

500 Days of Thingiverse: A Longitudinal Study of 30 Popular Things for 3D Printing

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Abstract

Purpose

This study provides insight into the way object data on Thingiverse changes over time, analyzing the relationships between views, downloads, likes, makes, remixes and comments over five hundred days.

Design/methodology/approach

Thirty of the most popular things on Thingiverse were tracked between the 26th August 2018 to 7th January 2020, with data collected about the different interactions at five intervals.

Findings

Highlights include: '#3DBenchy' became the first thing to reach one million downloads during this study. The 'Xbox One controller mini wheel' achieved the highest documented download rate of 698 downloads per day. The average conversion rate from downloads to makes for all thirty things was one make for every 474 downloads at the start of the study, declining to one make for every 784 downloads by the conclusion.

Research limitations/implications

With over 1.6 million things on Thingiverse, this study focused on an exclusive group of things that have gained significant attention from Makers, and does not represent most things on the platform.

Practical implications

While often considered a novelty or niche Maker community, this research shows that things on Thingiverse are achieving popularity comparable to digital music, video and imagery, and a large ecosystem of things has been growing that has implications for designers, manufacturers, supply chain managers and universal popular culture.

Originality/value

This is the first study to track the digital behaviors of 3D printable things over time, revealing new knowledge about how people interact with content and the scale of these interactions.

Keywords: 3D Printing, Digital Downloads, File Sharing Community, Maker Movement, Social Network Analysis

Type: Research paper

Introduction

Desktop 3D printing technology has evolved rapidly over the last decade, a fact often attributed to the expiry of key patents for Fused Deposition Modeling (FDM) (Gibson, Rosen & Stucker 2015; Novak, Liu & Loy 2019; Quinlan et al. 2017), also known as Fused Filament Fabrication (FFF), and the improved performance for decreased cost of the required hardware systems. This has led some to suggest the existence of a Moore's Law for 3D printing (Benson, Triulzi & Magee 2018; Greenfield 2017; Krassenstein 2014), increasing access to low-cost desktop 3D printers and underpinning the Maker Movement (Anderson 2012; Dougherty 2016; Gershenfeld, Gershenfeld & Cutcher-Gershenfeld 2017). This has led some to suggest 3D printing is a disruptive technology (Maresch & Gartner 2020; Petrick & Simpson 2013).

Supporting the physical hardware of 3D printing and the physical objects produced, the Internet has allowed digital eco-systems to simultaneously evolve and mature, empowering Makers to share, modify, print and sell 3D models. Numerous platforms exist to address different Maker needs, from those that allow Makers to use cloud-based Computer-Aided Design (CAD) tools to create and edit geometry for 3D printing (e.g. Tinkercad), to service bureaus that allow anyone to upload a model and have it professionally 3D printed in a range of materials (e.g. i.Materialise, Shapeways). Much like the music and film/video industries, file sharing is also a significant part of the digital ecosystem (Birtchnell & Urry 2013), allowing amateurs and professionals alike to upload 3D models to be shared under Creative Commons (CC) licenses. Such licensing is predicted to grow further in popularity over the next decade due to 3D printing (Jiang, Kleer & Piller 2017). *Thingiverse* (www.thingiverse.com) is the most popular of these file sharing platforms (Thingiverse 2020; Alcock, Hudson & Chilana 2016; Kyriakou, Nickerson & Sabnis 2017), with over 1.6million 3D files in its library at the time of writing (Thingiverse 2020) and millions of users (Alcock, Hudson & Chilana 2016). 2019 data shows this is more than twenty times larger than any other 3D printing file sharing website (Novak & Bardini 2019), and for this reason, has been the focus of several academic studies.

Thingiverse was founded in 2008 by MakerBot Industries, early manufacturer of desktop FFF 3D printers, conceived as the online companion to its popular hardware system (Fordyce et al. 2016; Moilanen et al. 2015; Oehlberg, Willett & Mackay 2015). "In the same way that iTunes adds value to iPhone purchases, but generates little profit in its own right, the site is ancillary to MakerBot's main line of business – sales of 3D printing hardware" (Moilanen et al. 2015). However, Thingiverse quickly grew beyond a community of MakerBot owners, with users operating all manner of desktop and commercial 3D printing hardware. Like many online communities, the platform allows users to create a login and display a page about themselves, follow their favorite designers, like and comment on content, share their projects, and receive alerts when others interact with them or their designs (Novak 2019). Content is freely shared by members, and others are encouraged to interact with content, either digitally through likes and comments, or physically by 3D printing the design for themselves and sharing photographs of their result, known as a "make." This feedback loop results in a network effect for Thingiverse (Novak & Bardini 2019; West & Kuk 2016), attracting new members and increasing interactions.

