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Social Practices of 3D Printing

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Abstract

This paper considers the social practices of 3D printing by comparing consumer perspectives and practices with legal scholarship on intellectual property regimes. The paper draws on data gained through a mixed-methods approach involving participant observation, focus groups, and social network analysis of 3D printing file-sharing practices. It finds that while consumers display a level of naivety about their 3D printing rights and responsibilities as individuals, they possess a latent understanding about broader digital economies that guide their practices. We suggest that the social practices associated with 3D printing function through communication networks to decentralise manufacture and reconfigure legal capacities for regulation. The paper concludes by introducing nascent paths forward for policy frames across industry, government and consumer concern to address the opportunities and challenges of 3D printing?s evolving interface with society.

Introduction

3D printing has existed for a number of decades as specialist and experimental projects in manufacturing research. Originally designed as a rapid prototyping technology, it has come to develop other unique qualities that make it relevant outside of a manufacturing environment. The technology is scalable, distributed, and innovative, and many models easily connect to networked computer services to access printable files. These attributes mean that educational institutions and everyday citizens are finding it possible ? if still somewhat difficult ? to own and operate 3D printers in domestic or educational settings. A wealth of corporate and user-generated online and offline resources that individuals consult to operate their printers means that 3D printing is emerging as a broad set of social practices that build on the technologies of additive manufacturing. Examples include various types of tinkering, small business, personal craft, DIY, and hobbyist activities.

These 3D printing cultures are enabled by extensive online sharing of files and information that situate consumer knowledge about 3D printing in the context of the current online discourses involved in the evolutions of rights, responsibilities, and regulations. In other words, the fact that these technologies are able to produce and distribute designs around the world means that 3D printing technologies are implicated in the complexities of global intellectual property regimes (IPR), and, importantly, many end users only seem to be marginally aware of what impact the relevant laws, treaties, and policies might have. This, understandably, opens the space for both na?ve breaches of intellectual property law; but also there is the possibility of a chilling effect in users who are wary of engaging with 3D printing due to a perception of potential legal issues.

Citizens are aware of 3D printing as cutting-edge technology. Current developments in 3D printing exists within widespread rhetoric around a coming 3D printing ?revolution? that promises social transformation, and which has been attested to by even relatively conservative publications such as The Economist (?A Third Industrial Revolution?, 2012). This rhetoric is being spouted without providing evidence towards how the revolution is being enacted, and as a result, citizens have a higher degree of expectation about the capacity for 3D printing to solve problems in their own lives. Questions about how users are applying the technology in their social lives (and vice versa), or how different intellectual property regimes are responding to these social practices, and how these intersections will shape trajectories of digital cultures, economies, and citizenship in a networked society are often left unanswered. Citizens themselves are not necessarily sure about what it is they ?know? or ?don?t know?.

This research paper begins to provide detail on this gap in citizen knowledge by drawing on empirical data gathered from participant observation in open educational workshops on 3D printing, focus groups of Australian consumers, and a Social Network Analysis (SNA) wherein we mapped what is currently the largest online 3D printing file repository: ?Thingiverse?. From this, we identified the various uses of 3D printed files shared online among extant 3D printing communities. From this data, we suggest that the social practices associated with 3D printing function through communication networks to decentralise manufacture and reconfigure socio-political power and legal capacities for regulation.

The paper locates our empirical data on consumer perspectives and practices within relevant regulations. Specifically, those regulations relevant to 3D printing based on ?law in context? approach of recent legal scholarship grappling with how 3D printing intersects with copyright, trademark, design, and liability law. Although the study of law is necessary, it is not sufficient to understand evolving user experience. Internet intermediaries that mediate file sharing and modification, industry application of current IPR via automated measures, and the cultures that surround the designing, sharing and printing of goods all affect the future trajectories of 3D printing?s place in society. The paper concludes by introducing paths forward for policy frames across industry, government and consumer concern.

Additively Manufacturing the Social Context of 3D Printing

A key analytical move which we make in order to address 3D printing and its cultures is to separate out the technology (additive manufacturing) from the culture (3D printing) to better describe and explain cultural and social uses of the technology. Our claim is that 3D printing is the social practice that sits on top of additive manufacturing technology which we can address through a brief history of the techno-societal interface. We observe three phases of 3D printing culture emerging, developing centralised, decentralised, and distributed behaviours over time. Each new phase *adds to*, rather than replaces, the sum total of 3D printing culture, such that the phase that is currently emerging ? the distributed practice ? is operating in parallel with centralised and decentralised modes. Note that these phases inform and bleed into each other, with peer-to-peer practices being taken up by institutions, while at the same time practices created through R&D are being used in community hobbyist workshops.

