Barriers to Using, Customizing, and Printing 3D Designs on Thingiverse

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ABSTRACT
Thingiverse is the largest 3D design-sharing online community with millions of users. Thingiverse provides a low-barrier-to-entry for exploring 3D printing as users can quickly download premade 3D designs and ask design-specific questions. In this paper, we investigate users' activities on Thingiverse and their conversations by using quantitative and qualitative analyses. Our findings shed light on various barriers in using, customizing, and printing premade 3D designs. The results suggest that although Thingiverse plays a key role in helping users get started with basic 3D printing, there are many opportunities to streamline the design-download-customize-print workflows. In particular, opportunities exist for designers to provide richer metadata, clarifications, and expert tips to help users succeed in printing objects and customizing existing 3D designs.

Keywords
3D communities; Design discussions; Thingiverse; 3D printing;

1. INTRODUCTION
Digital Fabrication has evolved dramatically over the last few years, with an increasing interest in 3D printing among untrained and nontechnical users [3,7,9]. These users face significant difficulties in learning 3D modeling and developing expertise in complex 3D printing workflows. For example, they rarely research the appropriate software to model their design, do very little planning for their design, and have difficulty thinking in 3 dimensions [5]. As an alternative to learning 3D modelling, users often turn to online communities such as *Thingiverse.com* [2] to download and print premade 3D design files. Thingiverse is the largest online 3D modeling community [13] and allows users to share, download, customize and print 3D designs. Thingiverse contains over 1 million 3D designs, has over 2 million active monthly users, and sees 1.7 million downloads per month [13].

Although Thingiverse facilitates the process of sharing 3D designs, both novice and expert users often have a number of questions related to the printability, functionality, or assembly of the resulting 3D objects [6]. One problem is that designers who post 3D designs do not always share details about whether their design will print on a specific 3D printer, what materials would work, or what the machine settings should be [8]. In addition, designers may be new to 3D modelling and may not be actual users of the objects that they design (e.g., in the assistive technology domain [1]). Furthermore, designers rarely document changes to their design files, and if they do, it is usually through a comment which can be overlooked and difficult to decontextualize [11]. Since Thingiverse is largely community-driven, there is currently no formal provision for screening 3D designs to check for potential issues before the designs are shared on the site.

To help users cope with design-specific issues, Thingiverse provides an embedded social platform for users to post comments and questions on individual 3D designs. In fact, a quick inspection of popular designs on Thingiverse shows that some designs have drawn over 200 comments within a span of a few days of being shared. However, despite the growing active user community on Thingiverse, we know little about how users actually make use of this social platform in tackling 3D design and printing tasks. Knowing the content of design-specific comments and questions can help us better understand the kinds of challenges that may exist for end users and how community participation could be improved on platforms like Thingiverse.

In this paper, we investigate users' conversations on Thingiverse to understand their experiences in using, customizing, and printing premade 3D designs. We carried out quantitative and qualitative analyses to systematically explore user activities on Thingiverse and the content of users' questions, comments, and responses. Our main findings reveal 4 key barriers that users faced in understanding: 1) how a given 3D object would be used or assembled in real life; 2) how a design could be customized or remixed; 3) how a 3D object would print on a given 3D printer; and 4) how a 3D design was actually created. Our findings show that although Thingiverse plays an instrumental role in helping users get started with basic 3D printing, there are many opportunities for designers to provide richer metadata, clarifications, and expert tips to help users succeed in printing objects and customizing existing 3D designs. Our primary contribution is in establishing an understanding of the barriers in using, customizing, and printing premade 3D models based on users' conversations on Thingiverse.

2. AN ANALYSIS OF THINGIVERSE
2.1 Research Approach and Data Collection
To understand users' conversations on Thingiverse, we carried out our study in two parts, as described below.

2.1.1 User Activities on Thingiverse
To get a snapshot of various user activities on Thingiverse, we used their API to download metadata for a sample of 23285 designs, design-specific comments (n=22952) and user profiles (n=21893) of the designers and commenters. We randomly selected this sample from public Thingiverse designs in September 2015 and only considered designs that had been available for at least 4 weeks to ensure that users would have had some time to explore the designs. We looked into the different categories of designs that were uploaded on Thingiverse (Table 1), how actively designers and users were commenting on

GROUP '16, November 13-16, 2016, Sanibel Island, FL, USA

individual designs, the different file types being shared, and to what extent designs were being customized.

