The popular culture of 3D printing: when the digital gets physical

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Handbook of Research on Consumption, Media, and Popular Culture in the Global Age

Ozlen Ozgen
Atilim University, Turkey

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Chapter 12
The Popular Culture of 3D Printing:
When the Digital Gets Physical

James I. Novak
https://orcid.org/0000-0003-4082-4322
Deakin University, Australia

Paul Bardini
Griffith University, Australia

ABSTRACT

As 3D printing technology achieves mainstream adoption, people are forming new relationships with products as they shift from passive consumers to "prosumers" capable of both producing and consuming objects on demand. This is fueled by expanding online 3D printing communities, with new data within this chapter suggesting that prosumers are challenging existing understandings of popular culture as they bypass traditional mass manufacturing. With 3D digital files rapidly distributed through online platforms, this chapter argues that a new trend for "viral objects" is emerging, alongside the "3D selfie," as digital bits spread via the internet are given physical form through 3D printing in ever increasing quantities. Analysis of these trends will provide academics, educators, and prosumers with a new perspective of 3D printing's socio-cultural impact, and further research directions are suggested to build a broader discourse around the opportunities and challenges of a cyberphysical future.

INTRODUCTION

Futuristic visions within popular culture have often portrayed the ability for a machine to materialize any desired object on-demand. According to *Star Trek: The Next Generation Technical Manual*'s description of a device on board the starship Enterprise:

Recent advances in transporter-based molecular synthesis have resulted in a number of significant spinoff technologies. Chief among these are transporter-based replicators. These devices permit repli-

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cation of virtually any inanimate object with incredible fidelity and relatively low energy cost. (Okuda & Sternbach, 1991, p. 90)

This vision of a replicator system may have appeared futuristic several decades ago; however, the technology today known popularly as 3D printing has evolved over a relatively short period of time from being a specialist prototyping tool used by designers and engineers, to one of mainstream adoption within a society hungry for new and more personalized products and experiences. As a result, many of the technical aspects of replicator-inspired 3D printing systems are now widely disseminated through both academic and popular media sources, and 3D printers have even made their debut on board a real starship in the form of the International Space Station. Science fiction has become science. Despite the technical aspects of this technology being well investigated through engineering discourse, literature examining the popular cultural context of the technology has received little attention; this chapter will address the shortfall in knowledge by analyzing how the popular culture trends from the digital world are now migrating to the physical world through 3D printing.

Through this analysis it will be argued that consumers are empowered through 3D printing to both produce and consume their own products, no longer reliant on mass manufacturing to determine their choices. The rise of the so-called 'prosumer' is tightly coupled with broader shifts described by the fourth industrial revolution and a hyperconnected society that increasingly allows individuals to shape their personal experience of both the digital and physical worlds. With numerous facets of popular culture increasingly intertwined with 3D printing, this chapter will present new data to demonstrate the significance of growing online communities and appearance of 'viral objects' which spread through the physical world in similar fashion to digital viral media campaigns and videos. Digital bits allow the spread of viral objects, while 3D printers turn the bits into atoms, spreading them through the physical world in increasing numbers and permutations. Similarly, the selfie has also begun to leave the constraints of the digital world, benefiting from the growth of 3D scanning and facial recognition technology and shifting this phenomenon into the physical world. The '3D selfie' raises new questions about user privacy and the emotional effects on individuals whose narcissistic tendencies may be reinforced by a 3D selfie culture.

This chapter will help researchers of popular culture, as well as academics, educators and prosumers utilizing 3D printing, to identify the relationships between 3D printing and broader socio-cultural factors that are transforming the way people consume products. Through this knowledge, emergent opportunities and challenges that will appear during the coming years, as 3D printing becomes increasingly ubiquitous, will be more readily examined with objectivity. This will be used to inform future research directions in academic, commercial and educational contexts. The chapter is a catalyst for a new research focus on 3D printing within popular culture, and is necessary to prepare for a future where the boundaries between the digital and physical worlds are increasingly blurred.

Background

Prior to the first industrial revolution, the 'consumer' was closely linked with the producer; local artisans and craftspeople produced and sold products directly to their community, and many items were custom made or repaired dependant on individual needs. The notion of product *consumption* did not exist; people bought or made items they needed to survive and make a living, and products were rarely identical, with skill and availability of materials defining the characteristics of the final product. Following the first and second industrial revolutions and rise of mass production, artisans and craftspeople gave way to

large manufacturers, and people lost touch with these new manufacturers as a one-size-fits-all mentality shaped the physical world. Products have since become consumables similar to food, mercy to changes in trends and readily discarded even when still perfectly functional. With such a consumer culture described as synonymous with popular culture by leading academics (Danesi, 2005; Storey, 2015), this chapter must begin with a contextual assessment of popular culture as it relates to manufacturing and the shift in production being brought about by 3D printing.

Storey (2015), whose frequently cited book *Cultural Theory and Popular Culture: An Introduction* is currently in its seventh edition, provides six interrelated definitions for popular culture, including a quantitative measure of popularity, an antithesis to high culture, and "a culture of the people for the people" (Storey, 2015, p. 9). The necessity for multiple definitions is related to the complexities in multiple meanings of the words 'popular' and 'culture,' and has led numerous experts, including Storey (2015) and Parker (2011), to suggest that any sort of precise definition is difficult, elusive, and perhaps even "delusive" (Parker, 2011, p. 169). However, a common thread to leading theoretical discussions is the link of popular culture to concepts of mass production, industrialization, and consumerism; in other words, there is a tight coupling between popular culture and the production of goods, whether these are physical, digital, or increasingly a combination of the two. While mass production has shaped much of the physical world for over a century, Schwab (2017) argues that:

we are at the beginning of a fourth industrial revolution. It began at the turn of this century and builds on the digital revolution. It is characterized by a much more ubiquitous and mobile internet, by smaller and more powerful sensors that have become cheaper, and by artificial intelligence and machine learning. (p. 7)

The fourth industrial revolution, also known as Industry 4.0 (Bonciu, 2017; Drath & Horch, 2014), is ultimately about cyberphysical systems whereby digital information is linked to the physical production of an object, a connection which may continue throughout an object's life through its connection to the Internet in a system known as the Internet of Things (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012; Want, Schilit, & Jenson, 2015). With a defining characteristic of 3D printing being the link between an object and the digital information used to 'print' it, Schwab goes on to explain 3D printing as one of the technological "megatrends" driving this revolution (Schwab, 2017).

