How designers benefit from free 3D design sharing

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Abstract
3D printing has been described as a technological revolution, and it has already changed the way how some low-demand items are designed, produced and delivered to the customers. The threshold for new players entering the 3D business is lower than ever; the lowering costs of printers and the availability of free planning software provide new opportunities for entrepreneurs. However, at the same time, the availability of free 3D designs has exploded, and there is an enormous selection of them available. This raises questions: What kind of designs in particular are being uploaded and downloaded, and can the designers benefit financially from sharing their work for free?

Based on former literature, this paper identifies four different strategies how to benefit financially from free 3D design sharing. By analyzing the data gathered from Thingiverse, the largest free 3D design repository, it describes how these different strategies realize in the case of Thingiverse.

Keywords: design, additive manufacturing; 3D printing; personal 3D printing; maker movement; sharing economy; distributed manufacturing; open innovation; online communities

1 Introduction

Additive manufacturing (AM), also referred to as 3D printing, has received increasing attention in the media as well as in research in many fields. AM has been characterized as an industrial revolution, which illustrates the potential it is considered to have, not only in product manufacturing but in the design and supply chain as well (e.g. The Economist, 2012; Fawcett and Waller, 2014; Oettmeier and Hofmann, 2016; Despeisse et al., 2017). With AM, supply chains have better potential to access and respond to the end value demand by cutting out much of the traditional chain (Laplume et al., 2016). In the literature, AM is presented as an ideal technology for making such products as replacement parts (e.g. Bradshaw et al., 2010; Berman, 2012; Sasson and Johnson, 2016), customized gifts and usable prototypes (Sasson and Johnson, 2016). The AM technology has already had great impacts in some industries, such as aviation (Khajavi et al., 2014) and medical industry (Holmström et al., 2010). Even though AM is predicted to bring about a revolution in the way products are designed, manufactured and distributed to end users, many entrepreneurs are still struggling with how to utilize this disruptive innovation technology in their business models and networks (Laplume et al., 2016).

One factor that has presumably an influence on how business models will evolve in the future is the democratization of design and production. Low cost printers are available, which enables utilizing 3D printing even on the hobbyist basis. Several parties support hobbyist communities e.g. by providing them with free 3D design software, e.g. FreeCAD, OpenSCAD, and online design repositories that allow designers to exchange design files. These repositories represent a phenomenon that is often referred to as “Maker Movement” (Anderson, 2010), which is based on the idea that product innovation and design, which have formerly been dominated by industrial companies, are possible also for enthusiasts and even ordinary consumers. Due to this phenomenon, the availability of free 3D designs is in continuous increase.

In general, online communities have become an important and widely studied economic and cultural phenomenon (e.g. Füller et al., 2014; Alavi, 2014), and user communities are expected to compete increasingly with and in some cases displace corporate innovation in many sections of the economy (e.g. de Jong and de Bruijn, 2014). As examples in e.g. Wikipedia and open source software show, online communities may already have a dominant role in some parts of business. With 3D printing, online communities can be expected to have impacts also on physical products business.

This study explores the role of online community, and more specifically free design sharing, in 3D printing business. Using data captured from Thingiverse, the largest free 3D design repository (Moilanen et al., 2014), we analyze what kind of designs are being downloaded, and who provides the designs and why. The results help to notice the areas of business where free 3D designs have an impact, to classify the designers who provide free 3D designs, and to identify possible revenue models related to publishing free 3D designs.

The paper begins by reviewing the relevant literature concerning personal 3D printing and motivations for contributing to free 3D design repositories. After that we explain how the data was gathered from Thingiverse and how it was analyzed. Then we review the results, and finally conclude and discuss the implications of the study.

2 Personal 3D printing

Additive manufacturing (AM), also referred to as 3D printing, is a digital technology for producing physical objects layer by layer from a three-dimensional computer-aided design (CAD) file. The first 3D printers were introduced in the 1980’s. However, the first 20 years were limited to industrial and commercial vendors, who used patented technology to sell devices at prices exceeding $100,000. A triggering event for the development of personal 3D printers was the RepRap project in 2005. Utilizing his experience in 3D printing with a commercial Stratasys printer, Adrian Bowyer, a UK mechanical engineering professor, started planning a low-cost 3D printer that could be used by people to make things at home. After the expiry of the first Stratasys patent in 2006, Bowyer shared his design for free under the GNU general public license, to ensure that his ideas could not be patented (Berman, 2012; West and Kuk, 2016; de Jong and de Bruijin, 2014).

After the launch, 25 core contributors gathered in the open-source hardware (HW) community called RepRap (Replicating Rapid -prototyper). The purpose of RepRap was to create “self-replicating” 3D printers and share all the designs of the machine free in the Internet with anyone who would want to use them (de Jong and de Bruijn, 2014; Wittbrodt et al., 2013). The open-source HW of RepRap stimulated subsequent emergence of new start-ups in 3D printers. Though some printer manufacturers utilizing RepRap, notably MakerBot, have abandoned the original idea of RepRap and moved to a closed HW, the availability of free designs has led to much lower costs for any personal 3D printer manufacturer, and nowadays it is possible to buy a 3D printer for even less than 100$ as a DIY KIT (All3DP, 2017).