From a technical perspective, the patented inventions of Charles Hall (1986 [10]) and Scott Crump (1992 [11]) ? who respectively went on to found the 3D Systems and Stratasys ? are often credited for kick-starting 3D printing practices. We suggest that these inventions, along with the continuing stream of technical innovations in 3D printing, interface with and evolve within social contexts that can be categorised in three phases. The first phase involved 3D printing becoming ?available?, reflecting economies of pre-production including rapid prototyping of one-off models as well as functional analysis and testing (Kellock 1989 [12], Pham and Gault 1998 [13], Wood 1990 [14]).

The second phase of ?utility? decentralised manufacture from in-house pre-production to production houses that shifted supply chain logics and provided new utility for industry (Birtchnell, B?hme, & Gorkin, 2016 [15]; Krogmann, 2012 [16]). This phase also included material and process advances that enabled additively manufactured objects to withstand stress and strain or be designed with unique geometries or aesthetics that added value for products where customisation and complex geometries trumped economies of scale (Bak 2003 [17]; Hopkinson, Hague, and Dickens 2006 [18]). Examples of the decentralised production include aerospace and military applications that reduce weight through 3D printed designed parts and customised medical fittings, such as hearing aids.

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Figure 1: Social phases of 3D printing, coloured borders denote organisations

Phases	Availability	Utility	Practicality
model	centralised	decentralised	distributed
economy	Pre-production	production	Peer-production

The third phase we identify is still emerging but already speaks to a wider ?practicality? of 3D printing practices. It is defined through a more fully distributed network of 3D printers that rely on aspects of peer-production. This phase specifically addresses independent users coming together outside of the industry to share, learn and act upon 3D printing. Industry consultants Wohlers and Associates, for example, suggest that while 86% of 3D printing revenues came from industrial applications, 92% of the printers sold were for consumer purposes (2015 [20]). This shift to consumer adoption shows how the uses of 3D printing are distributing beyond industrial use cases and capitalist economies. Moilanen and Vad?n (2013 [21]) explain this trend through the increasingly inexpensive open source and mass-market 3D printers targeted towards hobbyists and enthusiasts under the general label of ?makers?. Chris Anderson (2012 [22]) explains the cultural and economic cache of ?makers? through the ability to use digital networks for practices of open design that combine with novel small scale manufacture technologies. From this frame, new forms of entrepreneurialism and innovation extend economic growth online in highly distributed niches. Apart from economics, such practices are important in the cultivation of self-identity and culture, both locally and worldwide (Luckman, 2015 [23]). Schrock (2014 [24]) describes the physical spaces where these practices blossom as hacker-maker spaces (HMS) that are made up of community-maintained workshops that allow individual tinkering, social learning, and collaboration on creative-technical projects. According to work by Kostakis et al. (2014 [25]) HMS spaces are growing at an exceptional rate, from 40 globally in 2007 to around 1000 by 2013. The forms of sharing and production enabled by 3D printing within HMS clearly diverge from the organisational hierarchies seen in the first phase and the price markets that enabled the second.

Specifically, much of the digital maker economy relates to and in many aspects relies upon what Benkler (2002 [26]; 2006 [26]) describes as commons-based peer-production. This involves the re-use of others? contributions with minimal restrictions on that use. From the perspective of a commons-based sharing economy and culture, IPR raise the cost of interaction or restrict re-using information, while also limiting the creative uses of the technology, and consequentially decreasing innovation in the field. Benkler?s work draws from observation of open source software communities and a context of ubiquitous low-cost processing, storage, and networked connectivity that connects individuals to create and exchange information and culture in patterns of sharing and reciprocity (Benkler 2006:463 [26]). 3D printing as a distributed social practice also relies on low barriers to networked connectivity and exchange for both design and cultural content. Thus one of the policy challenges of 3D printing is how to facilitate education, innovation, and governance systems that make use of the large-scale, widely distributed creativity in online settings within incumbent IPRs that apply the logic of (product) scarcity instead of (information) abundance. How innovation and governance concerns are perceived by everyday ?consumers? interested in 3D printing is where this article now shifts.

Research Design

To explore 3D printing as a social practice, we engaged context appropriate methods across multiple sites (Yin, 2008 [27], 2011 [28]), in order to build a collective case study (Stake, 2000, p. 437 [29]). This included expert interviews, participant observation at 3D printing workshops and trade shows, focus groups of individuals interested in but novices to 3D printing, and a social network analysis of data scraped from the largest online 3D printing file-sharing intermediary, the Thingiverse website. The full methodological outline of our project has been detailed previously.