Known more formally as additive manufacturing, 3D printing is defined most concisely by the ISO/ASTM 52900 standard which describes a "process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies" (ISO, 2015, p. 1). The significance of this technology is that material is deposited precisely where it is needed to represent the geometry of an object, rather than traditional manufacturing processes which begin with a solid block of material and subtract material until the desired geometry remains. Campbell, Bourell and Gibson (2012, p. 258) categorize four primary opportunities afforded by this process of adding material in the creation of an object: firstly, because the 3D printer is replicating information described by a 3D Computer-Aided Design (CAD) file, it is possible to modify the digital data and print a different design each time. This means that customization is possible, with the requirement to reproduce many of the same design due to the expenses of tooling (as in injection molding) or machine setup (as in CNC machining) all but removed. Secondly, improved functionality is possible by printing more complex and organic structures that may reduce weight or improve other characteristics of a design, features that could not be manufactured through traditional means (Novak, 2015). Thirdly,

3D printing has the ability to fabricate assemblies of multiple parts, or consolidate the number of parts needed to produce a product, requiring less assembly. And finally, Campbell, Bourell and Gibson (2012, p. 258) describe that new aesthetic qualities may be included in each print, allowing further customization.

The ISO/ASTM 52900 standard goes on to define seven broad categories of 3D printing technologies that utilize different methods of joining materials. For the purposes of this chapter, focus will be limited to "material extrusion," (ISO, 2015, p. 2) a process that "can be visualized as similar to cake icing, in that material contained in a reservoir is forced out through a nozzle when pressure is applied" (Gibson, Rosen, & Stucker, 2015, p. 147). This is the most common form of desktop 3D printing, known as Fused Deposition Modeling (FDM), or Fused Filament Fabrication (FFF). Typically the materials used in this process are common low-cost polymers like Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA), although an increasing variety of exotic materials are available including carbon fiber, bamboo, algae, and even metals. FDM printers are available for prices ranging from hundreds to thousands of dollars, with some machines allowing ongoing upgrades and modifications depending on user need and expertise, such as 3D printers based on the popular RepRap open-source model.

As a result of the affordability of desktop 3D printing machines, combined with access to materials widely used in traditional manufacturing, 3D printing is challenging definitions of popular culture that focus on its commercial and mass-produced nature. Returning to Storey's revised research on popular culture, the fourth definition explains it as a "culture that originates from 'the people.' It takes issue with any approach that suggests that it is something imposed on 'the people' from above" (Storey, 2015, p. 4). With 3D printers enabling people to produce their own products, rather than relying on some other external power to create products for them, 3D printing can be seen to empower culture originating from 'the people.' However, the second aspect of Storey's fourth definition is challenged by 3D printing. Storey claims that "people do not spontaneously produce culture from raw materials of their own making. Whatever popular culture is, what is certain is that its raw materials are those that are commercially provided" (Storey, 2015, p. 4). As described previously, 3D printing materials are increasingly of a commercial quality, with ABS in particular being a common plastic used in the manufacture of laptops, mobile phones, toys, car interiors and a plethora of objects encountered in daily life. Thus 'the people' are capable of 'manufacturing' objects of the same material as those defined as being essential to popular culture, and new consideration must be given to the link between popular culture and manufacturing as it shifts into the hands of the masses.

Despite this capacity, the reality today is that homes have not become micro manufacturing centers free from the need for mass manufacturing. For example, recent data from Australia estimates that three percent of Australian households own a 3D printer, with consumer awareness estimated at 75% (Bailey, 2017). Furthermore, despite the quality of materials available, the layer-by-layer nature of 3D printing results in weakness between layers and a rough surface finish, not often desirable in end-use products. However, growth is high with the latest Wohlers Report estimating a doubling in global desktop 3D printer sales in 2018 (528,952) compared with 2015 (Wohlers, Campbell, Diegel, & Kowen, 2018), and the technology has conservatively been described as being on the tipping point of becoming mainstream in recent years (D'Aveni, 2015; Quinlan, Hasan, Jaddou, & Hart, 2017; Winnan, 2012), if not already mainstream depending on how this is defined. While technology developments continue to improve the quality of 3D printed objects, and the ease of using the machines, the most active area of 3D printing has been the digital aspects of the technology; file generation and file sharing through online communities

where the geographically dispersed hobbyists, designers, makers and engineers gather as a much larger collective. This will be analyzed through the following section of this chapter to explore the changing relationship people have towards goods that begin their life as digital data.

THE ONLINE WORLD OF 3D PRINTING

As a digital technology, 3D printing must first begin with a digital file to describe the object being printed, much like a 2D printer requires a digital image or text file to print on paper. The most common 3D file is known as a Stereolithography (STL) file, although new formats such as the Additive Manufacturing File (AMF) are poised to take over in the future due to their ability to describe a greater amount of detail more suited to the increasing capabilities of 3D printers such as multi-material ((ISO), 2016). More traditional manufacturing technologies tend to operate without this direct link to 3D geometry, for example injecting plastic into a mold or bending sheets of metal. As described previously, this is the impact of shifting to cyberphysical systems, with the bits and atoms of a design no longer mutually exclusive. Anderson, long-time editor-in-chief of *Wired* magazine, describes that "just as the Web democratized innovation in bits, a new class of "rapid prototyping" technologies, from 3-D printers to laser cutters, is democratizing innovation in atoms" (Anderson, 2012, p. 14). This has led to the so-called 'Maker Movement,' a term closely aligned with the establishment of *Make: Magazine* in 2005 by Dale Dougherty, who began his first article with the line "more than mere consumers of technology, we are makers, adapting technology to our needs and integrating it into our lives" (Dougherty, 2005). Recent research estimates that half of all Americans call themselves Makers (Lou, 2016) and physical 'Makerspaces' in libraries, workshops and schools are rapidly emerging alongside digital communities of Makers.

Makers: 3D Printing and the Rise of the Prosumer

The significance of making and the Maker Movement is its symbiosis with the Internet, a "planet-wide extension of the human nervous system that transmits information, thoughts, and feelings to and from billions of people at the speed of light" (Gore, 2013, p. 44). Makers who 3D print are able to connect like never before using specialized online platforms that provide many of the social features popularized by Facebook and Instagram, combined with the ability to share 3D model files for free or even for a fee chosen by the creator. This is similar to the disruption experienced by the music industry earlier in the twenty-first century when it became possible to download, stream, copy and remix digital music, transforming the entire industry in a relatively short period of time. The digitization of such entertainment means that content is available on-demand, twenty-four hours a day, on a multitude of fixed and portable devices, allowing individuals to personalize their consumption of music, as well as television, movies, shopping, news and an increasing array of social experiences. "It is a world of the *now*" (Schwab, 2017, p. 54). Furthermore, Anderson (2012) explains:

The greatest change of the past decade has been the shift in time people spend consuming amateur content instead of professional content... Now the same is happening with physical goods. The 3-D printers and other desktop prototyping tools are the equivalent of the cameras and music editing tools. They allow anyone to create one-offs for their own use. (p. 66)

Anyone with an internet connection is able to both consume and create content, and 3D printing is maturing at a time where the consumption of both digital and physical goods is shifting towards more personalized, user-centered experiences rather than those driven by a top-down, mass-production approach. This challenges the existing discourse and definitions of popular culture which has been aligned with mass production and the standardization of goods, rather than the emerging trend for customization and the decentralization of manufacturing, now possible at home or at a local Makerspace.