The technology used in most personal 3D printers is Fused Deposition Modeling (FDM), also referred to as Fused Filament Fabrication (FFF) (West and Kuk, 2016). The process takes any material, usually polylactic acid (PLA) or acrylonitrile butadiene styrene (ABS) filament, and lays it down. The printer adds layers and through heat or adhesion causes the layers to “fuse” together. (Petersen & Pearce, 2017).

It is important to note that personal 3D printers cannot guarantee the part quality and scalability of current production methods, though the gap is expected to be reduced significantly in the near future (Gao et al., 2015). Although the impact of metal printing on spare parts supply chains has also been studied (eg. Pérès & Noyes 2006; Khajavi et al., 2014), these two technologies should not be confused, as personal metal printers do not exist.

2.1 Expected business implications of personal 3D printers

Rayna and Striukova (2016) divide the development in the adaptation of 3D technology into four successive phases: rapid prototyping, rapid tooling, digital manufacturing, and home fabrication. Whereas rapid prototyping and rapid tooling are expected to merely speed up processes without changing them significantly, direct manufacturing, and even more so, home fabrication are said to have potential to be highly disruptive, as they will change the way value is created.

In general, AM is expected to be most advantageous in market environments characterized by demand for customization, flexibility, design complexity, and high transportation costs of the delivery of end products (Weller et al., 2015). Especially concerning spare parts, there are expectations for AM to change the current modes of operation (e.g. Bradshaw et al. 2010, Jiang et al. 2017). Sasson and Johnson (2016) suspects that if not mass manufacturers, the 3D community will provide increasing number of replacement designs for plastics.

Some studies (Wittbrodt et al., 2013; Petersen & Pearce 2017; Petersen et al. 2017) have identified a personal 3D printer as a good investment for an average household. These studies compared the manufacturing costs with a low-cost personal printer, using free designs from design repositories (e.g. Thingiverse and Youmagine), to the purchase costs of commercial substitutes. Petersen et al. (2017) predicts that personal printing is set to have a significant impact namely on the toy and game markets in the future. It has to be noted, however, that these studies compare the purchasing/production costs and not the life cycle costs of the items. The PLA that was used in the studies is vulnerable to moisture, heat and ultraviolet light, and especially combinations of these (Copinet et al., 2004). Therefore, the lifetime of some PLA items may be considerably shorter than that of the equivalents. It also remains unknown how consumers will receive the reduced visual quality of 3D-printed items. In addition, the attraction of 3D-printing to the home or non-technical user is frustrated by the difficulty in deploying the software and the technology, which both need understanding and training. The investment in time may be a greater obstacle to adaptation than the purchase price of a printer.

The social dimension of AM has been noticed by some authors. E.g. Chen et al. (2015) present that democratized production enables equal possibilities to all participants in markets and society, and it is foreseeable that the entry barriers of becoming an active member of value creation through manufacturing of goods are reduced down by the cost decrease of the system. Sundararajan (2016) states that the potential for commercial peer-to-peer interaction increases dramatically when pure data is exchanged instead for physical objects. According to Waller and Fawcett (2014), new technologies, such as 3D printing, enable inventors to become entrepreneurs, and it will result in even more new products coming to market more quickly, and will erode market share of large incumbents. However, new possibilities may be paralleled with fierce competition. E.g. Rayna and Striukova (2016) note that just like any previous digitization episode (e.g. music), AM is likely to trigger an increase in competition, as it lowers the barriers to entry significantly, and successful products are easily copied. In such a context, finding a good revenue model may become increasingly difficult.

Online user communities are potential platforms that enable the realization of the democratizing impacts of AM. According to e.g. de Jong and de Bruijn (2014), user communities are expected to compete increasingly with, and in some cases, displace corporate innovation in many parts of the economy. According to the authors, open collaborative innovation occurs in three types of environments: (1) nascent industries, where commercial markets do not yet exist or are still too small and uncertain to attract established companies, (2) industries where some potential users are not yet served, in other words the technology has not matured sufficiently to offer low-cost consumer products, and (3) industries where some users are not served adequately, in other words there are not sufficiently customization options. As a summary, users have a possibility to add value by offering designs that are not offered by commercial markets.

According to Wohler's report (2013), there was exponential growth in the development of personal desktop printers between 2007 and 2012. This growth seems to continue. According to Wohlers report (2016), the sales of desktop printers with a retail price below $5,000 jumped from 163,999 in 2014 to 278,385 in 2015. In 2016, 96% of the 3D printers shipped worldwide were personal/desktop printers, carrying an average price of just under $1,000 (PR Newswire. 2017). The potential for disruption and the growing trend together make home printing a noteworthy phenomenon.

3 Motivations for free 3D file sharing

In order to understand the phenomenon of free 3D file sharing, it is essential to understand the motives behind it. Even though former literature rarely discusses the motivation of the providers of 3D designs, a lot is known about the motives of the providers of other types of open content in open innovation projects (e.g. Frey et al., 2011; Natalicchio, 2014; Burtet et al., 2018) and in open HW and open source projects (Hars and Qu, 2002; Hertel et al., 2003; Bonaccorsi and Rossi, 2006; Thompson, 2008; Oreg and Nov.,2008). These activities can be considered to be remarkably analogous to 3D design.