Alcock et al. (2016) examined 23,285 things on Thingiverse and revealed that on average, things receive 14.8 likes and 1.0 comments. The study also revealed that the most popular category of things was Household (20%), followed by Art (14.5%), and found a high level of engagement by users commenting on things, with the most frequent comments requesting clarification about functionality

(26.78%), followed by requests for modifications or access to customizable files (i.e. CAD files, 23.94%). Özkil's (2017) analysis of 348,509 things and 247,768 registered users, revealed that only 15.6% of users are content creators (designers) with one or more things uploaded to their profile. Correspondingly, most users of Thingiverse are passive consumers of content, downloading designs for 3D printing and participating in digital interactions without having the skill or desire to share content. Of those with uploaded content, the average was 4.05 things for each designer, with an almost even division between original content (48.8%), and derivative or hybrid content (51.2%). Derivative content is also known as a *remix* on Thingiverse and is an adaptation of another design on the platform, whereas a hybrid borrows elements from multiple parent designs. Remix culture is common to many forms of digital media, including music, images and video (Oehlberg, Willett & Mackay 2015). A lower average number of uploads was found in a study analyzing assistive devices on Thingiverse (Buehler et al. 2015), with only 1.32 original things uploaded for the 273 designers found to have contributed to the platform.

More recently, Novak and Bardini (Novak & Bardini 2019) collected data in August 2018 for thirty of the most popular designs on Thingiverse, finding that the most popular model called '#3DBenchy' had been downloaded over 500,000 times at an average rate of 469 downloads per day since its upload to the platform in 2015. Yet a newly released model called the 'Xbox One controller mini wheel' was at that time being downloaded at a rate of 698 downloads per day, exhibiting "viral object" behavior that could see the design become the most popular thing on Thingiverse. While these studies provide a valuable snapshot into user behavior and performance of things on Thingiverse, there have been no longitudinal studies that track things over time in order to understand how views, likes, comments, downloads, makes and remixes change, and how designs uploaded five or more years ago perform compared to newly uploaded designs that are entering a significantly larger community of Makers on Thingiverse with each passing year (Novak & Bardini 2019).

Therefore, this study aimed to provide insight into the way object data on Thingiverse changes over time. Building upon Novak and Bardini's (Novak & Bardini 2019) original dataset, this study continued collecting data for each of the thirty things for 500 days, marking the period 26th August 2018 to 7th January 2020. The data shows trends over time for some of the most iconic and popular things on Thingiverse, providing researchers of 3D printing, online social culture, popular culture and file sharing with new insights into the relationships between 3D printing and digital content platforms. Interestingly, the period of this research marked a milestone as '#3DBenchy' became the first thing to reach one million downloads on Thingiverse, and the implications of this are discussed.

Method

On 26th August 2018, Novak and Bardini (Novak & Bardini 2019) collected data for thirty of the most popular things on Thingiverse. Popularity was determined by using the *Explore* feature on Thingiverse and sorting things by the available *Popular* function. The top thirty things were selected through "assessment of the number of likes, downloads, makes, comments and remixes, combined with more qualitative analysis from the authors' years of experience in the 3D printing community" (Novak & Bardini 2019). This research continued tracking the same thirty things periodically from the initial data collected on 26th August 2018 for a total of 500 days. Specifically, the data collection dates and periods were: 3rd January 2019 (130 days), 10th May 2019 (127 days), 13th November 2019 (187 days) and 7th January 2020 (56 days). At each interval, the number of views, downloads, likes, makes, comments and remixes for each thing were recorded. Additional metrics were calculated

incorporating the initial upload date of each thing to show trends over the lifetime of a thing, and the total number of things on Thingiverse was also recorded to provide context, which is reported on the About page of Thingiverse (<https://www.thingiverse.com/about/>).

Results

During the period of this study the total number of things on Thingiverse grew from 1,141,450 to 1,625,050 – an increase of 483,600 (42.4%). Growth remained steady, as shown in Figure 1, and equates to an average of 967 uploads per day, more uploads per day than the entire contents of Thingiverse during its first two years (West & Kuk 2016). For the thirty things tracked during this study the total number of views, downloads, likes, makes, remixes and comments is shown in Figure 2, with views and downloads measured in millions, likes measured in hundreds-of-thousands, while makes, remixes and comments are measured in thousands. Views, downloads and likes grew by 83.4%, 98.8% and 64.2% respectively, whereas makes only grew by 27.8%, remixes by 27.7% and comments by 24.7%. This data indicates that viewing a thing, which is recorded anytime anyone on the internet opens a thing page, is the most common way people experience things on Thingiverse, although downloads are the most common interaction requiring some level of active engagement with a thing.