Our focus group participants were recruited from clusters of city libraries and businesses with 3D printing facilities, services, or classes in Melbourne, Australia. The cohort of participants was stratified according to self-reported 3D printing experience to ensure some level of homogeneity within each group. Focus groups allowed us to consider how normative beliefs of 3D printing as a social practice are communally produced (Smithson, 2000 [30]). Our limited sample does not represent the Australian public at large, but the knowledge gained is indicative of demographically diverse consumers that wish to embark on 3D printing use.

The web-scrape and SNA enabled us to determine empirical patterns and cultural trends via hundreds of thousands of objects that people have uploaded to print. Through Python scripts run on the Australian National eResearch Collaboration Tools and Resources (NeCTAR) cloud servers, we obtained individualised metadata from all publicly accessible items (355,867) on the Thingiverse website. We then were able to employ descriptive statistical and social network analyses on the scraped dataset to obtain insights from real-world data about what users are actually printing and how they?re managing the visibility and dissemination of their work (for detail on these methods see Author(s)). We leveraged the user created ?tags? associated with objects to discern meaning and relations in ways that allowed us to map the relevance of certain tags to others and aggregate themes and their links in different types of 3D printing practice. This method allowed insight to a number of limited categories of use that were not apparent during our qualitative phase and allowed novel, data-based perspectives on the use of 3D printing independent but complementary to other research approaches. By addressing socially-sorted data related to 3D printing, we were able to develop an understanding of different types of practice, and different categories of interest for users of 3D printing, which are indicative of likely uses in the future for Australian 3D printer users.

Consumer Perspectives & Realities of 3D Printing Practices

A significant portion of our project involved qualitative research methods; specifically, interviews, participant observation of workshops and trade shows, and focus groups. Data from these events brought to light a lack of centralised systems for managing accountability in terms of the rights and responsibilities that come with 3D printing for end users. In short, the networked structure of even fairly simple household 3D printer setups involve complex and hidden supply chains, and the technology natively lacks any structure of accountability for either legal or insurance purposes ? a concern that is amplified in educational settings. We also found that consumers tended to approach 3D printing with an apparent naivety regarding their own rights and responsibilities for managing the sharing and printing of designs while possessing scepticism about protections to be found online. These themes are summarised below through elements that emerged most strongly and consistently across research sites and methods, and then by situating these insights in relation to practices of tagging files on the Thingiverse repository.

Decentralised Control

The data suggesting an inbuilt lack of centralised accountability for the rights and responsibilities that came with 3D printing presented a classic ?wicked problem? (Rittel & Webber, 1973 [31]), defined through from complex distributed interdependencies across social and technological concerns. For instance, attempts to centrally regulate what is printed that are reliant on restrictive censorship regimes or other negative-use measures alternately work against the interests of users, hardware manufacturers, online intermediaries or the affordances of specific digital technologies themselves.

The manufacturers we spoke did not want to implement restrictions on their own hardware, as limitations regarding what content could or could not be printed (beyond the technical limitations of individual types of 3D printer) were seen to be undesirable restrictions on consumers. Meanwhile, online intermediaries are loathe to introduce new regimes that police content their users upload, pointing to the historically successful safe harbour laws that have allowed freedom of expression (and commerce) on the internet to flourish. Finally, if both manufacturers and intermediaries are not the choke points for restricting prints, deep packet inspection of users? uploading and downloading habits present an alternative, but presents a costly option both technically and politically. Deep packet inspection has the further limitation that it can be defeated by publicly-available encryption technologies such as the Tor Network or the BitTorrent protocols, which distribute the publication of files and efficiently obfuscate origins and recipients amongst other network traffic. While some expert respondents introduced the idea of individual licensing for the ability to print (like a fishing or driving licence), we could find no evidence of any governments, manufacturers, intermediaries, or consumers interested in this pathway, as it was seen to stifle capacities for innovation and freedom of expression without providing useful protections against nefarious uses of printers.

Potential alternatives to broad restrictive powers that were suggested to by respondents include increased transparency. In public and educational settings, recording who prints what may create a public forum for accountability that can reduce risk. Calls for transparency also find utility through using standards to reduce risk. Making standards openly known, and encouraging them to be openly arrived at, can mediate some quality issues from an otherwise distributed printing practices that decentralise liability.