The most famous open source projects have been reported to have originated from certain individuals' dissatisfaction with available products, described as an "itch that needs scratching" (e.g. Thompson, 2008). The development of the Linux operating system was started in 1991 by the Finnish computer science student Linus Torvalds, who was dissatisfied with the existing operating systems and wanted to code a better one. In the very beginning, Torvalds did not plan to start a worldwide OSS project. In his first announcement of Linux he called the project a "pet project" (Hertel et al., 2003). The birth of Arduino, an open source micro controller that is used also in the control of RepRap 3D printers (Locker, 2017), is very similar. Massimo Bandzi, one of the founders of Arduino worked as a teacher at a high-tech design school in Ivrea, Italy, and wanted to offer his students an inexpensive, powerful microcontroller to drive their robotic projects. In both these cases, keeping the source codes open make it possible for anybody to suggest improvements, and thereby it benefits also the prior contributors (Thompson, 2008).

However, the motivations for contributing to open source projects are more manifold, and have been a subject to several surveys. Hars and Qu (2002) divide the motivations of people participating in OS software projects into two categories: internal factors (e.g., intrinsic motivation, altruism) and external rewards (e.g., expected future returns, personal needs). Their survey results show that both play an important role. Hertel et al. (2003) studied the motives of 141 contributors to the Linux kernel operating system software (OSS) project, and the suggested motives are consistent with the ones presented by Hars and Qu (2002). The context of open source projects seems to have an impact on the emphasis of internal/external motivation. The survey results of Oreg and Nov (2008) show that software contributors put greater emphasis on gaining reputation and self-development, compared to content (namely Wikipedia) contributors, who placed a greater emphasis on altruistic motives. According to Bonaccorsi and Rossi (2006), companies emphasize economic reasons (revenues from software-related services) and technological reasons (feedback and contributions from the Open Source community), and do not subscribe to many social motivations that are typical of individual programmers. In addition, many studies have quantified the important and pervasive role of the contributors' perceptions of fun as their motivation factor for contributing to innovation communities (e.g. Franke and Shah, 2003; Füller et al., 2007; Lakhani and von Hippel, 2003; Lüthje et al., 2005). It can be hypothesized that in the case of small-scale contribution, internal motivations are emphasized, but when the workload increases, the expectations of economic benefits will increase.

Motivations precisely in the context of free 3D design sharing have been studied by Moilanen and Vadén (2013). Based on the results of a 2012 survey on people doing 3D printing, the authors present that "intrinsic" enjoyment ("for fun") and direct practical benefit ("scratch an itch") are the two biggest drivers. However, as the size of the 3D community has grown and the technology has become more mature, greater variation in motives can be expected, and also extrinsic motivation may have a role.

Extrinsic motivation is related to expectation for monetary rewards. What are the possible ways of gaining monetary rewards, i.e. revenue models, for free 3D designs? Some analogies can be expected to be found to the revenue models of open source software. Popp (2015) summarizes commercial open source revenue models to have the following possible revenue streams:

1. Revenue stream for commercial licenses
2. Revenue stream for adaptation/extension
3. Revenue stream for support
4. Revenue stream for maintenance.

In addition to the revenue streams, some open source companies use other services to create revenues, like certification and compliance testing, HW sales, and advertising. In some cases, also voluntary donations are collected.

The revenue stream for commercial licenses represents a situation in which the free software serves as a free sample of the actual product. An analogous case could be a situation where a free 3D design serves as a sample of a product/products that are distributed commercially elsewhere. *The revenue stream for adaptation/extension* represents a situation in which the product is partly free and partly commercial. The term "extension" gives the impression that the commercial part is simpler than the actual product. Since 3D-printable items are typically rather small, this may be the other way around, so that the free 3D printable item serves as an extension to a commercial product, e.g. a hook to a bookcase or shells for a mobile phone, etc. *The revenue stream for support and maintenance* represents a situation in which the free software is used as a means for selling expert services. This is similar to job concerns, which open innovation research has identified as a dominating motivation factor for participating in open innovation projects (Frey et al., 2011). Providing free work samples allows individuals to demonstrate their talent to potential employers or customers.

Possible revenue models relating to free 3D designs can be summarized to be three: *1)The design serves as a free sample of a commercial product, 2) The design serves as an add-on for a commercial product, and 3) The design serves as a sample of expert services.* Some of the other revenue streams mentioned by Popp (2015) (advertisements, volunteer donations) are also possible in the case of 3D design.

4 Research design

According to Yin (1994), explorative case study is a suitable research approach when studying a new phenomenon with a limited amount of prior research. The present study is a case study where quantitative and qualitative methods are combined in order to get a picture of free 3D design sharing. All the data has been collected from a 3D design repository, containing both numerical data and written material provided by the repository users.

First of all, descriptive statistics give a view of what type of designs are available and on what scale they are downloaded. Secondly, we study what factors relate positively with the demand for designs, and identify focal themes of interest. This is done by classifying the designs and examining the differences of mean numbers of downloads between the classes. Thirdly, we build a descriptive model of the designer base. This is done by classifying the designers by their activity and by the information they provide about themselves. The R: a software environment for statistical computing and graphics is used for data analysis.

