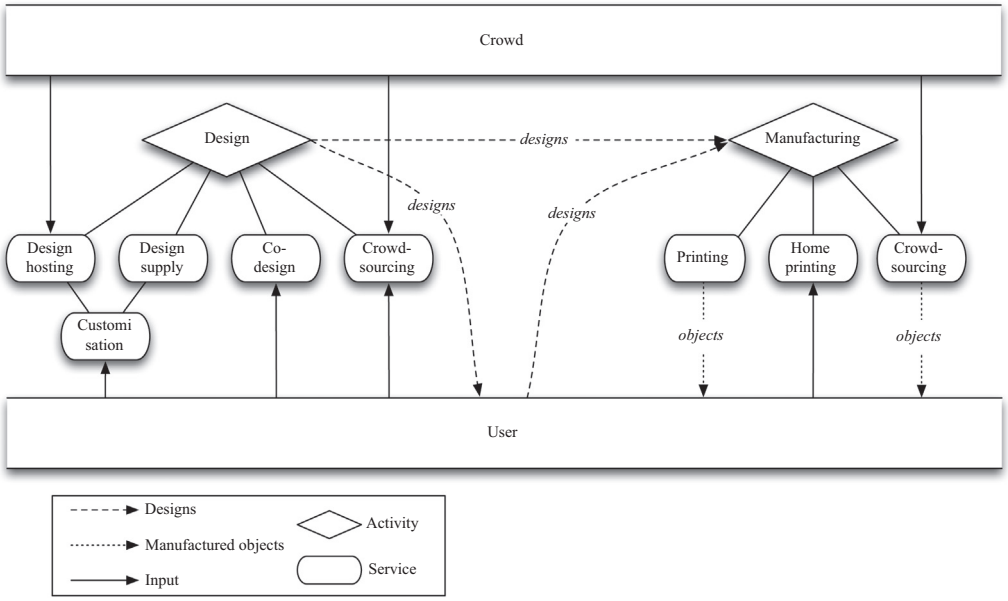

Fig. 3. Summary of design and manufacturing activities of online 3D platforms.

5.3. Different types of platform of different needs

Based on the type of services they supply, it is possible to classify the platforms in four broad categories: design marketplace, printing service, printing marketplace, crowdsourcing platforms (Table 5).

Nine of the 22 platforms (3Dagogo, 3D Burrito, 3DLT, Cubify, i.Materialise, Ponoko, Sculpteo, Shapeways, Trinckle) can be categorised as *design marketplaces*. Their main activity is to host and sell third-party designs of 3D objects. A few of these platforms (Cubify, i.Materialise, Sculpteo) also provide their own designs and two (i.Materialise and Shapeways) offer co-design services to help users turn designs into 3D objects. Finally, one of these platforms (Trinkle) offers a design crowdsourcing service, which enable users to involve the community in design creation. Once consumers have purchased 3D objects from these marketplaces, they can either print them themselves (at home with a personal 3D printer or using a 3D printing service) or have them printed directly by the marketplace (six of the nine design marketplaces also operate a printing service).

The second main category of platforms relates to 3D printing services. The main purpose of these platforms is to print on demand 3D objects supplied by users. The resulting objects are then either shipped directly to customers or could be picked up from the store (for the four platforms that also have 'brick-and-mortar' stores). Out of the eight platforms that fall in this category, only two (3DPrintUK and Materialise Onsite) offer a 'pure' printing service, as the remaining six offer complementary services, such as co-design, design repository (Thingiverse) and design supply (White Clouds). Two of these platforms (iMakr and Makerbot) also sell personal 3D printers.

The third group in Table 5 consists of platforms that operate a printing marketplace service. 3D Hubs and MakeXYZ act as intermediaries between individuals or firms that own a 3D printer and users who want to manufacture 3D objects. They generally list the location of the printer, materials available, lead times, prices and act as intermediaries for the payment.

The final group consists of two platforms, Additer and Kraftwürx, which are significantly different from other 3D printing platforms, as they operate as a one-stop crowdsourcing service and enable users to crowdsource both design and manufacturing aspects of the production of the object. For instance, there is a board on Kraftwürx's website, where users can post ideas and projects at any stage of development. Some of them post a very generic idea (for instance, showing different pieces of jewellery and asking the crowd to produce a personalised object 'in the spirit of' of the design of the objects posted). Other post 2D designs and need help turning them into 3D objects. Finally, users who already have a rough 3D model of the object can ask the crowd to help refine it or make it functional. Likewise, although some users seem to already have a precise idea of the material they would like to use, others expect the crowd to offer them different options. The crowd is also used to advise on a variety of other manufacturing aspects (cost, proximity, quality, etc.).