Makers digitally connected in this way are a revolution (Anderson, 2012), leading to the term 'prosumer' to describe the ability for consumers to both *pro*duce and con*sume* content (Ahluwalia & Miller, 2014; Fleischmann, 2015), no longer reliant on large manufacturers to produce goods for them. Despite the term 'prosumer' being coined in 1980 by Alvin Toffler (Ahluwalia & Miller, 2014; Kelly, 2016), the concept has been slow to proliferate the physical world due to the complexities of fabricating even the most basic functional object. This is an effect of industrialization and the shift of manufacturing away from 'the people' to large centralized factories, often in distant countries, with highly specialized technologies capable of mass manufacturing goods in large volumes, making them for cheaper than could be done by a lone individual. The traditional hand-skills of making have been de-valued in a culture fascinated with technology and the virtual world (Loy & Canning, 2013), and Dougherty (2016) suggests that:

Consumer culture disables us in some ways, and people can feel entitled, expecting others to do things for them... This kind of consumerism disconnects our desires from our own work, the work that is required to realize our desires. We are often left unsatisfied and unfulfilled, perhaps not even knowing what we truly desire. In the extreme, consumerism is a form of learned helplessness. (p. 17)

However, as described by Anderson (2012), the democratization of innovation in bits has seen prosumers rise rapidly in the digital world, consuming and producing video content for YouTube since 2005, music content for SoundCloud since 2008, and software on GitHub since 2008. Access, downloading, and contributing to such platforms is typically free to anyone with an Internet connection and suitable device. With a decade or more of such platforms becoming mainstays of popular culture, the evolution of desktop 3D printing within this context has transferred the same sharing culture to the production of physical things for the first time, making Toffler's concept of the prosumer a reality for the physical world. Yet many challenges remain for the prosumer, not least of which is the expertise necessary to create 3D digital files suitable for 3D printing (Schmidt & Ratto, 2013). Traditionally such skills have been the domain of designers and engineers, trained through years of university level education to operate complex CAD software which often costs several thousands of dollars. However, similar to the trend for video, music and photographic editing software to become more accessible and user-friendly, a similar trend in CAD software is being observed with freely available examples including Sketchup, Meshmixer, Tinkercad, Sculptris and FreeCAD, enabling prosumers with digital tools capable of creating or editing files for 3D printing.

Primary and secondary education has also adopted 3D printing and CAD education as part of a broader Science, Technology, Engineering and Mathematics (STEM) agenda (Elrod, 2016; Novak, 2019a; Wilson, 2013), with the coming generation gaining hands-on design and 3D printing experience, increasing the demand for more advanced software, online collaborative tools, and 3D printing technologies. As this generation matures, prosumers will have a different relationship with products, as well as the skills necessary to improve, repair, modify and share design files, circumventing the need

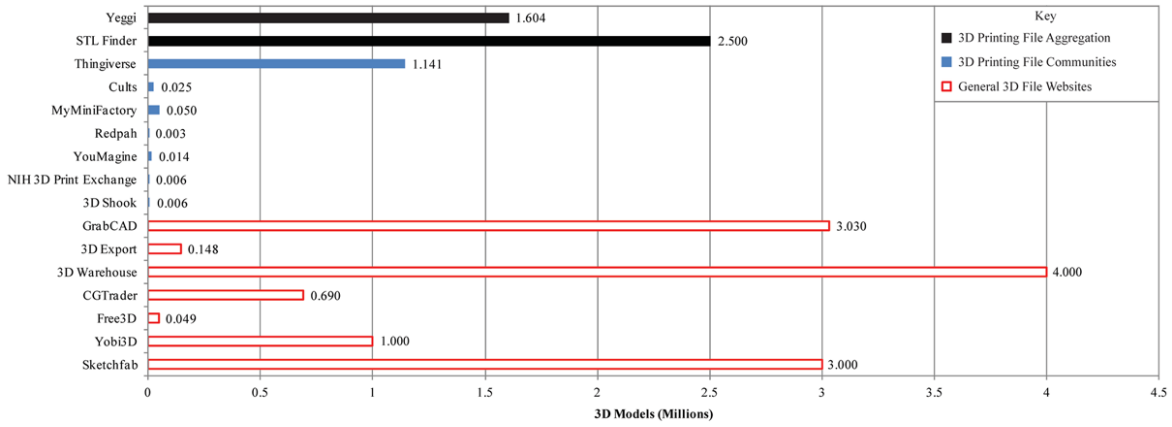
for traditional mass-manufacturers in many situations. The online communities where prosumers gather are a significant part of this emerging ecosystem, aligning with current trends for the open sharing of information within an active social network.

3D Printing Communities

Within online 3D printing communities, both professional and amateur content coexists in volumes measured in the millions. Figure 1 captures the quantity of files available for download from many of the most well-known online 3D file communities at the time of writing. The first section includes *Yeggi* and *STL Finder*, which are STL file aggregation websites, compiling files from many of the websites in the second section of the graph which are specific 3D printing websites. *Thingiverse* is the most popular and well-known 3D printing community ("About," 2018; Alcock, Hudson, & Chilana, 2016) with 1.14 million downloadable files at the time of writing. Platforms like Thingiverse allow users to create a profile and share their designs for others to download, as well as features such as commenting on other designs, participating in forums, sharing photographs of 3D prints, and following favorite designers. The third section of Figure 1 shows data for general 3D file websites which may include architectural models, characters for video games, virtual reality content and 3D scans not specifically created for 3D printing; however, being 3D files, many, if not all of these files, could be 3D printed with some modification. For comparison with another icon of popular culture today, in 2018 Netflix features just over 5500 movies and TV shows (Clark, 2018), and would be the smallest data set if graphed in Figure 1. Similarly, LEGO® data from popular fan website *Brickset* (www.brickset.com) claims to have a database directly from LEGO® with 35,772 different items produced over the last 35 years, which would also make it one of the smaller collections if graphed in Figure 1.