4.1 Description of the empirical setting: Thingiverse

The empirical setting of this study is Thingiverse, an online design repository in which all designs are free to upload and download. Its commercial function for its owner, MakerBot, is to add value to printer sales by offering a free and easy way for users to find designs they can print out at home. Thingiverse was selected as the source of data for this study due to its leading position in the field (Moilanen et al. 2014), and because the service has an application programming interface (API) that allowed the collecting of relevant data.

The repository hosts both publicly visible designs and designs that are kept private. Previous studies indicate that the proportion of private things is considerable (48% in 2015) and has increased over time (Moilanen et al. 2014; Özkil, 2017). In January 2013 Thingiverse presented the "Customizer" (Makerbot Blog, 2013a), which allows users to produce custom variations of customizable things easily by simply just changing the parameters of the design in a web interface. Downloading these customized things requires saving the resulted design to the database. Thingiverse had 28,774 designs created before the platform introduced the "Customizer". After that, they crossed the milestone of 100,000 designs in just six months (Makerbot Blog, 2013b). It has been noticed that a great portion of public things are actually just customized versions of a few things (Kyriakou et al, 2017). Accoring to Özkil (2017), more than 51% (n = 81,039) of the publicly available designs in 2015 could be identified as derivatives and hybrids. It can be assumed that the motivation for publishing these customized versions is lower than publishing original designs, since they are customized for a personal need, and rarely offer anything new for the community. This partially explains the increased proportion of private designs.

The Thingiverse site allows for some different means of metadata classification of designs. One of the means is “tagging” which means using freely selectable keywords. Fordyce et al. (2016) have studied the use of tags Thingiverse, and note that the tags are used in a very disorganized manner: the number of tags used varies a lot, misspellings are common, and there are many unique tags that do not serve the purpose of a keyword.

Thingiverse has a default classification to 11 categories that have altogether 69 sub-categories. When uploading the design, the user selects a category and can optionally fine down their selection to sub-categories. All the categories are listed in the Appendix. The name of the sub-category implies the purpose of the use of the design. E.g. under the main category “Gadgets”, there are such sub-categories as “camera”, “computer” and “mobile phone”. The designs in these categories are e.g. holders for these equipment.

The designer has a user profile that is visible to other users. The user profile contains the name of the user, a profile picture, a freeform presentation, and personal statistics. The user profiles vary a lot by their length and content, leaving many users anonymous.

4.2 Data collection

Thingiverse has an application programming interface (API) that allows anyone a relatively easy access to data that is somewhat the same to that which can be seen when browsing the Thingiverse website. A custom-built Python script was used in this study for capturing the data and saving it into a comma-separated values (CSV) file. Since the rate of data requests is limited in Thingiverse, and collecting all data for a single item requires a minimum of 5 requests, the speed of data collection was limited. The data was collected between 26th November 2016 and 22th February 2017. In the beginning the data collection, the item number of the latest thing was 1,942,970, and at the end 2,126,999. These numbers include deleted and private things that were excluded in the data collection, as no metadata was available for them. In the latest data, private things were dominant, and the resulting data set consisted of 685,688 publicly visible designs. The metadata included names and short descriptions of the designs, the number of files, designer information, counter data of likes and downloads, dates of adding and modifying the design, and the tags and categories used. Designer data was collected later. The designer metadata used in this study consisted of the ID number, username, optional full name, and freeform presentation text.

4.3 Defining variables

Some variables needed to be defined for this study. Figure 1 presents two explanatory variables, *designs category* and *originality of design*, whose impact on the dependent variable, *demand for a design* was studied. Measuring the *demand for the design* is rather straightforward. The download count measures the demand per file. However, some designs consist of several files, and therefore an average download count per file was calculated. To make the numbers comparable, the demand was measured as the average number of downloads per month (30 days).

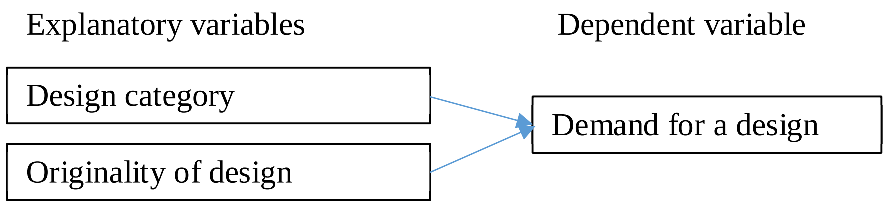

Figure 1: Studied design-related variables

Both explanatory variables are of categorical nature. The *design category* (categories listed in the Appendix) indicates the purpose of use of the item on a rough level. Since the number of categories was high, the statistical analysis focused only on the 11 main categories, though some descriptive statistics is presented about the sub-categories as well.

It is noteworthy, that it is possible to create new designs by simply changing some design parameters in Customizer-program, and this is not comparable to making original designs. When a new design is made using the Customizer, the default name for the design starts with “My customized”. If the name of a design starts with “My customized”, it was considered as a customized design, in other cases not customized. Even though this classification criterion is less than perfect, it will offer some idea of the *originality of design*.

Figure 2 presents the variables related to the designer. The variables were mainly used for classifying designers, but also the relation between the contribution volume and identity transparency was studied in order to provide a more detailed view on the designer base.