One of the latest launched platforms, Maker6, does not quite belong to any other group, but is, in fact, a combination of different types of platforms, as it is, at the same time, a design marketplace, a printing marketplace and a printing service.

6. Co-creation and 3D printing platforms

By combining the typology of co-creation presented in Table 2 with the taxonomy of 3D printing platforms in Table 5, this section aims to assess and categorise the role that online 3D printing platforms play in regard to co-creation with consumers.

Table 5
Categorising online 3D printing platforms.

	Platforms	Design						Manufacturing			
		Hosting (sales)	Hosting (repository)	Design supply	Co-design service	Design crowdsourcing	Design customisation	Printing service	Printer sales	Physical store	Printing crowdsourcing
①	3Dagogo	+			+						
	3D Burrito	+									
	3DLT	+						(+)			
	CubifyCloud	+		+			+	+	+		
	i.Materialise	+		+	+		+	+			
	Ponoko	+						+			
	Sculpteo	+		+			+	+			
	Shapeways	+			+			+			
	Trinckle	+				+		+			
②	3DPrintUK							+			
	Materialise Onsite							+			
	3DCreation Lab				+			+			
	FastProtos				+			+			
	iMakr				+			+	+	+	
	Makerbot/ Thingiverse		+				+	+	+	+	
	The 3D Printer Experience				+			+		+	
	White Clouds			+	+			+		+	
③	3D Hubs										+
	MakeXYZ										+
④	Additer					+					+
	Kraftwürx					+					+
	Maker6	+			+			+			+

①, Design marketplaces; ②, Printing services; ③, Printing marketplaces; ④, Crowdsourcing platforms.

Printing marketplace (Fig. 4) is one of the most straightforward types of platform to assess. Indeed, they correspond to differentiated roles (users supply designs that are manufactured by people who own a printer and offer their services through the platform) and are clearly used to produce customised objects (printers available through printing marketplaces are generally small scale printers that are not economical for anything but a couple of units manufactured).

Printing services (Fig. 5) also belong in the 'differentiated/custom' quadrant as roles are clearly differentiated (consumers supply a design that is printed by the platform) and they are essentially used to manufacture custom objects (while such services use higher grade printers, mass production is still uneconomical in comparison to traditional manufacturing methods).

Yet, some of the *printing services* also offer co-design services (Table 5). In that case, roles are more integrated (even though they are seldom fully integrated – usually users supply a 2D design that the platforms turns into a 3D design) and such *printing services with co-design service* overlap partially with the 'integrated/custom' quadrant.

Design marketplaces (Fig. 6) are slightly more complex to categorise. In particular, unlike for *printing services*, it is harder to create sub-categories of platform, because co-creation activities on the same platform can be of different nature depending on which of *design marketplace's* services are used.

For instance, the majority of *design marketplaces* also offer printing services. In that case, if a non-customised (beyond basic options) design is purchased from a *design marketplace* and is printed by the platform as well, no co-creation takes place.

When a design is purchased from a *design marketplace* to be printed at home, categorising the resulting co-creation requires knowing whether the design was customised or not. If the design was not customised, the co-creation activity can be considered as being a part of a mass-production process (albeit a distributed one), since many consumers purchase and print the same design (i.e. object), and co-creation is of a 'differentiated/mass' nature.

When a design was (significantly) customised prior to purchase, co-creation can be (logically) characterised as 'custom'. Whether the customised design is then printed by the consumer or by the platform, there is at least some degree of integration in the roles. The actual degree of integration depends on the type of customisation service, i.e. whether a