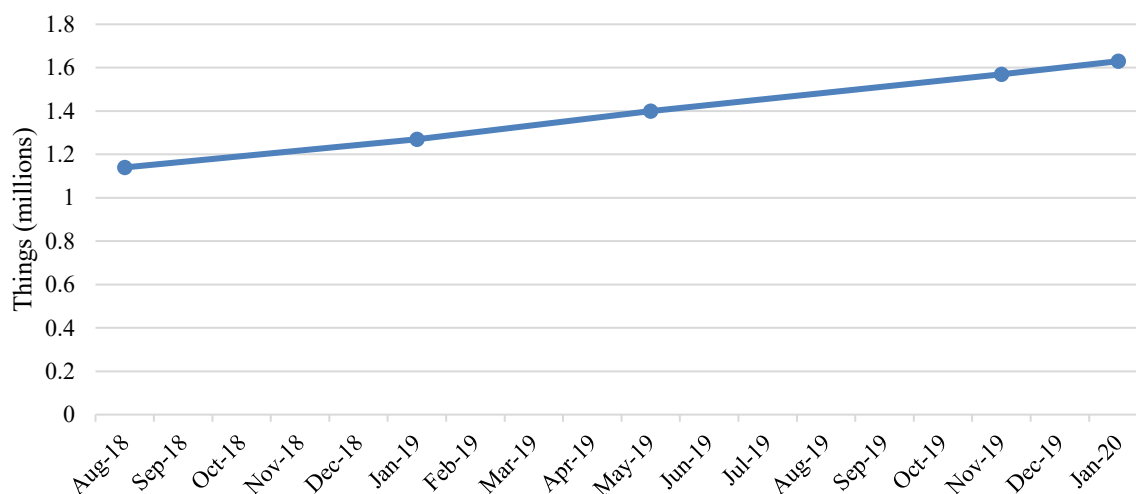


Figure 1. Total number of things on Thingiverse.

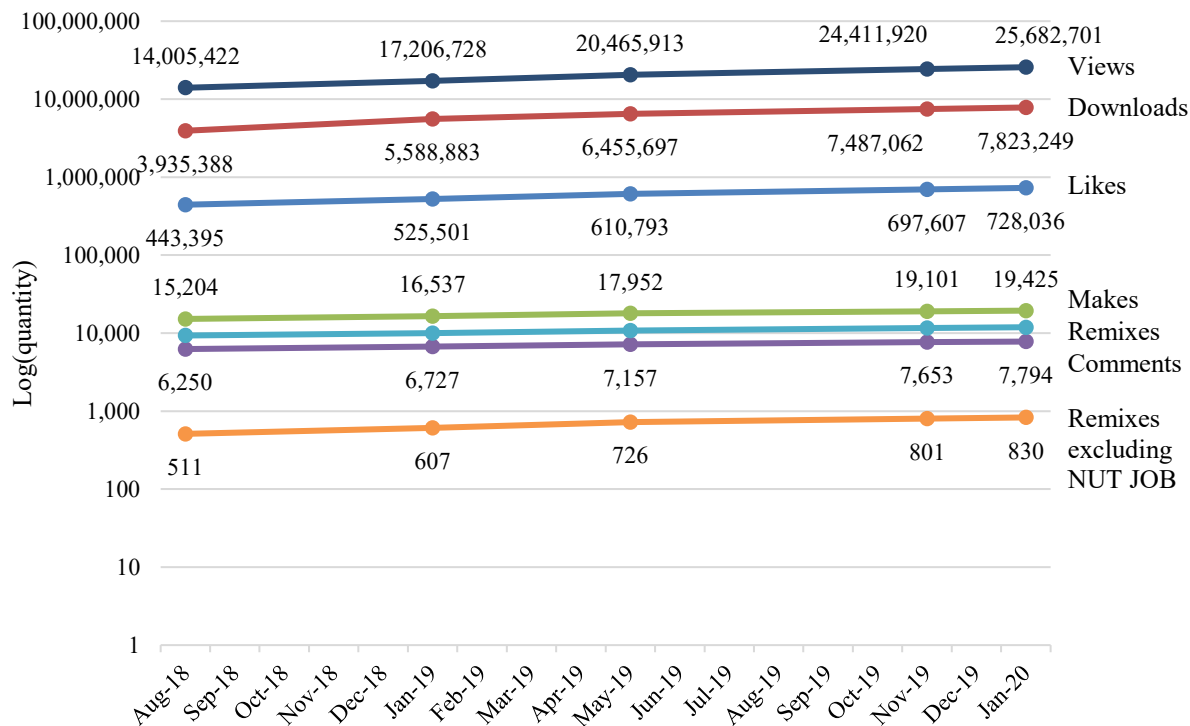


Figure 2. Total views, downloads, likes, makes, remixes and comments for thirty things over time. Additional data showing remixes excluding data for the thing called ‘NUT JOB.’

Summarized interaction data recorded at the start and end of this study for each of the thirty things is shown in Table 1. Things with the highest value in each category at the start of the study remained highest after five hundred days, suggesting a network effect also applies to individual things, with higher values perpetuating the cycle of liking, downloading and making. However, new uploads such as the ‘Xbox One controller mini wheel’ which had some of the lowest values at the start of the study (only being uploaded twelve days prior to the initial data collection), continued to grow rapidly as predicted by Novak and Bardini (Novak & Bardini 2019) and overtake some of the older things which had more stagnant growth. In fact, the ‘Xbox One controller mini wheel’ experienced the highest growth percentages for all categories except makes, where it was second behind another new upload, the ‘Secret Butterfly Box.’ Downloads of the ‘Xbox One controller mini wheel’ experienced the highest growth for any thing or category, rising from 8,378 to 129,578, representing 1446.6% growth. This was significantly higher than any other thing, supporting predictions by Novak and Bardini (2019) for this thing to be a “viral object,” spreading rapidly amongst Makers. For comparison, ‘#3DBenchy,’ which had the highest overall download figures, experienced a 99.8% growth in total downloads during this time, although this represents significantly more downloads in total - 578,451 compared to 121,200 for the ‘Xbox One controller mini wheel.’