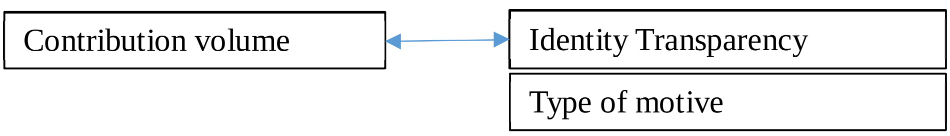

Figure 2: Studied designer-related variables

The *contribution volume* of a designer can be measured with two metrics: the number of designs and the number of downloads. Since it is possible to publish automatically customized versions of existing designs, the number of designs published may be a misleading metric. The number of downloads represents the contribution to the end-users better, and therefore it was used as the metric of contribution volume.

In this paper, *identity transparency* means how much the designers reveal of their identity. The levels of identity transparency were defined in the following way:

0: The designer does not reveal their name or any other information
1: The designer provides their name and no other information
2: The designer provides a user profile text / name and user profile text
3: The designer provides a user profile text that contains a link to external designer-related content. The “other designer-related content” can be personal or corporate web-pages, a

Twitter account etc. It was tested experimentally if some user-related content could be accessed via the offered links.

Since analyzing the identity trasparency and motives of designers cannot be done automatically, and there were approximately 150,000 designers, there was a need to limit the case sample. For analyzing identity transparency, 30 designers with the highest contribution volume, 30 designers with mediocre contribution volume, and 30 designers with low contribution volume were selected for analysis.

The *motive* of each designer was construed from the information that they provided themselves. This information could be provided in two locations: on the profile page of the designer, or in the description text of individual designs. If a clear revenue model could be identified, it was considered as an indication of a commercial motive. If there was no indication on how the designer could, in theory, benefit financially from their work, it was assumed that the motive for sharing their work was mostly intrinsic. In analyzing the motives of the designers, the focus was on the 30 designers with the highest contribution volume. This focus was considered justified, as they have the biggest business potential.

4.4 Sample description

Table 1 presents some descriptive statistics of the data sample. The table in the Appendix presents the number of designs divided into categories used by Thingiverse, as well as the number of designs and mean numbers of downloads in each category. Figure 3 presents the age distribution of the designs. It can be seen that the number of uploads has had a growing trend.

Table 1: Overview of the case data

	n	Mean of downloads/m	Median of downloads/m	SD of downloads/m
Total number of designs	685,686	8.99	2.56	52.26
Customized designs	157,897	1.62	1.31	4.01
Total number of designers	150,043	41	6.5	248.87

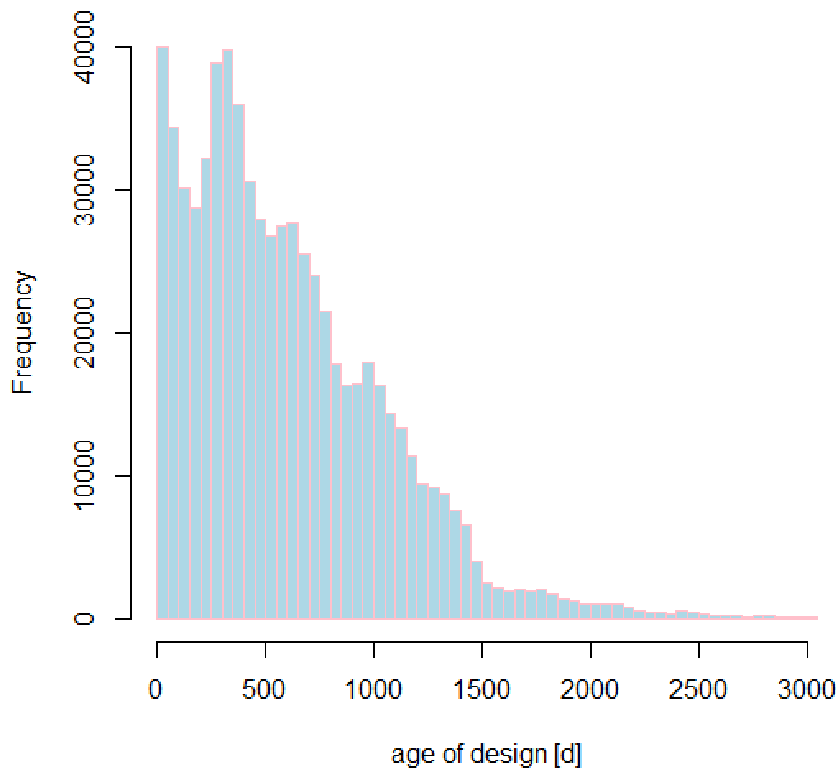

Figure 3: Age distribution of the designs

5 Results and discussion

5.1 Factors explaining the demand for designs

An independent-samples t-test was conducted to compare the mean monthly number of downloads for customized and not customized designs. There was a significant difference in mean monthly downloads of not customized (M=11.20, SD=59.33) and customized (M=1.62, SD=4.02) designs; $t(543660)=116.33$, $p < 0.001$. Not surprisingly, the results show that users prefer downloading original designs instead of customized versions of existing designs.