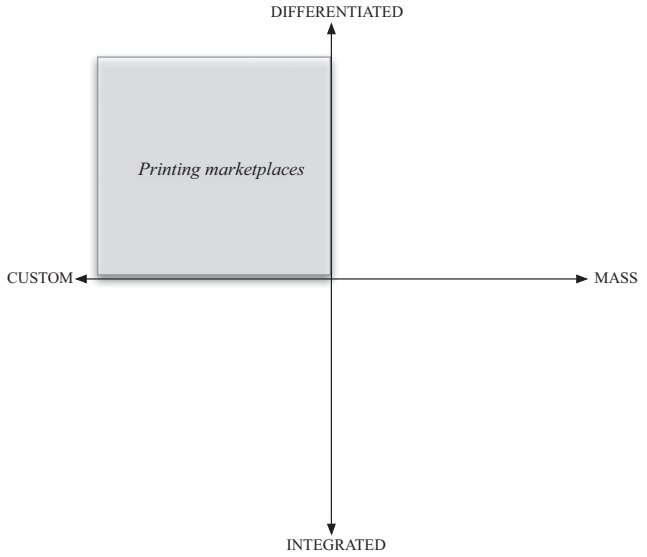

Fig. 4. Type of co-creation enabled by Printing Marketplaces.

co-design service, *design crowdsourcing* or a simple existing *design customisation* has been used, and on the respective input of the consumer and of the platform.

Crowdsourcing platforms (Fig. 7) are the most complex to categorise, as depending on the type and extent of activities that are crowdsourced (whether design or printing or both), the co-creation process can potentially fall in any of the four co-creation categories. Indeed, some customers use Additer and Kraftwürx with the aim to mass-produce (again, not with the aim to produce millions of units, but in order to sell the same object to many customers), while other use such platform to fulfil a personal need (e.g. co-design and manufacturing of a jewellery for a wedding anniversary, of a trophy for a local competition). Furthermore, depending on whether specialisation occurs (e.g. the crowd does the design and the consumer prints, or vice versa) or not (e.g. co-design and co-manufacturing with the crowd) co-creation can range from fully differentiated to fully integrated.

Hence *crowdsourcing platforms* deploy the whole spectrum of co-creation and categorising co-creation activities carried out through such platform requires considering each particular project.

It is worth noting that these platforms give raise to a new form of co-creation activities: crowd-customisation, which is a combination of crowdsourcing and mass-customisation. In such a case, the 'wisdom of the crowd' is used not to satisfy the

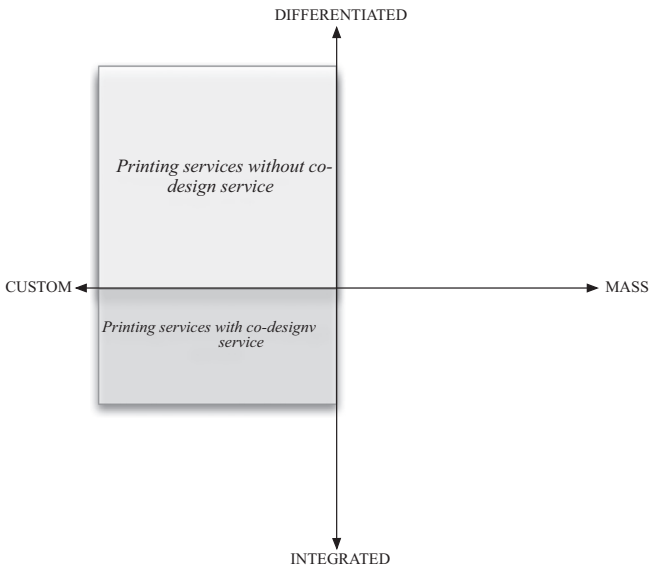

Fig. 5. Type of co-creation enabled by Printing Services.

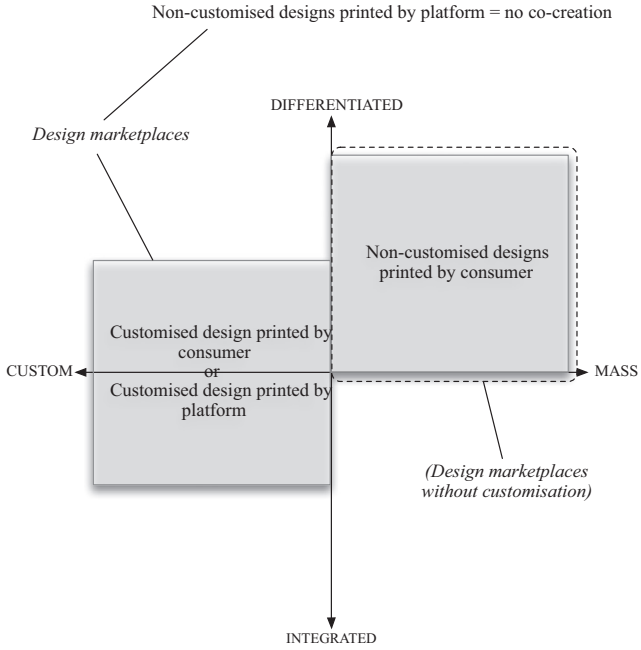

Fig. 6. Type of co-creation enabled by Design Marketplaces.

needs of the many (like it is for instance with Threadless), but to satisfy the needs of one, in other words the crowd is asked to help design and manufacture an object which has value for only one particular customer.