2.1.2 Discussions on Thingiverse

Next, we carried out a qualitative analysis to understand the content of users' design-specific conversations in more detail. We used a uniform random sample of 500 designs and the corresponding comments (n=2202) as our dataset, restricting it to Thingiverse uploads that were designed for 3D printing (i.e., excluding designs for laser-cutting) and had at least one comment. To carry out the qualitative analysis, we wrote our own custom web application that displayed comments to be coded in context of the conversation and the 3D printable design, making it easier for us to understand the (often obscure or complex) designs.

2.2 Data Analysis & Classification Scheme

To systematically classify the content of conversations on Thingiverse, we first created a separate random sample of 120 designs with 460 comments. Three of our researchers conducted an open coding analysis [10] to look for frequently occurring topics. While studying design-specific Q&A, we discovered a wide range of posts, from praising the designer for his/her work to requesting links to similar designs, to understanding how to purchase materials needed for printing the design. Furthermore, users contributed a lot of miscellaneous information on extraneous topics, such as comparing printers (unrelated to the design), jokes, and questions about items that were not a part of the design. Using these observations, we iteratively developed our coding scheme until the researchers settled on a list of 8 codes (shown in Table 2).

To assess the reliability of our coding scheme, we extracted a new random sample of 100 Thingiverse designs with 350 comments, and two researchers individually coded each of the comments. To find the overall agreement between coders we computed the Cohen's Kappa score and found strong agreement in the coding of the Thingiverse discussions (κ=0.82).

We applied our final coding scheme to the 2202 comments in our sample (in most cases, we assigned only one code to a comment, with the exception of a few longer comments).

Before presenting our main findings on the barriers that users faced in using, customizing, and printing premade 3D designs, we provide a brief overview of user activities on Thingiverse.

3. USER ACTIVITIES ON THINGIVERSE

3.1 Design Categories Selected by Users

The Thingiverse community is made up of many different types of designs. When designers upload their models to Thingiverse they are required to choose a category that best represents their design, such as art, household, gadgets, 3D printer parts, and tools. In our larger random sample of 23285 designs, we found that the largest number of designs (20.0%) were in the household category, followed by art (14.5%), 3D printing (14.4%), and fashion (9.9%). Table 1 shows all of these categories and commonly shared designs within each category (except the 8.6% of 3D designs that were uploaded to the "Other" category).

Table 1: Top 8 Categories of Designs on Thingiverse

Category	% of sample	Example
Household	20.0%	Toothpaste tube squeezer
Art	14.5%	Vases, replicas of statues
3D Printing	14.4%	Printable 3D printer parts
Fashion	9.9%	Bracelets, keychains, charms
Hobby	8.3%	Parts for RC vehicles
Gadgets	7.2%	Virtual reality headsets
Toys/Games	5.6%	Printable catapult
Models	5.1%	Figurines of characters
Tools	4.8%	Screwdriver handles
Learning	1.7%	Models of human bones

3.2 Types of Files Shared by Users

Thingiverse users have several options for uploading their 3D design files. Although the majority (84.0%) of files in our sample were 3D models in the STL[1] format, we observed 197 different file types in our sample, including source code files, 2D graphics, and spreadsheet files. STL files are only capable of representing 3D triangle meshes and contain no editor metadata, making them very difficult to modify for an inexperienced user compared to a 3D software package's original source files [5]. The next most common file types were dramatically less common: *OpenSCAD* .SCAD files (3.7%), *SketchUp* .SKP (2.0%), and *Solidworks* .SLDPRT files (1.2%). This fragmentation puts users who want to customize a 3D model in a difficult place—even if the 3D design's source file is available, it may be in a format for software that the user is not familiar with or cannot easily access.