A one-way between-subjects ANOVA was conducted to compare the influence of the main category on the demand for design in the 11 main categories used by Thingiverse, and the results are summarized in table 2. There was a significant influence of the main category on the demand for the design at the $p<.05$ level for the 11 main categories [$F(10, 685675) = 404.4$, $p < 2e-16$]. Post hoc comparisons using the Tukey HSD test indicated that the mean of monthly downloads for Models and Toys & Games was significantly different than those of any other category. Hobby, 3D printing, Learning and Gadgets did not differ from each other significantly, except for Hobby vs. Gadgets. Tools and Other did not differ from each other, but in rest of the categories, Art, Household and Fashion, the mean of monthly downloads differed significantly from all other categories. These results suggest that the main category that a design belongs to does have an influence on the number of downloads.

Table 2: Mean and standard deviation of the number of downloads/m for designs in 11 main categories

Main category	Number of downloads / m	
	M	**SD**
Models	22.78	111.20
Toys & Games	14.99	62.82
Hobby	11.09	38.99
3D Printing	10.75	10.75
Learning	10.09	37.26
Gadgets	10.01	40.76
Tools	8.26	60.63
Other	8.12	27.06
Art	6.90	73.68
Household	5.92	34.92
Fashion	4.66	23.36

However, the differences can be partly explained by the numbers of customized designs in each category. In the Models category, the percentage of customized designs is the lowest (9%), whereas in the Household and Art categories the percentage is 31% and in Fashion it is highest, 35%. When customized designs are removed from the data, the means of monthly downloads in different main categories come closer to each other. Still, the means of monthly downloads for Models and Toys & Games are the highest and significantly different from any other category. For Gadgets, Hobby, Learning, 3D printing, and Tools the means of monthly downloads do not differ from each other significantly. For Art, Other and Household the means of monthly downloads do not differ from each other significantly, except for Art vs. Household. The mean of monthly downloads for Fashion is significantly lower than that for any other category. All in all, the main category has an influence on the demand for the design, and customized designs highlight the differences between different main categories. Playing and experimenting are emphasized in the categories where the numbers of downloads are the highest.

5.2 Producers of free 3D designs

A relatively small number of designers represent a large share of all downloads, which is visualized in Figure 4. 1% of the most productive designers represent 74% of the total monthly downloads, 2% represents 86% etc. The other way around, 70% of the least productive designers represent only 9% of the total monthly downloads.

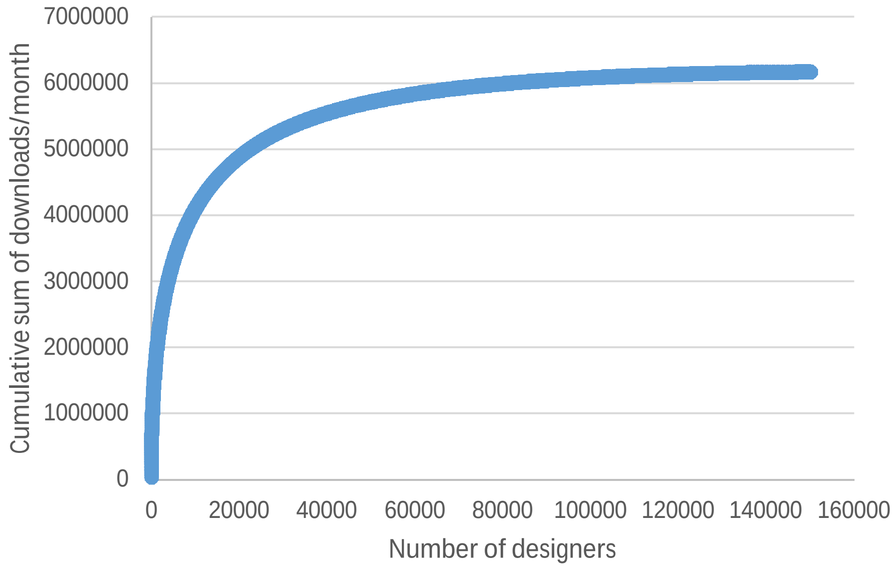

Figure 4: Cumulative sum of downloads/month as a function of number of designers

90 designers with different contribution volumes were put in categories based on their identity transparency. The result is presented in table 3. The Pearson correlation test shows that the contribution volume correlates significantly with identity transparency, with 0.64 correlation coefficient and p-value of 1.048^{-11}.

Table 3: 90 designers categorized on the basis of contribution volume and identity transparency

Identity transparency class	Designers with high contribution volume (10514-34169 downloads/m)	Designers with mediocre contribution volume (~17 downloads/m)	Designers with low contribution volume (~3 downloads/m)
0	0	4	11
1	1	16	17
2	8	7	2
3	21	3	0

This result shows that a majority of designers are not likely to share their contact information, but it becomes more likely as the contribution volume grows. A basic requirement for commercial activity is that the actor can be identified, so it seems that activity in publishing noteworthy designs is connected to professional activity.

Designers can be put roughly into four categories on the basis of their contribution volume and identity transparency (Figure 5). A majority of designers have relatively low contribution volume, and typically low contribution volume relates to low identity transparency. This group of designers can be labelled as "experimenters". Characteristic examples of experimenters are designers who upload simple designs, such as keychains, 2D art or customized versions of existing designs.