7. Leveraging user innovation with 3D printing platforms

The previous sections have detailed the role that 3D printing platforms can play in regard to co-creation activities between users and firms. This section aims to investigate when these platforms can be used to leverage user innovation. This question is particularly critical because, while 3D printing technologies are strong drivers of innovation, in general, and of open innovation, in particular, the relative cost of these technologies (especially in relation to quality) and their complexity of use (knowledge of CAD, materials, calibration is required) creates high barriers of usage.

As discussed in Section 5.2, 3D printing platforms have emerged precisely to close this gap. Hence, just like Web 2.0 platforms have (1) freed people from the necessity to know coding, HTML, JavaScript, FTP in order to publish content

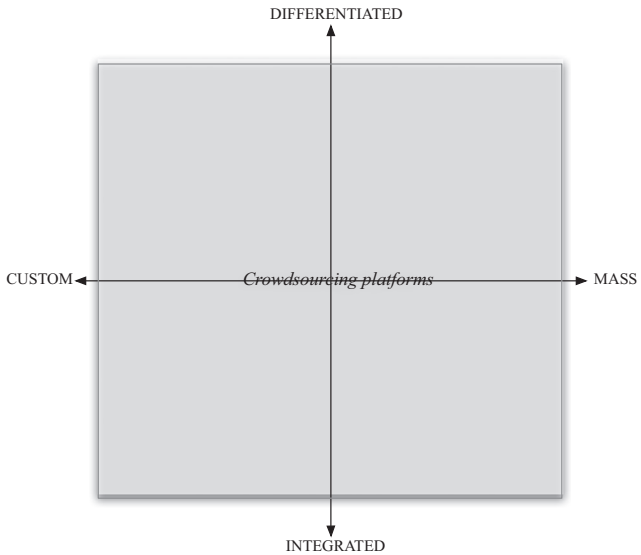

Fig. 7. Type of co-creation enabled by Crowdsourcing Platforms.

online and (2) given them access to tools they would not otherwise be able to afford (e.g. cloud storage system), one would expect online 3D printing platforms to unleash open innovation by reducing the cognitive and financial barriers to entry.

But, as mentioned in Section 2, co-creation does not necessarily imply innovation. This is clearly the case for online 3D platforms, as not all the co-creation activities they enable result in user innovation. For instance, a digital design purchased from a *design marketplace* and printed at home without any modification is an act of co-creation but does not entail any innovation. This is the same for a spare part model downloaded from Thingiverse and manufactured using one of the many *printing services* or *printing marketplaces*.

In fact, user innovation is far less likely to arise when roles are differentiated. Taking the example of a consumer printing a digital object at home, user innovation would require the consumer to provide input into the design of the object, which would mean more integrated roles. Short of that, user innovation can only be fairly minor (for instance, printing with a different material). Likewise, a consumer using a printing service would have to be somehow involved in the manufacturing process (e.g. provide printer settings or suggestions about the process) for user innovation to take place.

Yet, at present, while online 3D platforms have emerged as powerful tools of co-creation, they do not enable significant user innovation. Indeed, out of the 11 platforms involved in design hosting, only four enable users to customise digital objects. While the rest of them offer customisation options (e.g. size, colour and materials), this corresponds (as noted in Section 2) to mass-customisation activities that cannot be considered either as co-creation or as innovation.

In contrast, *crowdsourcing* platforms are potentially better suited to lead to user innovation, however, currently, the projects hosted on those platforms do not appear to involve significant interactions with product users. Instead, these platforms are generally used to access resources that firms or individuals lack (e.g. design skills, software knowledge, engineering skills).