3.3 Likes and Comments on Designs

Similar to many social platforms, Thingiverse allows users to "like" designs so that they can build up a collection of favorite designs. Overall, a given 3D design attracted an average of 14.8 likes and 1.0 comment (0.3 comments by the designer who uploaded the design file). Objects in the Models and Toys & Games categories attracted the most likes, with 37.8 and 27.6 likes per design on average, while Fashion-related designs attracted the fewest (6.7 on average). Comment length, which averaged 30.4 words per comment, also varied across categories. Users in the 3D Printing category, for example, wrote longer comments averaging 37.7 words per comment, while users commenting on Art designs wrote the shortest comments (16.5 words on average).

3.4 Remixing and Customizable Designs

One phenomenon of particular interest on Thingiverse is remixing, where a new variation on a design can be created to meet a different set of needs or constraints [8]. For example, an uploaded phone case might be remixed to include a sports team's logo, or an uploaded tripod can be remixed to use metric screws instead of imperial. Remixes may be roughly grouped into two categories: parametric and freeform. Parametric changes consist simply of altering the object's existing parameters, such as changing the diameter or width of the wheels on a car [12]. Conversely, freeform changes involve the addition of entirely new elements to the design, such as changing the wheels on the car to tank treads.

While remixes can be created manually by importing a 3D model into a typical 3D modelling application, Thingiverse also offers the *MakerBot Customizer* tool (Customizer, for short), a built-in web application that allows for limited 3D design remixing. This tool allows objects that have been modeled in a specific manner using *OpenSCAD.org* to be altered in parametric ways, such as changing the diameter of a ring, or the text on a nametag [14]. These changes can only be parametric, not freeform, and must be explicitly specified by the designer of the customizable design in the SCAD file. After the designer has uploaded this customizable design, other

[1] The STL file format is commonly used for 3D printing, and describes a 3D surface built up of triangles. STL files are typically not used natively by 3D software, but are generated to be shared online or processed by the 3D printer [4].

Table 2. Classification of Design-specific Comments

Code	% of sample	Example	Top Category
Understanding Object Functionality	26.78	*"What makes the watch sit up in the cradle?..."*	3D Printing
Understanding Design Customizability	23.94	*"Any chance you can post the .scad file so I can modify it?..."*	Hobby
Praises/ Positive Reports on Designs	17.13	*"it's beautiful"*	Models
Understanding Design Printability	14.50	*"Would you suggest adding exterior, full, or no support?"*	Learning & Models
Miscellaneous Q/A	7.28	*"Nothing to do with your part, but I need to vent!..."*	Fashion
Understanding Design Creation	6.48	*"This is too cool. What did you use to make this?"*	Toys and Games
Discussion on License Choices	3.43	*"You could make the license include no derivatives, but that is not what you selected."*	Gadgets
Insults/ Negative Reports on Design	0.48	*"Man, this part is full of mistakes"*	Toys and Games

users can alter these parameters using a simple web interface to generate 3D printable STL files.

We found that the Customizer tool was popular among users: close to half of all designs (n=10613, 45.6%) in our dataset had been generated using this tool. However, we also found that all of these customized designs were derived from a small number of 1298 unique parent designs. Furthermore, our dataset included only 236 designs (1.0%) that could actually be customized using the Customizer tool. This suggests that only a small number of designers were creating Customizer-compatible designs, but, if they did make such designs available, users were likely to generate a large number of derivatives. These customizable designs also received about 6 times more likes (89.4 likes/object) compared to 14.1 likes/object across the whole repository.

3.5 User Participation in Discussions

Our analysis of individual users who commented on designs revealed that they were highly active on the site, with 89.9% having liked at least one design, and 64.4% having liked 10 or more designs. More surprising, however, was that 84.0% of these commenters had at least one design uploaded to their profile. This suggests that users who participated in design-specific discussions tended to be more experienced with Thingiverse (in fact, 43.8% of commenters had uploaded at least 10 designs).

Based on our qualitative analysis of the 2202 design-specific comments, we have listed the most frequent to least frequent discussion topics within these comments (Table 2). As with activities on other online forums, we observed that people also used the Thingiverse social platform to post miscellaneous comments, insults, and praises. However, we will focus the next part of our results on conversations that were specific to barriers in using premade 3D designs.