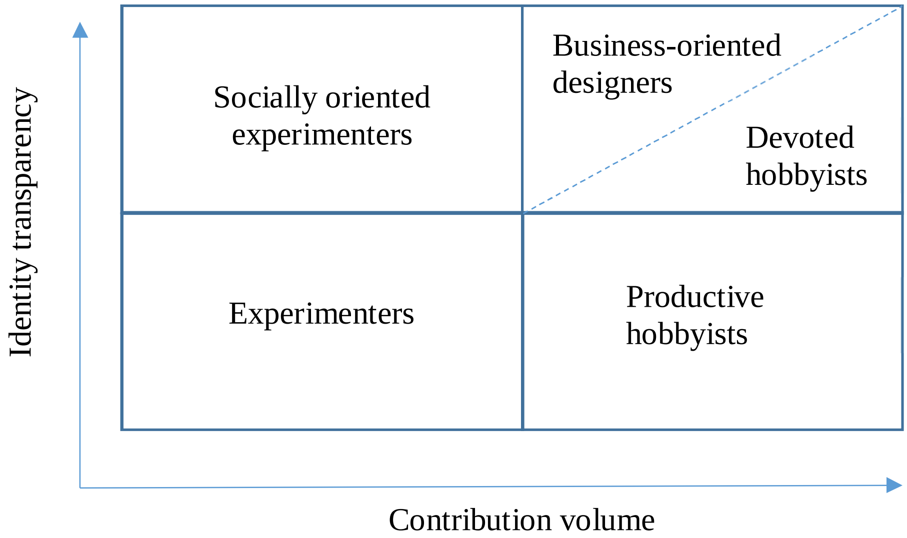

Figure 5: Classification of designers of free 3D designs

The most productive and transparent designers can be put in two categories on the basis of their motives. *Business-oriented designers* have commercial motives, whereas *Devoted hobbyists* are led by intrinsic motivation. Among the top 30 designers in Thingiverse, these two groups seem to be somewhat equally strong. The designers that fall outside these categories can be labelled either *Socially oriented experimenters* if they share personal information despite their relatively low contribution volume and *Productive hobbyists* who have a high contribution volume but do not share personal information.

The group of business-oriented designers can be distinguished from devoted hobbyists by whether a revenue model can be identified from the information they provide. The motives of the 30 designers with highest contribution volume were analyzed in order to find examples of different revenue models. In 15 cases, such a model could be found. In a couple of cases the designer had more than one revenue model. A summary of found revenue models is presented in table 4.

Table 4: Examples of the four revenue models the business-oriented designers apply

Revenue model	Examples
1. Design serves as a free sample of a commercial product	- bqLabs - CarryTheWhat
2. Design serves as an add-on for a commercial product	-Makerbot -Adafruit -Ill Gotten Games -Masterwork Tools
3. Design serves as a sample of expert services	-Graphical design (individual designer) -Mechanical engineering (individual designer) -3D-printing related services (3DWP, CreativeTools, 3D Central)
4. Crowdfunding	- Individual designers using Patreon (3 cases) - Individual designers using PaypalMe (2 cases)

Two examples were found of revenue model 1: *Design serves as a free sample of a commercial product. BqLabs* is a part of the Innovation and Robotics department of a company named BQ. For this designer, the free models are experimental and early released products to be tested by the community. *CarryTheWhat* is a group of designers that sells their products on Etsy webshop.

Of revenue model 2: *Design serves as an add-on for a commercial product*, four examples were found. *Makerbot*, a 3D printer manufacturer and the owner of Thingiverse, has by far the highest contribution volume. The selection of models published my Makerbot varies from spare parts to toys. As noted earlier e.g. by Moilanen et al. (2014), all models add value to 3D printers, which is Makerbot's main business. *Adafruit* is a company specialized in DYI electronics projects. Adafruit's free models are e.g. cases for these projects. *Ill Gotten Games* sells board games, for which parts can be 3D printed. *Masterworks Tools* is also specialized in gaming, through computer gaming. They offer free "dungeon tiles" to print, from which miniature sceneries can be built.

Of the revenue model 3: *Design serves as a sample of expert services*, six examples were found. In three cases the company promoted 3D printing services such as 3D printing, 3D scanning and rapid prototyping (*3DPW*), training, service, and support in 3D design, printing etc. (*CreativeTools*) and custom design work and printer sales (3D Central). In 3 cases an individual designer emphasized his/her design-related education and skills in graphical design or mechanical engineering.

In five cases, a designer suggested monetary support, in three cases using Patreaon and in two cases using PayPal.Me. *Patreon* is an Internet-based platform that allows content creators to build their own subscription content service. It allows artists to receive funding directly from their fans, or patrons, on a recurring basis or per work of art. *PayPal.Me,* owned by PayPal is a peer-to-peer payment platform that allows users to send a custom link to request funds via text, email, or other messaging platforms. "Crowdfunding" was identified as a fourth revenue model since there were as many observations about them as the other revenue models. In addition to these revenue models, one designer suggested clicking on an affiliation link before shopping in amazon.com. That is an example of the use of advertising as a revenue stream.