More significant than the number of files is an understanding of the interactions driving them. A recent study into 23,285 Thingiverse files revealed that on average, designs received 14.8 likes and 1.0 comments, with comments averaging 30.4 words in length (Alcock et al., 2016). This word length is more than a simple greeting, with users asking specific print-related questions and providing updates, building what has been described as a "knowledge community" (Jeong, Cress, Moskaliuk, & Kimmerle,

Figure 1. Graph of significant 3D file sharing websites recorded on 26th August 2018



2017) rather than simply a platform for socializing. Such communities amass large amounts of highly specialized knowledge on a topic like 3D printing, which is openly available for anyone to find online, with open sharing of information becoming the default for the digital generation (Anderson, 2012; Kelly, 2016). Novak (2019b) provides data as to the scale of some additional 3D printing knowledge communities such as *3D Hubs* (an online manufacturing service which was originally exclusive to 3D printing) and *RepRap* (the most popular open-source 3D printer which began in 2004) which feature posts and threads in volumes that exceed the total number of entries in Encarta Encyclopedia when it closed in 2009. Similar well-known knowledge communities include Wikipedia, YouTube, Arduino and Scratch (Jeong et al., 2017; Novak, 2019b).

The 3D printing forums and the 3D file sharing websites in Figure 1 exhibit the characteristic known as a 'network effect,' a "situation where the value of a resource for each of its users increases with each additional user... digital information is not "used up" when it gets used, and it is extremely cheap to make another copy of a digitized resource" (Brynjolfsson & McAfee, 2016, p. 60). The majority of files on platforms like Thingiverse are freely available under Creative Commons 4.0 (CC 4.0) licensing (Özkil, 2017), and while it is possible for the designer to associate a fee-per-download or receive a tip on many platforms, these are typically in the range of dollars, the majority of which goes back to the designer with the platform taking a small percentage. This model is similar to online music stores like iTunes, while more recent 3D printing file repositories like *3D Shook* are offering monthly subscription services to download models on their platform, more like streaming services Spotify and Apple Music. These new modes of producing and consuming raise new questions about the role of manufacturers in a world where anyone can become a manufacturer. As an example, a search on Thingiverse for "GoPro mount" reveals 4,991 freely available objects, some directly modeled off the manufacturer's standard range (normally costing tens of dollars), while others are unique to allow mounting of a GoPro camera in specific situations, such as on a specific 3D printer to record time-lapse footage. For a Maker with a GoPro camera, the cost of consuming accessories may simply be the cost of material to print them (typically several cents for a part the size of a GoPro mount), disrupting the traditional business model of a company like GoPro who could not economically manufacture the full range of designs available on Thingiverse through their traditional manufacturing structure.

Another significant feature of these online 3D printing communities is the open source nature of the designs, with a recent study into 348,509 files on Thingiverse finding that 90.6% of all files are available to be downloaded and modified by anyone with the skills to do so under a CC 4.0 license (Özkil, 2017). Similar to the digitization of music, this has led to a culture of remixing, modifying and appropriating 3D files, which are then fed back into the online community as a 'derivative' (Rimmer, 2017), or in Thingiverse terms, a 'remix.' Furthermore, of the files openly available to be modified on Thingiverse, 86.2% allow commercial sale of modified files, meaning that hundreds of thousands of designs are currently available for anyone to use for financial gain, without any consequences or need to return funds to the original designer. Hypothetically this could include GoPro, who may choose to commercialize a popular design downloaded from Thingiverse. Within a traditional manufacturing context driven by sales and intellectual property, the free sharing of designs may seem like an alien concept. However, Danesi (2005, p. 1452) explains that "the makers of pop culture make little or no distinction between art and recreation, distraction and engagement," with the value to the individual often in the process of problem solving and sharing rather than through financial reward. Reputation and a sense of being part of something bigger are highly motivational to members of online communities (Jeong et al., 2017;

Raymond, 2001), who now have a platform to react against over a century of being constrained by top-down pressures to consume products which are standardized and designed for the 'average' user, rather than the unique needs of an individual.

Whatever type of revolution it might be, it certainly raises some important questions about the nature of long-established relationships in the field of design, and feeds the tensions between community and individuality, producing and consuming, professionals and amateurs, testing the limits of control, ownership and authorship, and redefining the very nature of our relationship with technology and material culture. (Narotzky, 2016, p. 157)

These issues are multifaceted and in themselves topics of increasing discussion within academia and the broader community. From the perspective of popular culture, 3D printing is part of broader shifts transforming the way people consume physical goods linked to a digital facsimile, as well as how they contribute back into the cycle of product iteration now becoming open, accessible, and in most cases free. The following section will quantify the scale of 3D printing popular culture, and focus on two trends poised to make significant impacts on society as they shift from the digital world to the physical in the coming years.

SELFIES AND BENCHY AND GROOT, OH MY!

For those without a background in design and engineering, the first question people find themselves asking after purchasing a 3D printer is 'what am I going to print?' Learning CAD software takes time, and the plethora of online 3D printing file repositories provide an instant fix with millions of files ready to search and download. This is similar to music, which is easily consumed, but takes training and experience to produce. As ownership of 3D printers increases, along with growth in Makerspaces, FabLabs, libraries with 3D printers, local printing bureaus, and online service providers like Shapeways and i.Materialise, memberships and downloads on websites like Thingiverse also grow at exponential rates (Özkil, 2017). A side effect of this growth is the appearance of 3D printed 'viral objects,' a term proposed by the authors to define a new viral trend no longer constrained within the digital world.

Viral Objects

Viral videos and marketing campaigns are a feature of popular culture that has grown alongside the spread of the Internet. Driven by a "viewer pull and control rather than advertiser push" (Hayes, King, & Ramirez, 2016, p. 31), viral media campaigns are increasingly consumed and shared on social platforms such as Facebook, Instagram and Twitter due to the ability for one-click sharing and rapid proliferation through a global network of users. As a result of being driven by 'the people,' viral media and marketing are a modern feature of popular culture, although researchers are only recently beginning to understand the unique social relationships and factors that lead to a campaign going viral on social media (Hayes et al., 2016; Ketelaar et al., 2016). A challenge in viral media research is defining the threshold at which a video or piece of advertising becomes viral; Kalyanam, McIntyre and Masonis (2007) propose an equation based on the number of requests sent out by a user of a service or platform, and the conversion rate of those requests into new users. In advertising, "the amount of consumers that forward an ad to others"

(Ketelaar et al., 2016, p. 2604) is how the spread of a viral piece of advertising is assessed, although the exact threshold at which an ad is considered viral remains difficult to define. With 3D printing communities built upon similar social principles, when digital bits go viral they can become viral objects given form through 3D printing. However, a threshold has not yet been established within this context, and as 3D printing growth continues, researchers must shift their knowledge of viral digital media to an understanding of the consequences in the physical world of a similar viral trend.