So far, out of the 22 platforms in the study, the only one that demonstrates significant user innovation is Thingiverse. The 3D objects hosted in this repository are generally made available under GNU General Public Licence (widely used for Open Source software) and Creative Commons licences. As such, many objects are tinkered with, improved and 'remixed' by users. However, doing so requires an advanced knowledge of Computer-Aided Design software that relatively few people have. To overcome this problem, early 2013 Thingiverse was equipped with an online customisation tool ('Customizer') that enables users to alter designs directly, without need to know how to operate CAD software. However, possibilities of customisation are so far limited in extent and restricted to 3D objects specially designed to accommodate this feature.

Aside from the question of whether user innovation arises, there is a question of who actually leverages user innovation. As could be expected,[3] all companies that supply products through 3D platforms are SMEs and individual entrepreneurs. Many of them are young companies that would benefit from user innovation (especially in early stages of production), as the ability to involve the right users at the right time and in the right form is a critical determinant of success (Lettl, 2007). Unfortunately, at the moment, most platforms lack the tools that would enable this to happen. However, considering that technologies enabling users to radically customise designs in an intuitive manner already exist,[4] it is probably only a matter of time before online 3D Platforms enable to leverage significant user innovation.

Furthermore, firms using online 3D Platforms may not be the only recipients of user innovation. A quick look at the objects offered on online 3D platforms shows that many of such objects relate to products of large companies (e.g. adapters, spare parts, objects using known brands or designs). Thus, these platforms are a source of autonomous co-creation, which is both at the advantage (user innovation takes place autonomously) and at the disadvantage (difficulty to leverage user innovation and capture the resulting value) of these companies.

Finally, when assessing how 3D platforms enable to leverage user innovation, one needs to consider the radical changes that have occurred in the role of consumers (Section 3). Since consumers are increasingly playing an active role in the production processes, their role may overlap with those of companies. In such case, it is the society as a whole that becomes the recipient of the user innovation that is generated through the numerous co-creation activities that take place between consumers on crowdsourcing platforms, but also on marketplaces and repositories such as Thingiverse.

8. Conclusion

Co-creation with customers is a critical aspect of user innovation, but technological and cost constraints were, until recently, such that this form of innovation could only be used in very specific situations. By providing customers with easy to use and effective means of productions, recent progress in ICTs has empowered consumers with the ability to create goods in the digital realm, thereby initiating their transformation from consumers to prosumers. 3D printing technologies have the potential to do the same in the world of physical object and, thereby, take co-creation to its full potential. However, for this to happen adequate co-creation platforms need to be built and this requires to fully understand the different aspects of co-creation, the consequences of prosumption and the key roles of information systems.

In this paper, the following key aspects were addressed. First, the relationships between open innovation, co-creation and mass-customisation were detailed. Then, it was shown how access to means of production have turned consumers into prosumers and a framework enabling to assess consumers' involvement in the production process according to three

[3] Large companies are unlikely to use intermediaries, but instead set up their own platforms.
[4] For instance the technology developed by Digital Forming, http://www.digitalforming.com.

dimensions (design, manufacturing, distribution) was provided. Next, a typology enabling to classify co-creation activities according to their aim (mass-market or individuals) and type of collaboration was presented. Based on the individual services provided by the 22 platforms in the study, a taxonomy of online 3D printing platforms was then provided.

The typology of co-creation and the taxonomy of 3D printing platforms were then combined to assess the role these platforms can play in a context of open innovation with customers. Finally, the role of 3D printing platforms in leveraging user innovation was discussed. To this respect, it was noted that, while current online 3D printing platforms provide clear co-creation opportunities, they do not always provide significant ways for firms to directly leverage user innovation. It was emphasised that while technological progress is expected to create even more opportunities to leverage user innovation, many platforms do not even take full advantage of what technology has to offer nowadays.

Nonetheless, most online 3D printing platforms already provide significant means for consumers to take advantage of other consumers' innovations. Thus, a further avenue for research would be to investigate the role of online 3D printing platforms in leveraging innovation within communities of users.

References

Anderson, C., 2012. Makers: The New Industrial Revolution. Random House Business Books.

Baldwin, C.C.H., von Hippel, E., 2006. How user innovations become commercial products: a theoretical investigation and case study? Res. Policy 35 (9), 1291–1313.

Berthon, P., Pitt, L., Campbell, C., 2008. Ad lib: when customers create the ad? Calif. Manage. Rev. 50 (4), 6–30.