In Thingiverse, there are also two other incentives that may have some effect on designer motivation. The “Tip designer” -option allows users to donate money for other users. However, none of the top 30 designers mentioned that option in their profile text. In addition, Thingiverse organizes design competitions with product awards occasionally. However, it was not possible to analyze the impact of these incentives in this study.

The results of the study indicate that even though a majority of designers seem to be led by mostly intrinsic motives, sharing free 3D designs has also different types of links to commercial activity. The revenue models were noticed to have some similarity with the revenue models of free software, but they also had original characteristics. It can be expected that the revenue models described here will become more common in the future. If the price competition of 3D designs for the consumer sector is tough, as can be expected, merely selling 3D designs might not offer a profitable business for very many. Instead, 3D designs may serve as a value-adding service for some other businesses. For example, some people make their living today by video blogging. It is possible that a similar fan culture may evolve around people who publish content also in 3D formats. At least, there are already individuals who publish frequently and are followed by many people in Thingiverse.

6 Conclusions

The aim of this study was to enhance understanding of the demand and supply of free 3D designs. Both 3D printing and online communities are expected to change the way business is done in the near future, and therefore it is interesting to explore the activity that is currently taking place in 3D design repositories. This study used data captured from the leading free 3D design repository, Thingiverse.

This paper presented a model describing the designers providing free 3D models. The designers can be categorized on the basis of their contribution volume, identity transparency, and type of motive. The more downloads a designer is able to attract, the more likely the designer will reveal his/her personal/corporate information. Even though many of the even most popular designers seem to be led by intrinsic motivation, also indications of commercial motives were found in the form of different revenue models. Examples were found of all the following four revenue models: 1. The design serves as a free sample of a commercial product, 2. The design serves as an add-on for a commercial product, 3. The design serves as a sample of expert services, and 4. Crowdfunding.

This study helps to understand the linkages between hobbyism and business in the case of 3D printing. When an online community becomes an essential player in a business ecosystem, it is important to be able to describe how it works, and to dissect the motives of individual actors inside the community. For practitioners, this study provides an insight into what types 3D designs attract attention currently, and how sharing free designs could be related to their own business.

Free content sharing is not unique to 3D printing. Large-scale free content sharing takes currently place also in others areas, e.g. education, electronics design and fashion, to mention a few. The relationship between hobbyists and commercial actors and different revenue models in these other areas could be an interesting area for further studies.

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APPENDIX

The mean numbers of downloads in categories used by Thingiverse.

Main category Subcategory	Mean of number of downloads/m	n	Main category Subcategory	Mean of number of downloads/m	n
3D Printing	7.7	39,666	Bathroom	12.7	3,132
3D Printer Accessories	12.4	28,002	Containers	4.5	15,738
3D Printer Extruders	13.1	3,945	Decor	14.0	11,070
3D Printer Parts	11.9	28,608	Household Supplies	7.8	2,941
3D Printers	21.4	2,202	Kitchen & Dining	8.3	17,050
3D Printing Tests	12.8	5,850	Office	5.1	13,601
Art	8.3	12,432	Organization	3.0	48,038
2D Art	3.4	19,179	Outdoor & Garden	7.1	6,297
Art Tools	5.9	4,418	Pets	4.3	3,979
Coins & Badges	3.4	6,671	Replacement Parts	5.6	7,344
Interactive Art	5.3	6,752	Learning	9.6	2,139
Math Art	11.9	4,342	Biology	12.0	1,880
Scans & Replicas	15.6	4,500	Engineering	15.1	2,770
Sculptures	10.7	17,955	Math	5.9	2,965
Signs & Logos	4.5	17,061	Physics & Astronomy	8.3	2,174
Fashion	7.7	2,692	Models	19.5	3,713
Accessories	4.9	15,322	Animals	41.8	2,604
Bracelets	3.6	6,649	Buildings & Structures	15.4	4,691
Costume	22.5	2,390	Creatures	30.9	1,979
Earrings	6.0	1,482	Food & Drink	9.5	1,123
Glasses	7.0	1,237	Model Furniture	14.5	865
Jewelry	6.9	5,622	Model Robots	32.2	1,078
Keychains	3.2	34,251	People	14.8	4,469
Rings	3.4	10,376	Props	24.3	4,759
Gadgets	17.1	2,830	Vehicles	27.5	4,462
Audio	14.9	1,705	Tools	11.1	4,684
Camera	9.5	7232	Hand Tools	14.5	5,008
Computer	10.6	5,368	Machine Tools	16.9	2,109
Mobile Phone	7.3	21,402	Parts	4.4	19,317
Tablet	9.4	1,749	Tool Holders & Boxes	10.4	5,826
Video Games	22.4	2,464	Toys & Games	23.0	7,622
Hobby	11.7	4,528	Chess	19.5	784
Automotive	10.4	4,293	Construction Toys	4.8	8,056
DIY	10.7	9,443	Dice	9.3	1,537
Electronics	9.2	12,600	Games	16.9	4,187
Music	9.3	3,216	Mechanical Toys	16.1	6,306
R/C Vehicles	13.2	18,093	Playsets	19.7	550
Robotics	13.5	4,725	Puzzles	12.6	1,776
Sport & Outdoors	9.2	8,622	Toy & Game Accessories	16.6	7,959
Household	7.9	8,456	Other	8.1	40,774