In order to quantify the viral nature of 3D printable objects, the most popular 3D printing file repository from Figure 1, Thingiverse, was searched using the 'explore' function ranked in order of most popular files. Thirty objects at the top of the search were selected based on an 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 having observed these objects on 3D file websites, social media platforms and at 3D printing conferences and events. Table 1 lists some of the primary statistics of these objects ranked in order of highest number of downloads recorded on 26th August 2018. The most downloaded file is '#3DBenchy' with 579,537 downloads, as well as being the most made object with 2,742 documented prints being uploaded to the Thingiverse platform after users have 3D printed the file and taken photographs (called a 'make'). Countless more have been 3D printed and never documented back on the Thingiverse website, with an Instagram search revealing 2,875 photographs with the hashtag "#3dbenchy" at the time of writing, and a dedicated Instagram profile for #3DBenchy with over 2,000 followers. This popularity is confirmed in a blog by the creators of #3DBenchy who received statistics directly from Thingiverse (Tools, 2016).

#3DBenchy is the first example of a viral object, equivalent to the 'Hello World!' of coding, and a photograph of the small tug boat is shown in Figure 2. Originally created for in-house printer testing and calibration by a Swedish 3D solutions provider called *Creative Tools*, the design was publicly released on Thingiverse on the 9th April 2015, and can now be found on every file sharing website listed in Figure 1

Figure 2. A 3D print of #3DBenchy produced in Polylactic Acid (PLA) on a desktop Fused Filament Fabrication (FFF) machine

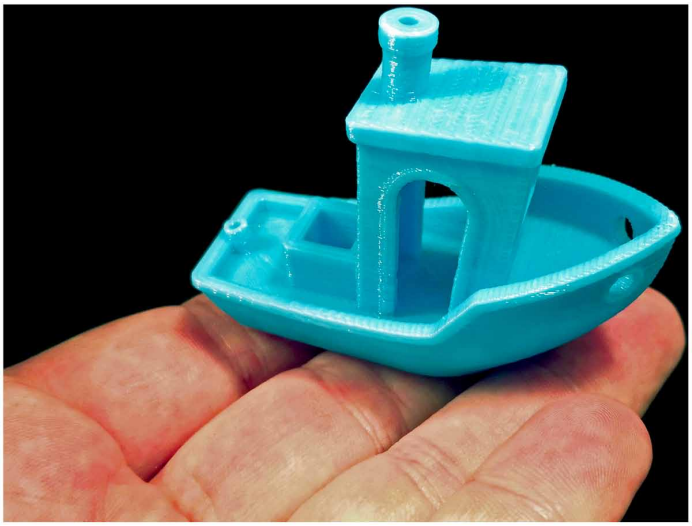


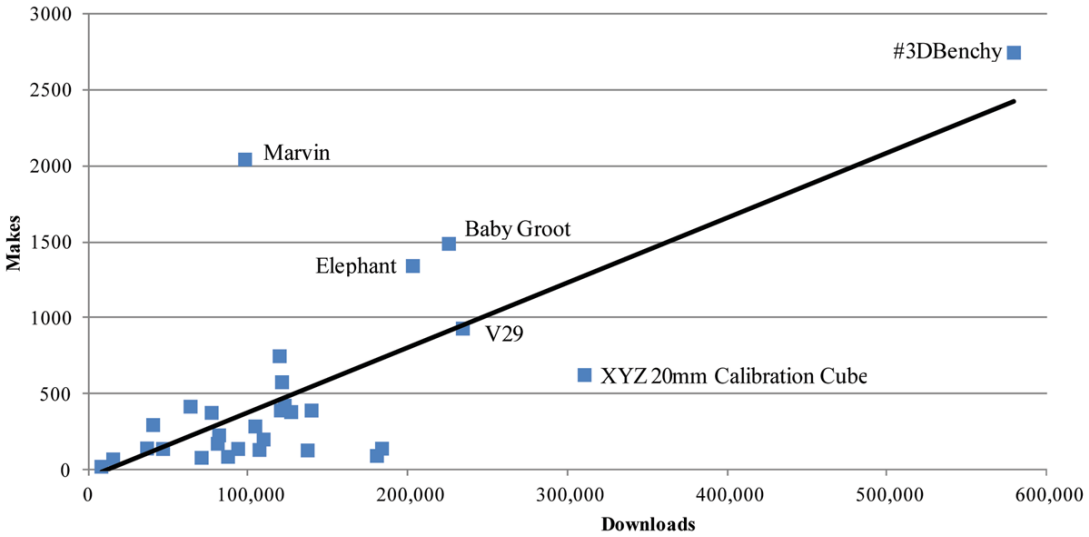
Table 1. 30 of the most popular files on Thingiverse measured on 26th August 2018

Object Name	Upload Date (MM/DD/YY)	Likes	Downloads	Makes	Comments	Remixes
#3DBenchy	04/09/15	22609	579537	2742	284	N/A
XYZ 20mm Calibration Cube	01/19/16	10038	310774	624	123	22
V29	12/07/15	22388	234590	929	395	22
Baby Groot	01/07/17	16677	225914	1486	336	N/A
Elephant	02/25/14	18154	203323	1340	262	5
Digital Sundial	10/13/15	24309	183998	140	245	14
NUT JOB | Nut, Bolt, Washer and Threaded Rod Factory	12/01/13	17488	180844	92	208	8811
Earbud Holder	12/01/12	16678	139925	390	191	17
Eiffel Tower	07/06/15	11402	137459	128	53	9
T-Rex Skeleton	05/17/16	11645	127182	380	265	15
Venus Box	05/12/16	18525	123125	423	222	11
Save pangolins	01/27/17	15055	121446	576	369	N/A
The 3D Printed Marble Machine #3	03/02/16	16127	120724	391	337	15
Labyrinth Gift Box	12/11/13	17313	119937	747	305	30
Headphone Stand	01/23/17	16591	109916	200	113	35
1.75mm Filament Clip	01/15/13	16361	107265	131	118	28
Stackable Battery Holders	09/09/15	20775	104726	286	114	16
Marvin	12/30/13	4383	98281	2040	54	56
Modular Mounting System	03/22/17	16645	94016	138	181	101
The $30 3D Scanner V7 Updates	09/09/16	25398	87687	86	494	13
Frankenstein Light Switch Plate	01/23/15	19109	82062	227	239	33
bakercube	12/01/17	15778	81176	172	242	N/A
Self-Watering Planter (Small)	07/02/15	20707	77425	375	234	N/A
The HIVE - Modular Hex Drawers	08/29/16	16902	71083	80	207	22
Yet ANOTHER Machine Vise	01/26/17	12784	64174	416	210	19
Easter Eggs	03/17/18	4808	47000	138	40	4
Articulated Butterfly	03/01/18	4565	40763	295	114	11
Air Spinner	03/12/18	5442	36941	141	36	4
Secret Butterfly Box	07/08/18	3280	15717	70	165	7
Xbox One controller mini wheel	08/14/18	1459	8378	21	94	2