Berthon, P.R., Pitt, L.F., McCarthy, I., Kates, S.M., 2007. When customers get clever: managerial approaches to dealing with creative consumers? Bus. Horiz. 50 (1), 39–47.

Bogers, M., Afuah, A., Bastian, B., 2010. Users as innovators: a review, critique, and future research directions. J. Manage. 36 (4), 857–875.

Chesbrough, H., Piller, F. (Eds.), 2012. Bridging Mass Customization and Open Innovation: Proceedings of the MCPC 2011 Conference on Mass Customization, Personalization and Co-Creation. San Francisco, November 16–19, 2011. Lulu, Raleigh, NC.

Chesbrough, H., 2003. Open Innovation: The New Imperative for Creating and Profiting from Technology. Harvard Business School Press.

Christensen, C., 1997. The Innovators Dilemma: When New Technologies Cause Great Firms to Fail. Harvard Business School Press, Boston, Massachusetts.

Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manage. Rev. 14, 532–550.

Kambil, A., Ginsberg, A., Bloch, M., 1996. Re-inventing value propositions. Stern Working Paper IS-96-21, New York University.

Karlgraad, R., 2011. 3D printing will revive American manufacturing. Forbes, 23/06/2011. URL: http://www.forbes.com/sites/richkarlgaard/2011/06/23/3d-printing-will-revive-american-manufacturing/

Kotler, P., 1986. The prosumer movement: a new challenge for marketers? Adv. Consum. Res. 13 (1), 510–513.

Lettl, C., 2007. User involvement competence for radical innovation? J. Eng. Technol. Manage. 24 (1), 53–75.

Moilanen, J., Vadén, T., 2012. Manufacturing in motion: first survey on 3D printing community. URL: http://surveys.peerproduction.net/2012/05/manufacturing-in-motion/.

Nambisan, S., 2002. Designing virtual customer environments for new product development: toward a theory? Acad. Manage. Rev. 27 (3) , 392-314.

Payne, A., Storbacka, K., Frow, P., Knox, S., 2009. Co-creating brands: diagnosing and designing the relationship experience? J. Bus. Res. 62 (3), 379–389.

Piller, F., Ihl, C., Fuller, J., Stotko, C., 2004. Toolkits for open innovation: the case of mobile phone games. In: Proceedings of the 37th Annual Hawaii International Conference on System Sciences, 2004. IEEE, pp. 1–10.

Piller, F.T., Tseng, M.M. (Eds.), 2010. Handbook of Research in Mass Customization and Personalization, vol. 1. World Scientific.

Poetz, M.K., Schreier, M., 2012. The value of crowdsourcing: can users really compete with professionals in generating new product ideas? J. Prod. Innov. Manage. 29 (2), 245–256.

Prahalad, C., Ramaswamy, V., 2004. Co-creation experiences: the next practice in value creation? J. Interact. Market. 18 (3), 5–14.

Rayna, T., Striukova, L., 2009. The curse of the first-mover: when incremental innovation leads to radical change? Int. J. Collab. Enterp. 1 (1), 4–21.

Ritzer, G., Jurgenson, N., 2010. Production, consumption, prosumption: the nature of capitalism in the age of the digital 'prosumer'. J. Consum. Cult. 10 (1), 13–36.

Sawhney, M., Prandelli, E., 2000. Communities of creation: managing distributed innovation in turbulent markets? Calif. Manage. Rev. 42 (4), 24–54.

Shah, S.K., Tripsas, M., 2007. The accidental entrepreneur: the emergent and collective process of user entrepreneurship? Strateg. Entrep. J. 1 (1), 123–140.

Stieglitz, N., Heine, K., 2007. Innovations and the role of complementarities in a strategic theory of the firm? Strateg. Manage. J. 28 (1), 1–15.

Tapscott, D., Williams, A.D., 2006. Wikinomics: How Mass Collaboration Changes Everything. Portfolio, New York.

Teece, D.J., 1986. Profiting from technological innovation: implications for integration, collaboration, licensing and public policy. Res. Policy 15 (6), 285–305.

Toffler, A., 1981. The Third Wave. Bantam Books, New York.

von Hippel, E., 1988. The Source of Innovation. Oxford University Press, New York.

Yin, R., 2003. Case Study Research – Design and Methods. Sage Publications, Thousands Oaks, CA.

Zwass, V., 2010. Co-creation: toward a taxonomy and an integrated research perspective? Int. J. Electron. Commer. 15 (1), 11–48.