Table 1. Thirty things sorted by upload date with key data collected at the start of the study, end of the study and percentage change. Highest (green) and lowest (orange) value in each column highlighted.

Thing Name	Upload Date (MM/DD/YY)	Likes			Downloads			Makes			Comments			Remixes		
		Start	End	%	Start	End	%	Start	End	%	Start	End	%	Start	End	%
Earbud Holder	12/01/12	16678	23669	41.9	139925	219083	56.6	390	476	22.1	191	222	16.2	17	24	41.2
1.75mm Filament Clip	01/15/13	16361	29630	81.1	107265	225529	110.3	131	176	34.4	118	167	41.5	28	35	25.0
NUT JOB Nut, Bolt, Washer and Threaded Rod Factory	12/01/13	17488	26460	51.3	180844	380366	110.3	92	99	7.6	208	244	17.3	8811	11073	25.7
Labyrinth Gift Box	12/11/13	17313	26240	51.6	119937	229558	91.4	747	963	28.9	305	372	22.0	30	38	26.7
Marvin	12/30/13	4383	5307	21.1	98281	134849	37.2	2040	2086	2.3	54	58	7.4	56	62	10.7
Elephant	02/25/14	18154	24531	35.1	203323	283930	39.6	1340	1498	11.8	262	298	13.7	5	5	0
Frankenstein Light Switch Plate	01/23/15	19109	26885	40.7	82062	131220	59.9	227	273	20.3	239	267	11.7	33	37	12.1
#3DBenchy	04/09/15	22609	37204	64.6	579537	1157988	99.8	2742	3450	25.8	284	367	29.2	N/A	N/A	N/A
Self-Watering Planter (Small)	07/02/15	20707	32471	56.8	77425	154192	99.2	375	506	34.9	234	269	15.0	N/A	N/A	N/A
Eiffel Tower	07/06/15	11402	17454	53.1	137459	243195	76.9	128	172	34.4	53	72	35.8	9	11	22.2
Stackable Battery Holders	09/09/15	20775	30967	49.1	104726	190272	81.7	286	393	37.4	114	139	21.9	16	27	68.8
Digital Sundial	10/13/15	24309	36233	49.1	183998	276847	50.5	140	158	12.9	245	277	13.1	14	20	42.9
V29	12/07/15	22388	36487	63.0	234590	431864	84.1	929	1175	26.5	395	499	26.3	22	28	27.3
XYZ 20mm Calibration Cube	01/19/16	10038	19123	90.5	310774	768689	147.3	624	885	41.8	123	206	67.5	22	47	113.6
The 3D Printed Marble Machine #3	03/02/16	16127	23751	47.3	120724	197895	63.9	391	492	25.8	337	384	13.9	15	22	46.7
Venus Box	05/12/16	18525	28442	53.5	123125	206093	67.4	423	512	21.0	222	250	12.6	11	14	27.3
T-Rex Skeleton	05/17/16	11645	20160	73.1	127182	251162	97.5	380	563	48.2	265	339	27.9	15	23	53.3
The HIVE - Modular Hex Drawers	08/29/16	16902	30312	79.3	71083	162472	128.6	80	119	48.8	207	283	36.7	22	35	59.1
The \$30 3D Scanner V7 Updates	09/09/16	25398	40920	61.1	87687	209156	138.5	86	110	27.9	494	532	7.7	13	16	23.1
Baby Groot	01/07/17	16677	28987	73.8	225914	463973	105.4	1486	2085	40.3	336	402	19.6	N/A	N/A	N/A
Headphone Stand	01/23/17	16591	30574	84.3	109916	255076	132.1	200	303	51.5	113	141	24.8	35	58	65.7
Yet ANOTHER Machine Vise	01/26/17	12784	19701	54.1	64174	107353	67.3	416	560	34.6	210	257	22.4	19	25	31.6
Save pangolins	01/27/17	15055	23206	54.1	121446	193882	59.6	576	694	20.5	369	427	15.7	N/A	N/A	N/A
Modular Mounting System	03/22/17	16645	31428	88.8	94016	229327	143.9	138	204	47.8	181	265	46.4	101	230	127.7
bakercube	12/01/17	15778	27997	77.4	81176	181098	123.1	172	256	48.8	242	291	20.2	N/A	N/A	N/A
Articulated Butterfly	03/01/18	4565	8776	92.2	40763	89427	119.4	295	428	45.1	114	128	12.3	11	14	27.3
Air Spinner	03/12/18	5442	13284	144.1	36941	118933	222.0	141	265	87.9	36	57	58.3	4	6	50.0
Easter Eggs	03/17/18	4808	12699	164.1	47000	117096	149.1	138	235	70.3	40	56	40.0	4	7	75.0
Secret Butterfly Box	07/08/18	3280	9010	174.7	15717	83146	429.0	70	225	221.4	165	314	90.3	7	29	314.3
Xbox One controller mini wheel	08/14/18	1459	6128	320.0	8378	129578	1446.6	21	64	204.8	94	211	124.5	2	17	750.0
Average		443395	728036	79.7	3935388	7823249	154.6	15204	19425	46.2	6250	7794	30.4	9322	11903	48.7