except *CG Trader* (mostly for virtual and augmented reality), *3D Shook* (one of the smallest 3D printing file sites), and *NIH 3D Print Exchange* (biomedical files only). While the figures are significant, following the equation developed in the research of Kalyanam et al. (2007) and appropriated for 3D printing, Figure 3 graphs the relationship between downloads and makes for the objects in Table 1. #3DBenchy is an outlier with nearly double the number of downloads of the nearest object, and the highest number of recorded makes. The trend line of this graph shows a similar growth to the research of Kalyanam et al. (2007) and supports the hypothesis that increased downloads typically leads to more makes, with each new make fed back into the Thingiverse system boosting a design's rankings in a self-perpetuating fashion. Photos and videos of finished prints, as well as the process, may also be shared across a Maker's social media and other platforms, generating interest from others outside the Thingiverse community. Interestingly, #3DBenchy is shared under a 'Creative Commons – Attribution – No Derivatives' (CC BY-ND 3.0) license, meaning that the file can be modified by a user, but not shared, hence there are no remixes recorded on Thingiverse. However, a search on Thingiverse for "3DBenchy" returns 205 results, including some files which may breach this license, similar to the GoPro accessories mentioned earlier which may also breach intellectual property rights. This highlights the concern with such openly distributed files that not all users will follow the terms of use, and researchers and policy makers are rapidly trying to translate the lessons from the music industry to the distribution and production of 3D objects (Depoorter, 2014).

#3DBenchy itself is a simple tugboat, not based on any popular movie character or piece of current consumer technology, yet the design has captured the imagination of Makers who continue to print the design at ever smaller (size of a small coin) and larger (over 600mm long) scales, as well as in multiple colors and materials as 3D printing technology matures. Given the spread of #3DBenchy across almost all popular 3D file sharing websites, combined with the significant statistics and appearance of dedicated Instagram and Twitter profiles, this design has gone viral amongst 3D printing enthusiasts in the same way as a viral video or advertising campaign, being driven from the bottom-up without any obvious explanation. While some of the most popular objects on Thingiverse share links with other aspects of

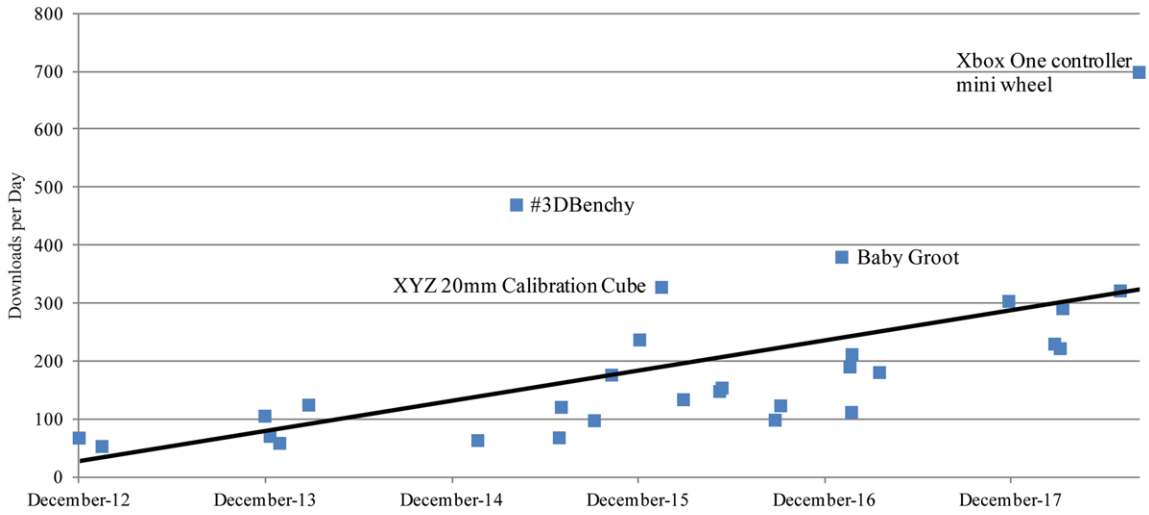
Figure 3. Conversion of downloads to makes on Thingiverse for the objects in Table 1



popular culture, for example 'Baby Groot' is based on the character Groot from the popular *Guardians of the Galaxy* films, the popularity and potential viral nature of other objects cannot be so easily explained. For example, the 'Venus Box' is a small opening container that, while featuring a novel opening mechanism, provides no significant benefit over any other design that can either be 3D printed or purchased cheaply in a store. Yet with over one hundred thousand downloads in two years, the design is clearly of value to the 3D printing community. The second most downloaded file, the 'XYZ 20mm Calibration Cube' is also an interesting case, being a simple cube similar to a game die that can be printed to test the calibration of a printer. There is nothing remarkable about the design, however, Makers frequently download and share photographs of this basic object, escalating it towards viral status. The hypothesis is that as designs such as these continue to be downloaded and made, the objects takes on lives of their own beyond the control of the original designer, becoming a part of 3D printing popular culture.

Another important metric to analyze in relation to viral objects is the number of downloads per day an object receives. Viral trends may vanish as quickly as they appear, and by averaging the number of downloads recorded in Table 1 by the number of days the design has been on Thingiverse, a new understanding about potential viral objects can be observed in Figure 4. While #3DBenchy has averaged 469 downloads per day since the 9th April 2015, at the time of writing the 'Xbox One controller mini wheel' has displayed viral behavior on social media and 3D printing news websites, and is averaging 698 downloads per day only two weeks after it was launched on Thingiverse. This initial hype may eventually slow down; however, the rapid spread of the design amongst the 3D printing community is viral in nature and interwoven with the popularity of video gaming as both a recreational and professional pastime (Beck & Wade, 2004). Many of the other objects in Table 1 may have shared a similar viral launch but have averaged out over months and years. Significantly, the trend line of Figure 4 shows an increasing likelihood for newly designed objects to be downloaded in higher numbers than older objects which were released when Thingiverse was a smaller community. This is interwoven with the spread of social media and a cultural shift towards sharing as the default response of Makers (Anderson, 2012).