4. BARRIERS TO USING PREMADE 3D DESIGNS ON THINGIVERSE

Prior work shows that there are many stages and barriers around creating and printing 3D designs from scratch [2,5] and non-professional users turn to Thingiverse in hopes of getting easy access to premade designs. However, our results show that this path can also present a number of challenges. Below, we highlight 4 key barriers based on users' questions, comments, and requests posted on individual Thingiverse designs. We also discuss the barriers in relation to the categories (Table 1) that users selected to classify their designs on Thingiverse.

4.1 Understanding Object Functionality

Before users download a design from Thingiverse to print, they need to understand what the design is, how it functions, and in some cases, how it would be assembled after printing. In fact, we observed that understanding the functionality and assembly of the object being designed was the most frequently occurring code in our classification (26.8%). For example, a common question asked by users was simply: "*I don't get it. It looks cool but what is it?..."* Other users had more specific questions about the assembly: *"I have not built a core xy printer yet so i am no expert but i have to ask about the belt tension. Don't you need a way to tension each belt [separately] to ensure that they have the same tension?".*

Although questions about object functionality occurred frequently among all of the categories on Thingiverse, it was the most common type of question in the 3D printing category. Users asked questions such as, *"if I understand how this works shouldn't there be some sort of feedback to the firmware to adjust the bed during print?".* As might be expected, fewer questions about object functionality were seen within the Art and Models categories, which featured more ornamental and less mechanical designs.

4.2 Understanding Design Customizability

When users were not satisfied with an existing premade 3D design on Thingiverse, they often asked for a remix or customization (i.e., a change in the design file). In fact, questions about customizing or remixing designs were the second most common theme (23.9%) in our sample. For example, users asked for clarification or made specific requests: *"It looks very nice. Can you please release a version that's just one subcube? I think it would be a lot more workable."* Such requests varied from resizing object parts, adding parts onto designs, or modifying functionality of objects. The hobby and household categories had the largest number of such customization requests.

We also observed that a large number (86%) of customization-related comments were about improving or changing the design's functionality and a small number of comments (14%) were about improving the design's printability. These types of discussions involved comments such as *"Nice improvement on my design! Less print time and less plastic!"* and *"It's too tall for a replicator [printer] so it'd have to be split in 2 parts".*

Our analysis further revealed that discussions around parametric changes such as changing an object's thickness, length, and adding text to the design accounted for 36% of the comments in remixing for custom needs. These types of requests included comments such as, *"[My] Wife has [a] miniature owl collection - I'd like to print a couple half sized ones. Can you provide scaled down versions[?]"* Surprisingly, ,freeform changes (which are not possible through Customizer*)* accounted for 64% of the remixing comments. Even if designers were to publish Customizer designs, many of the freeform user needs would still be unmet.

Overall, we found that users only received the customizations they asked for about one third of the time (32%) due to several reasons. For example, sometimes users requested designs that were not

practical or would not function as well as the original design: *"I just don't know if it will be stable / wobble free and if I have enough clearance for it to rotate."* Other times designers simply did not have time to follow-up to the request: "*It's not hard necessarily, just tough to make it look nice…I just need to find the spare time to make it.*" In other instances, designers simply did not respond to requests or users did not follow up to questions about dimensions or other desired features.

4.3 Understanding Design Printability

Another common barrier revealed in the Thingiverse conversations was trouble with understanding how to properly print the 3D design (14.5%). Users often did not know the correct print settings and it was difficult to receive help since different printer models and setups often required different settings. Common printer settings that were asked about included support structures (used to prevent the design from drooping or falling over during printing), infill (the percentage of the model that should be filled in with material when printed), wall thickness, scale, and printer fan speed. For example, one user posted, *"I [am] new to 3d printing and I really like this file. I am still confused on what supporting is and how to do it so that I can successfully print this blade..."* In addition to diagnosing problems and troubleshooting, users asked the designer about what printer they used, what filament was used, and how long it took to slice and print: *"every time I try to print this it starts spitting filament out in the air when it gets past the handle. could somebody tell me what settings they printed this with?"*

Designs within the model category received the most questions on printability, and many of them were on support structures. Surprisingly, the 3D printing category overall had the fewest questions on basic printability.