Generally, the trend for high growth in the early months of an upload is clearly shown in Table 1, with uploads from 2018 typically experiencing above average growth in likes, downloads, makes, comments and remixes, compared to more established things. However, this growth is fleeting, with popular established things like ‘#3DBenchy’ and ‘The \$30 3D Scanner V7 Updates’ remaining dominant in overall figures and gaining more interactions overall. This becomes clear in Figure 3 which shows a calculation of downloads per day, with all things uploaded in 2018, as well as the ‘bakercube,’ ‘Yet ANOTHER Machine Vise’ and ‘Save pangolins’ from 2017, experiencing declining average downloads. This supports the argument of Novak and Bardini (Novak & Bardini 2019) that initial hype, fueled by social media culture, can generate a high number of downloads in the initial months after a thing is uploaded to Thingiverse, particularly noticeable with the ‘Xbox One controller mini wheel’ which was being downloaded 698 times per day in August 2018. This rate declined to 254 by January 2020.

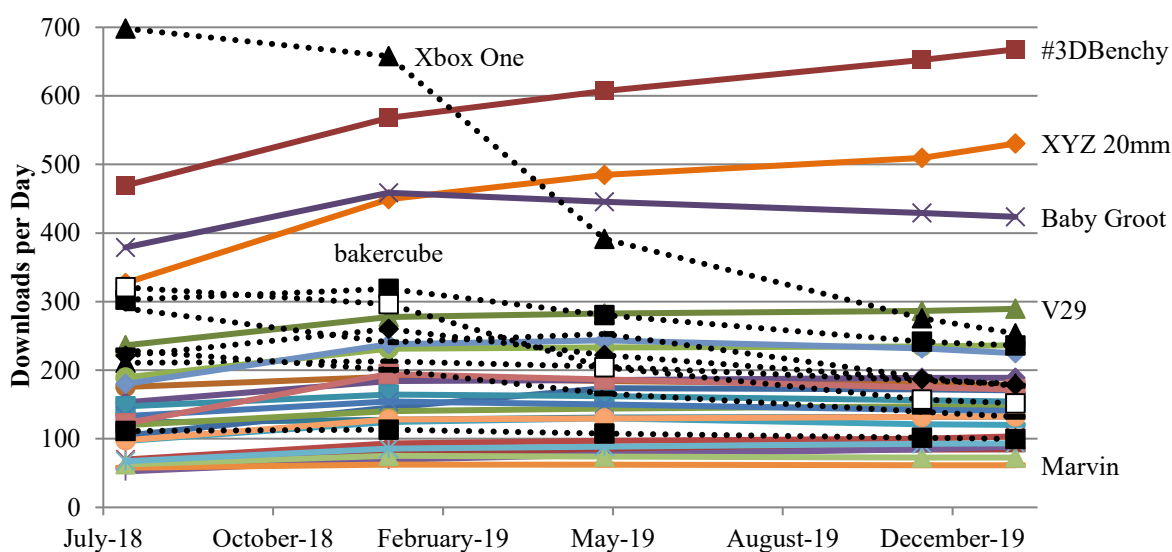


Figure 3. Downloads per day. Solid lines show things that resulted in a net increase, dotted lines a net decrease.

Conversely, more established things like ‘#3DBenchy’ and ‘XYZ 20mm Calibration Cube,’ experienced a continuous increase in downloads per day during this study. Both of these things have become popular calibration objects, 3D printed to test both hardware and software features of 3D printers, which may be increasingly downloaded as 3D printers become more ubiquitous. Most things show a relatively stable download rate between 60-300 downloads per day, with ‘Marvin’ the lowest performing thing with 61 downloads per day at the end of the study. The eight things which exhibited declining downloads per day were all within this range at the conclusion of the study period, and values may continue to stabilize.

‘Baby Groot’ showed an increase in downloads per day towards January 2019, reaching 458 downloads per day, before declining for the remainder of the study to finish at 424. This peak may be explained by the release of the film ‘Avengers: Endgame,’ featuring the character Groot, in April 2019, with fans downloading the ‘Baby Groot’ model after watching movie trailers and seeing other merchandise related to the film early in 2019. However, it is also possible that other factors, such as marketing, social media or other promotional material for this particular thing, resulted in this spike, and future studies may more closely analyze things in relation to simultaneous popular culture phenomena.

Remix data shows that one thing in particular, 'NUT JOB,' was responsible for most remixes in this study. Unlike many things on Thingiverse, which provide one or more fixed STL files which are not easily modified, 'NUT JOB' is a parametric model utilizing an additional app within Thingiverse called Customizer which allows users to change dimensions and other geometry to suit their needs prior to download (Oehlberg, Willett & Mackay 2015). Once customized, Thingiverse provides a custom STL file to the user to download, and the file instantly becomes logged as a remix. Excluding this thing, remix numbers even for things with hundreds-of-thousands of downloads are typically measured in tens, representing the least used category when graphed in Figure 2. Additionally, it is important to clarify that several things do not allow remixing of any kind, choosing a CC License such as 'Creative Commons – Attribution – No Derivatives' (CC BY-ND 3.0) that permits people to download, share and distribute the STL files, but not share any modifications they may make.