Figure 4. Downloads per day for the objects in Table 1 graphed against their upload date



Platforms like Thingiverse have only recently begun to be studied in such depth, and as 3D printing growth continues, ongoing research is needed to better understand the new relationships people are forming with objects, which may rapidly spread through non-traditional means due to their digital nature. The appearance of viral objects, whether they appear viral for a fleeting moment, or amass a viral quantity of downloads and makes like #3DBenchy, will only continue as more 3D printers make their way into homes, and membership to 3D printing platforms like Thingiverse grow at exponential rates. The concern with this trend is the high production of waste as viral objects, downloaded for free, quickly become obsolete or unfashionable. The low cost of common ABS and PLA filaments for 3D printing mean that objects like #3DBenchy cost a matter of cents to print, making them easily discarded despite the recyclability of ABS and ability for PLA to biodegrade. While recycling systems such as the *Filabot* (www.filabot.com) allow people to shred 3D prints and recycle them into new 3D printing filament, such systems have not seen the same growth and investment as 3D printing, and most prints become waste after their use. 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, and new solutions are necessary as the viral nature of 3D printable objects expands in the future.

The 3D Selfie

The combination of both a digital and physical component to 3D printing is also seeing more unexpected trends from the digital world begin to take physical form. In 2013 the 'selfie' was the Oxford Dictionaries' "word of the year" ("Word of the Year 2013," 2013) and it is a "key trend in the visual Web, assisted by new technological tools and services like Flickr, Pinterest, and Instagram that allow people to better express themselves visually" (Souza et al., 2015, p. 222). However, the selfie, which has been constrained by the flat interfaces social media is interacted with, is a two-dimensional photograph typically captured on a mobile phone, and individuals use filters and various photographic tricks to show "the world one's subjective self-image" (Souza et al., 2015, p. 222). With recent mobile phones such as Apple's 'iPhone X' featuring 3D facial recognition and Sony's 'Xperia XZ Premium' having native 3D scanning capabilities, the selfie is shifting to three dimensions where the full geometric detail of a face or body is captured in raw detail, no longer framed through the camera lens. This is fuelled by growth in dedicated 3D scanning technologies (Halterman, 2014), with 3D scanning being used in an increasing variety of industries including dental (Javaid, Haleem, & Kumar, 2018), orthotics (Telfer & Woodburn, 2010), heritage preservation (Wachowiak & Karas, 2009) and fashion (Gill, 2015).

3D scanners are essentially the reverse process of 3D printing; they digitize an artifact from the physical world using digital photogrammetry or laser technologies to ascertain the dimensional details of the object, resulting in a 3D computer model. Figure 5 shows an example of a facial scan captured in approximately thirty seconds with a handheld 3D scanner, with both geometry and color information recorded simultaneously. Such data can be directly 3D printed in full color (with access to high-end 3D printers), or printed on a basic desktop FFF machine to create a miniature, or even to create molds for vacuum forming or other purposes as shown in Figure 6. The combination of increasing accessibility and awareness of such technology is seeing the rise of the "3D selfie" (Dhar, 2015; Zannes, 2016), a term recently surfacing in the mainstream media but not yet part of academic discourse. Numerous companies offer 3D selfie services and technologies to scan people's faces or bodies to be used as wedding cake toppers, gifts and mementos of important life events. This has become particularly popular at events like Comic-Con where attendees can have their faces 3D scanned and transposed onto their favorite comic

Figure 5. A full-color 3D selfie of one of the authors captured using a handheld 3D scanner

Figure 6. 3D printed face from 3D scan data used as vacuum forming molds

book character, which can then be 3D printed in full color, or even have their full body 3D scanned while wearing costume and have a mini replica 3D printed (Rives, 2014). Disney has also trialed such a process for custom Star Wars figurines (Molitch-Hou, 2014) and Disney princesses (Izzo, 2012).

At the time of writing, a search on Instagram for "#3dselfie" reveals nearly 10,000 photos, while a free web-based tool called '3D Face Reconstruction from a Single Image' (http://cvl-demos.cs.nott.ac.uk/vrn/), by researchers at the University of Nottingham, has had 896,148 photographs of faces (2D selfies) uploaded and converted into free 3D models since launching in September 2017 (Jackson, Bulat, Argyriou, & Tzimiropoulos, 2017). Compared to the 3D files collated in Figure 1, this number of 3D selfies on a research website is significant, being close to the total number of files on Thingiverse which has been available since 2008. While the files created on the '3D Face Reconstruction from a Single Image' website largely remain digital rather than all being 3D printed, their high volume reflects research findings into the links between selfies and narcissism, with narcissistic behavior perpetuated and reinforced by a selfie culture (Halpern, Valenzuela, & Katz, 2016; Sorokowski et al., 2015). Should this trend continue into the physical world in a substantial way, new psychological concerns may arise alongside the concerns over material waste mentioned in the previous section.

While the 3D selfie is only a newly emerging process and mobile phone technology requires further development to accurately capture 3D geometry suitable for 3D printing, the ability for a digital trend to now shift into the physical world through 3D printing requires new research, particularly as academics question the privacy and ethical issues associated with the digital 3D scan data (Bindahman, Zakaria, & Zakaria, 2012). Tools such as the 2D to 3D software developed at the University of Nottingham already exhibit this privacy concern, with the home page of the website featuring 3D models of former US president Barrack Obama, as well as renowned scientists Marie Curie and Alan Turing who have been deceased for many decades. While these 3D reconstructions are not as accurate as a direct 3D scan, as software improves through machine learning and artificial intelligence, it is possible that such reconstructions will be highly accurate, particularly as more than a single photograph is combined into the equation to provide more details about an individual's facial and body geometry. With well-known figures like Barrack Obama having countless photos in mainstream media, and many people having personal photos on multiple social media platforms, it will be possible to reconstruct a 3D model of just about anyone, raising questions over who owns this 3D digital data? Who has the right to 3D print it and distribute it? Who has the right to distort the data or remix it? Similar questions have been debated in the 2D digital world, and must now be considered as the trends shift to the physical world. Further ethical issues may arise as new 3D filters or Photoshop-style tools allow individuals to modify their 3D scans and 3D prints in the future, potentially exacerbating body image issues and narcissistic tendencies observed in the digital world.