4.4 Understanding Design Creation

Although users often turn to Thingiverse to download premade models so that they can bypass the complex 3D modelling tasks [5], our analysis showed that many conversations (6.5%) on Thingiverse were actually about learning 3D design. For example, users were often interested in knowing what software was used for the 3D design (*"…how do you make one of these?")* and some asked for the actual source files for the design (*"Hey, do you happen to still have the model file lying around?").* Some users described more advanced usage, such as how to extract 3D models from video games, or how to import models into new pieces of software: *"Any tips on how to explode this file in the latest version of Sketchup?"*

As discussed earlier, users upload design files in hundreds of different formats to Thingiverse. Our analysis further showed that users often do not know the difference between file formats: *"I'm just curious as to why some of the files are "stl" and some ".obj", or more specifically, why not all files in one format or the other?"* Other comments revealed users' frustration in attempting to modify STL files: *"I don't understand how one is supposed to convert this into a stl (or other 3d printable file). I've tried inkscape, openscad, and a number of others. Anyone with knowledge, please help!!"* These comments were particularly common in the toys and games category.

5. DISCUSSION

In this paper, we have presented results from our quantitative and qualitative analyses of user activities and their design-specific conversations on Thingiverse. Among our key findings, we found that commenters on Thingiverse were not just consumers of premade 3D models—in fact, a large majority of them (84%) had uploaded at least one design. But, even these more experienced users tended to face a number of barriers in understanding how a design object actually functions, how it will print, how it can be customized, and how it can be designed from scratch.

Our study shows that although Thingiverse has over a million active users, simply making premade models available to download is not enough. For successful 3D design sharing, we see two opportunities for improvement: 1) designers need to provide additional metadata, clarifications, and expert tips to help users succeed in printing objects; and, 2) users need a better understanding of how and when customization is possible (or not possible) with 3D designs so that they can get better access to desired objects.

5.1 Augmenting Premade Designs

Our analysis showed that many users had to resort to asking the designer how the design functioned, what the recommended print settings were, which type of printer was used by the designer, and what software was used to create the design. Other works have also documented these difficulties in terms of understanding print settings [8] and understanding changes to the design [11]. Our findings suggest that there is opportunity to augment premade designs with printability and software-related information. For example, 3D modelling software could provide context on how a given feature may appear when printed. STL files (that are most widely used on Thingiverse) currently lack context on their own—it could be useful for users to access details such as assembly and print instructions through text and pictures. Future research may investigate interchange file types or better sharing systems that also communicate their designs' context within the 3D printing workflow by including details such as how the design is assembled and what print settings have been used for different 3D printers.

5.2 Helping Users with Customization

In spirit, Thingiverse encourages tinkering and all users to create, remix, and share 3D designs. In fact, the Customizer tool was added with the intention that even non-professional users could create customizable objects [13]. As we discussed in our results, about half of our designs had been generated using the Customizer. However, we have also shown several issues with this tool that emerged in our study. For example, users frequently requested remixes that were freeform in nature and not possible through the Customizer tool. However, designers appeared to be stymied by the difficulty of creating for the Customizer platform and shared only a small number of Customizer-ready designs. We observed that Customizer activity was largely driven by a small number of designers who were able to overcome those difficulties.

One potential avenue for research is investigating alternatives to *OpenSCAD's* scripting paradigm that could allow users to create parametric, customizable models through more user-friendly GUI interfaces. This would particularly be useful for non-professional designers who get frequent requests to generate customizable versions of their 3D models but are not well-versed with complex scripting languages. More generally, there is merit in also exploring how users could more clearly see the level of difficulty involved in creating different customizations for a given design.

In conclusion, our analyses of activities and conversations on Thingiverse have shed light on various challenges associated with using premade 3D designs and we have highlighted research opportunities that can help tackle these challenges.

6. ACKNOWLEDGEMENTS

We thank Nehal Gupta, Johnson Kan and Shaun Kane. This work was funded in part by NSERC (Natural Sciences and Engineering Council of Canada).

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