Another development from Novak and Bardini (Novak & Bardini 2019) that can now be tracked over time is the conversion rate of downloads to makes, i.e. how many people who downloaded the files from Thingiverse 3D printed them, took photographs, and shared these back onto the platform as a make. The average conversion rate for all things at the start of the study was 1:474, while by the end of the study it had declined to 1:784. The reasons for the decline are unclear but indicates a reduction in active participation on Thingiverse as people passively download without contributing back onto the platform, perhaps downloading volumes of files that could not be 3D printed and documented in a reasonable time. As shown in Figure 4, 'Baby Groot' shows a high conversion rate, with one make for every 223 downloads (1:223) at the end of the study, while '#3DBenchy' had a lower ratio of 1:336. The highest conversion rate was for 'Marvin,' achieving a ratio of 1:65 despite being one of the lowest performing things in this study. This suggests that while 'Marvin' is not as popular as other things in this study, those users who do download it value the 3D printed outcome and like to share their 3D print. By contrast, the 'XYZ 20mm Calibration Cube' was only receiving one make for every 869 downloads despite having the second highest number of downloads per day, suggesting that users may value the function of the thing for calibrating their 3D printer, but as a simple cube design does not inspire Makers to photograph the result and upload it as a make. 'NUT JOB' had the lowest conversion rate of 1:3842, however, this may be linked to the Customizer tool, with users able to upload makes to their remixed thing page, rather than the original thing page, affecting the data.

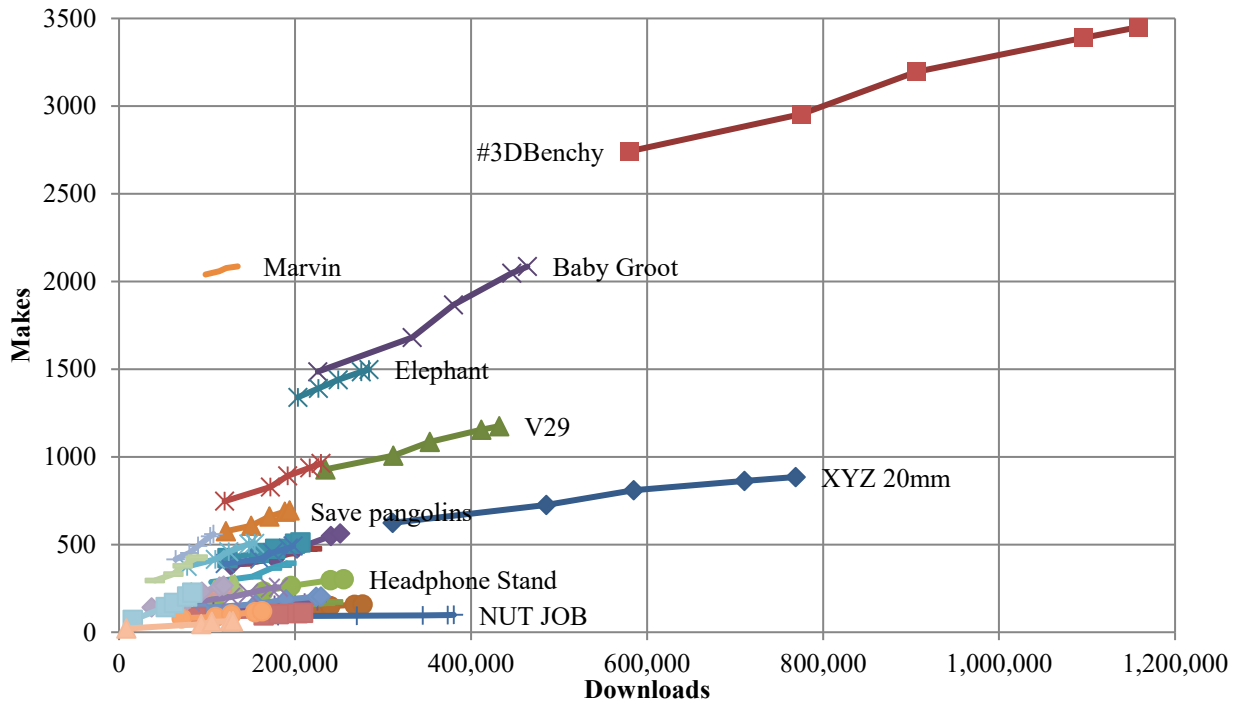


Figure 4. Conversion of downloads to makes.