LESSONS AND FUTURE RESEARCH DIRECTIONS

The topic of 3D printing and popular culture is extremely broad, and this research has necessarily been limited in scope to focus on trends that will be disruptive now and in the near future, particularly those that have not been well documented in academic or popular discourse. In recent years many trends from popular culture have converged with 3D printing technology and been featured in mainstream media, for example:

- A 3D printed Iron Man-inspired prosthetic arm presented to a seven year old boy by Robert Downey Jr. (Vincent, 2015).
- 3D printed guns, which at the time of writing have been a legal battle in the United States of America, led by a company designing downloadable gun files called Defense Distributed (Prasad, 2018).
- Popular children's toy 'My Little Pony' goes digital through a partnership with 3D printing bureau Shapeways, allowing fans to legally access the files owned by Hasbro, modify them, upload them back to the Shapeways online store, and earn a royalty off all sales (Duann, 2014).
- 3D printing is increasingly featured in the Guinness Book of World Records, including the recent achievement of the "longest 3D printed non-assembled piece" at 37.7 meters (B. Jackson, 2018).
- 3D printed sporting equipment is increasingly used at the elite level, for example Chinese speed skater Daijing Wu broke the 500m world record and won gold at the 2018 Winter Olympics wearing gloves featuring 3D printed titanium tips (Scott, 2018).

These examples illustrate the expansive appeal of 3D printing within a range of markets, with defining characteristics of these stories being the more direct, personalized relationship with the end consumer, and the shift in how physical products are produced and consumed at extremely low, or even singular, volumes. At the micro level of each individual user, 3D printing is empowering and transforming the relationships people have with products. At the macro socio-cultural level, 3D printing is disruptive to traditional business models and industries, and requires new discourse within the context of popular culture.

For decades academics have attempted to define popular culture, and a review of the literature suggests that no matter the details, there is a coupling between popular culture, the production of goods, and consumption (Danesi, 2005; Parker, 2011; Storey, 2015). 3D printing challenges how people consume physical goods, as well as how they are produced. While the technical aspects of 3D printing continue to be well documented in journals such as *Additive Manufacturing*, *Rapid Prototyping Journal* and *Progress in Additive Manufacturing*, the effects on popular culture are less documented within academic literature, sporadically dispersed within a variety of traditional and non-traditional publications. Perhaps this is a symptom of popular culture being driven by bottom-up processes which take time to reveal themselves, or the fact that "the only constant in pop culture is, in fact, constant change. With few exceptions, most pop culture products and styles come and go quickly" (Danesi, 2005, p. 1452). While popular culture may be fickle, 3D printing has percolated over recent years within a culture that is highly connected, open, and increasingly catering to the needs of the individual. New research is needed as 3D printing growth continues, with an increasing number of people engaging with online 3D printing communities (Özkil, 2017) and novel systems catering to those without design training simplifying the production of 3D files suitable for 3D printing.

CONCLUSION

3D printing is an exciting technology that, while used by designers and engineers for several decades as a prototyping tool, has only recently emerged within the broader community due to reducing hardware costs and increasing performance of desktop machines. The rapid growth brings with it new interactions between people online, and new relationships between people and objects which have both a physical and digital presence. This is disrupting the mass-production paradigm that has described the physical

world since the first industrial revolution, and by extension, the existing definitions and understanding of popular culture which has its roots in the mass production of goods for consumption. A major shift enabled by 3D printing technology is the ability for consumers to also produce their own goods, accessing vast online communities with millions of files available for download and 3D printing. This has given rise to the term 'prosumer,' representing the ability for people to manufacture their own goods without the reliance on large manufacturers. While many prosumers lack the design skills necessary to develop a product themselves, increasingly accessible software and an open-source ethos encourages 3D files to be edited, remixed, personalized and shared online, similar to the trends observed as music and video sharing shifted to the digital world earlier in the twenty-first century.

The research in this chapter has focused on trends which are newly surfacing as phenomena formerly constrained to the bits of the digital world are given form through 3D printing. 3D files are easily distributed across multiple platforms, with new data collected in this chapter showing popular files can be downloaded nearly 700 times per day when they are uploaded to the most popular 3D printing file website Thingiverse. Sustained downloading and the sharing of 'makes' of a design can see it reach viral status, spreading through the physical world as Makers continue to perpetuate the cycle of downloading and making. This has been described as the 'viral object,' and those recorded in this study will be tracked in the future to build greater understanding about this phenomenon. Similarly, the social media phenomena of selfies appears to be shifting to the physical world enabled by more accessible and affordable 3D scanning technologies, new software enhanced with artificial intelligence, as well as new technologies being embedded in mobile phones. The so-called '3D selfie' provides new entrepreneurial opportunities and the ability to capture significant events in a new way, but also raises new concerns over privacy and potential emotional and psychological effects of being represented in three dimensions rather than through the careful framing of a camera lens and application of filters. Ongoing research into the rapidly changing relationships between people and digital and physical products needs to be conducted in order to prepare for potential future challenges, and build upon the existing discourse of popular culture now shifting through the fourth industrial revolution.

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KEY TERMS AND DEFINITIONS

3D Printing (Additive Manufacturing): A digital fabrication technology that allows the production of an object by adding material layer-by-layer in three dimensions.

3D Selfie: Similar to the selfie phenomena, this is an emerging trend using 3D scanning technology, or software that converts one or more 2D photographs into a 3D model, to capture a person's face or full body as a 3D file which can then be 3D printed.

Computer-Aided Design: The use of computer systems to assist in the creation, modification, analysis, or optimization of a design in 2D or 3D.

Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF): The most common form of extrusion-based 3D printing technology that works similar to a hot glue gun; plastic filament is fed through a heating element, where it softens and is extruded through a small nozzle, which can move in 3D space to deposit the plastic layer-by-layer as it builds up an object.

Maker: A maker is part of modern do-it-yourself (DIY) culture, utilizing digital software and hardware as tools for making and hacking, closely intertwined with open source.

Open Source: Originally related to software, the term is increasingly related to hardware (open design), and is a principle whereby all aspects of a product or service are made freely available to the public for use and modification.

Prosumer: Empowered by digital fabrication technologies like 3D printing, people who are able to both *pro*-duce and con-*sume* products themselves are described as *prosumers*.

Viral Object: Similar to viral videos and viral media campaigns, a viral object extends this concept into the physical world through 3D printing, being first spread rapidly through online file sharing communities, then turned into physical objects in their thousands despite each being made in a different location, by a different machine.