Building upon this conversion metric, Figure 5 shows the conversion of views to downloads for all thirty things, with ‘#3DBenchy,’ ‘Baby Groot’ and ‘XYZ 20mm Calibration Cube’ performing well with conversion rates of one download per 2.0 views (1:2.0), 1:3.0, and 1:2.0 respectively at the end of the study. ‘NUT JOB’ achieved the best conversion rate with 1:1.8, suggesting that people who view the design have a high likelihood of downloading it, whereas ‘The \$30 3D Scanner V7 Updates’ had the lowest conversion rate at the end of the study, with one download for every 6.6 views (1:6.6). This is likely due to the complexity of the design which involves downloading and 3D printing many components which are assembled into a turntable photogrammetry device, requiring a lot of filament, 3D print time, assembly skill and interest in learning 3D scanning and associated software in order to make use of it. Overall, the average conversion rate at the start of the study was 1:4.6, which improved to 1:3.8 by the end of the study as more people who viewed content downloaded it. However, combined with the previous makes to downloads data, it is clear that while more downloading occurred by the end of the study, less people were likely to go on and record a make.

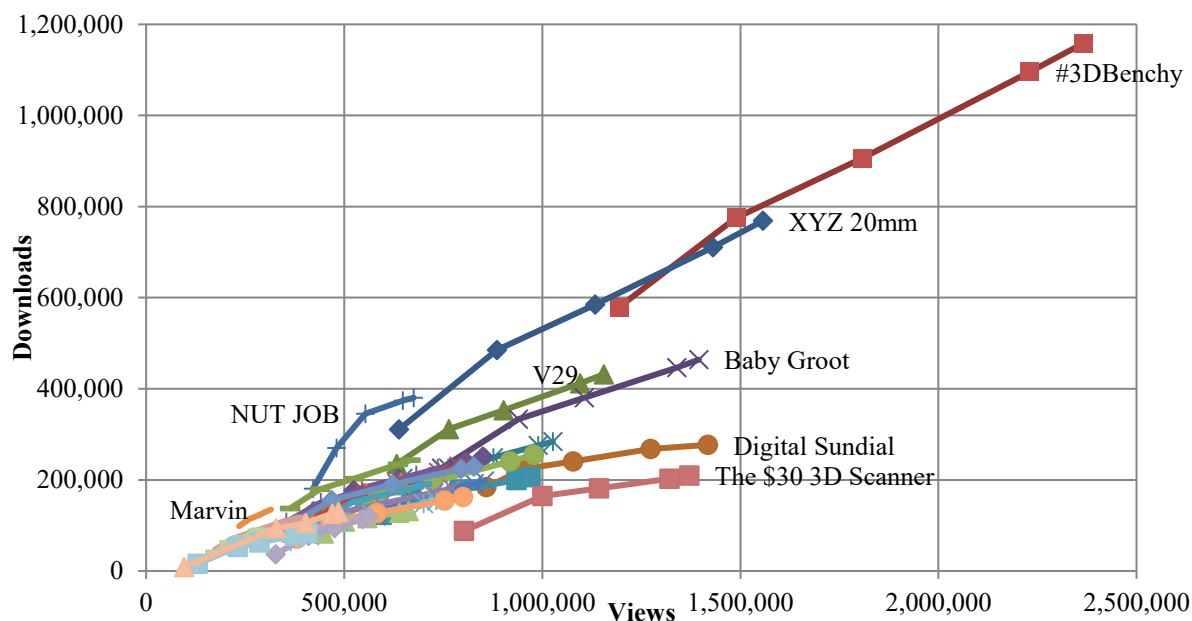


Figure 5. Conversion of views to downloads.

Discussion

When analyzing this data, it is important to remember that the thirty things were deliberately selected as examples of some of the most popular things on Thingiverse, and trends are unlikely to compare to the majority of the >1.6million things available on the platform. This is evident in random data collected by Alcock et al. (2016) mentioned previously, with things averaging 14.8 likes and 1.0 comments, compared to 24,268 likes and 259.8 comments for these popular things calculated at the conclusion of the study. This disparity between things that gain popularity and those that do not is common to all social media platforms, and significant research has been done to understand, predict and utilize engagement on social platforms (Dvir-Gvirsman 2019; Ferrara, Interdonato & Tagarelli 2014; Yu, Chen & Kwok 2011), although not through the lens of 3D printing communities like Thingiverse at this stage. While this study was observational and future research is needed to specifically understand what makes a thing popular on Thingiverse, the longitudinal trends provide new insight into the qualities, user behaviors and trends that are common to popular things, and will help in future predictions.

Downloads and likes are the most common interactions with things on Thingiverse, with downloads measured in hundreds-of-thousands, and likes in tens-of-thousands for popular things. These interactions are low-level, requiring a single click by a user, and downloads are highest for several reasons: Firstly, a download can be completed by any visitor to the website without requiring an account and login details, much like a view. This user may be described as passive, a consumer or a lurker (Khan 2017). Liking a thing requires a user to have an account and be logged in, becoming an active participant of the community. Secondly, downloads can be performed multiple times by the same viewer/user, whereas once a user has liked a thing, it cannot be liked again. These factors result in downloads occurring approximately ten times more often than likes.

Higher-level interactions of making or commenting require greater engagement from logged-in users and are instead measured in hundreds, with just five things receiving >1000 makes. Despite commenting on a thing being a simple task common to most social media platforms, the more

complex task of registering a make was performed nearly three times more often. This is thought to be a significant driver behind popular things on Thingiverse, with each make including photographs of the 3D printed result, optional information from the user about 3D printer settings and materials used, as well as observations and feedback about the design. Much like a review for a restaurant or hotel can influence consumer decisions, makes on Thingiverse increase confidence in users that the thing will print successfully, supported by guidance on how to achieve different results. It is no surprise that the most downloaded thing, '#3DBenchy,' has also received the highest number of makes, with 3,450 users taking the time to 3D print the model, photograph it, log into their Thingiverse account and upload photographs and comments. However, the relationship between downloads and makes requires further research, with low makes on newly uploaded things (e.g. 'Xbox One controller mini wheel') seemingly not deterring users from downloading a thing or being one of the first to make it.

The highest level of interaction monitored in this research is the remix, requiring a user to modify or build upon an existing thing, or design something new inspired by another thing and upload it as a designated remix, rather than as an original design. This requires CAD skills, creativity and time, with prior research showing that only 15.6% of Thingiverse users upload content (Özkil 2017), with approximately half of it derived from an existing thing. While the Customizer app, introduced in 2013, has led to an increase in contributions from Thingiverse users (Oehlberg, Willett & Mackay 2015), only 'NUT JOB' makes use of the feature out of all thirty things in this study. Therefore, low numbers of remixes are to be expected due to the complexity of manipulating STL files most commonly shared on Thingiverse, combined with licensing limitations placed on several things like '#3DBenchy' and 'Baby Groot,' which has not seemed to impact upon their popularity. As a result, it is not thought that the availability or quantity of remixes plays a significant role in the overall popularity of a design on Thingiverse.

As a key example, '#3DBenchy' became the first thing in Thingiverse history to reach one million downloads, a milestone that occurred around August-September 2019, nearly 4.5 years after being uploaded to Thingiverse. While this timeframe may not normally be associated with viral media, within the context of 3D printing and the Maker Movement, reaching such a milestone while almost doubling the number of downloads in five hundred days certainly suggests a new phenomenon that warrants further study. At current download rates the 'XYZ 20mm Calibration Cube' will be the next thing to reach one million downloads by March 2021, although if the download rate continues increasing, this will occur much sooner. Such download figures are more common to the music and video industries, but what does it mean when digital data, that can create a physical object, is being downloaded millions of times? How many physical copies of these things *really* exist, acknowledging that very few prints would be uploaded as a make by a registered Thingiverse user, and what happens to them when they are no longer wanted? "A viral video or piece of advertising made up of digital bits can easily be deleted, but a viral object made up of physical atoms is not so easily discarded in a responsible and sustainable manner" (Novak & Bardini 2019). With a combined 19,425 makes and 7,823,249 downloads on just thirty things, the data in this study indicates new patterns of interactions with 3D printable files, measured in proportions normally reserved for mainstream video, music and image media.

Lastly, it is important to acknowledge that Thingiverse, despite being the largest 3D printing community (Novak & Bardini 2019), is not the only one, and popular things like '#3DBenchy' are in fact available on numerous other platforms such as Pinshape (www.pinshape.com), MyMiniFactory (www.myminifactory.com) and others. Therefore, it is likely that there are many designs which have been downloaded millions of times in total across platforms, and continue to be made, remixed and

commented on daily. While the Maker Movement, file sharing communities and open source projects are often considered niche research fields within 3D printing, or adjacent to it, this study provides evidence that a large ecosystem of things has been growing that has implications for designers, manufacturers, supply chain managers and universal popular culture. Knowledge communities may hold significant social and intellectual capital (Birtchnell, Böhme & Gorkin 2017; Novak 2019), and research shows that the number of 3D printing communities continues to grow (Kwak, Kim & Park 2018); therefore, understanding the Thingiverse, both the branded website and the broader concept of a universe of things, requires renewed consideration by industry and academia, with parallels akin to those experienced over the last decade by the music, video, television and transportation industries due to digital transformation. Viewing, liking, downloading, making, remixing and commenting may seem like a novelty, but as figures for a single file become measured in millions, a new revolution may be under way.

Conclusion

As a longitudinal study, this research provides new insights into how thirty of the most popular things on Thingiverse perform over time, revealing new trends and relationships previously hidden by studies performed at a single point in time. Different patterns in behavior were revealed to characterize newly uploaded things, which receive rapid growth in likes, downloads, makes, remixes and comments, compared to more established things which may plateau between 60-300 downloads per day. In the case of two things, '#3DBenchy' and 'XYZ 20mm Calibration Cube,' downloads per day increased throughout the study period to values of 668 and 530 respectively, believed to align with the increasing access to 3D printers and use of these things as calibration models by Makers. However, the popularity and performance of things is not predictable or obvious in raw data, for example calculations of conversion rates from views to downloads revealed that the most liked and commented on model in fact had the lowest conversion ratio, while the thing with the lowest data was revealed to have the highest conversion rate of downloads to makes. Researchers can utilize such knowledge to compare various 3D files and file sharing communities into the future, providing new understanding about the digital and physical effects of accessible files for 3D printing. The first thing exceeding one million downloads on Thingiverse in 2019 signals a renewed urgency for researchers to consider the social, environmental and economic implications of digital file sharing for 3D printing, with the growing volume of files and users on Thingiverse quickly approaching levels seen in digital music, video and image sharing.

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