Sharing 3D designs

The qualitative data suggested an apparent naivety from those learning about 3D printing regarding their rights and responsibilities for managing the sharing and printing of designs. That being said there was wide consensus with regard to the normative and practical imperative to share designs with both friends and strangers across our respondents. However, the ethic of sharing designs was tempered by a caveat that as the complexity of designs increased, so too should intellectual property protections on them. Interestingly, the way that users approached specific IPR rules tended to be contradictory. Users largely believed that the value of 3D-printable objects came through the ability for people to collectively share designs, modify these designs, then re-share them to the community. Yet this was paralleled with a fatalist assumption that once something is put online, fully controlling its distribution is impossible, and that this was undesirable. Thus users both saw immense collective value in the networks and services that distributed printable content for negligible cost, but at the same time were highly reluctant to commit to sharing materials into this domain.

A second set of observations came through discussion on safety and liability. All focus groups and most interviewees tended to come to a consensus around users bearing the brunt of safety risks for sharing designs outside of market mechanisms. This was seen to be the case in almost every instance that research participants were questioned on, whether as a pessimistic expectation that ?big business always wins in court? or a ?responsibilisation? approach that end users need to take account of their own safety in these situations. The common metaphor used by participants to explain their thinking was to compare safety and liability to concerns for 3D printing to the responsible use of other power tools in DIY settings, such as bandsaws or drills. Experts commented that outside consumer protection regimes, which usually require business transactions to come into effect, negligence law would protect consumers of harms. However, consumer knowledge of the ?user beware? attitude was explained to researchers through both practical and normative assumptions. Practically, respondents thought the ability to enter into legal proceedings and see them through required access to large amounts of capital. Normatively, the respondents understood both the technology and the practices that surrounded it as experimental and explorative, and not aligned to market norms. Risk conceptualisation, assessment, and mitigation were topics that respondents conceptualised in terms outside of normal law-based social safety nets.

Overall focus group data suggested respondents? na?ve approach to the law did not cancel out their own subconscious knowledge of experience-based understandings of the limits of digital production practices. Our initial enquiries thus identified a need to inform both how the law in practice applies to 3D printing, and how practical user experiences online might differ from that law in practice template.

Interestingly, ownership was another concept that was tested by the discursive social interactions of the focus groups. For instance, many individuals present at the 3D printing workshop as well as focus group respondents were fearful of how large corporations would treat their intellectual property online, regardless of current IPR. One participant summed up their fear when stating,

you can print it, but it doesn?t say anything about where you got it [...] that?s something that?s very easy to take advantage [of] by big companies [...] you can see people have a passion for printing, for 3D drawing, but that doesn?t mean that companies are going to respect that...

At the same time, respondents struggled with finding new meaning to ownership in economies of digital abundance. Overall, consumer-participants had a strong preference for sharing under a Creative Commons Share-Alike licensing structure (Creative Commons n.d. [32]), where modifications are allowed as long as credit is given to previous contributors and the license is kept under the same terms. Interestingly, our web scraping dataset suggested this licensing type was most popular, with over 53% of publicly available objects being assigned a similar licence. However, this licence type showed no significant increase in use, measured in downloads, compared to other more restrictive license types (see chart 1). The only intellectual property ?license? that correlated with increased downloads was the abrogation of private intellectual property rights - objects rendered to the public domain.

The general use of Thingiverse objects showed a striking ?long tail? (Anderson, 2012 [22]) pattern that is common with economies of digital abundance, wherein a limited number of objects have a high degree of engagement, while the majority of the database has a vanishing small level of recorded engagement. That is to say that a minority of items on Thingiverse were viewed very frequently, while most were barely viewed at all (mean views: 6038, Std. Dev.: 3801). The ?long tail? was also pronounced for what was downloaded (mean downloads: 264, Std. Dev. 1179).

The SNA of the Thingiverse dataset also suggested the social utility of objects shared online are extremely varied. Our methods mapped social patterns within 3D printing on Thingiverse through how users tagged objects they uploaded, and how these tags related between objects. We found users employed 3D printing for purposes that seemed to include both purposive and aesthetic outputs. While these purposes often referenced the intellectual property of others (mostly through brand identifiers that signify form and fit or aesthetic properties), there were also prominent uses of non-branded (and thus non-infringing) uses for tags given to objects.

Tagging 3D files

Our SNA map of tags gave visual insight to how the relationship between different types of 3D printing practice clump together by identifying related themes through recording incidents of tags being used alongside other tags to label 3Dprinter files. This allows us to infer aggregate practices different to what individual users shared in interviews or focus groups. For instance, we detected a particularly wide array of braille-tagged objects that were not visible through other research methods. To show the largest trends and explicate what certain ?clumps? of tags signified in social practice, we used open coding to create summative categories of use from numerous reoccurring tag connections and suggest the themes users interact with as part of their 3D printing practices (see Table 2).

Table 2: Themes of use in 3D printing on Thingiverse via tag concurrence

Category	Example tags	Apparent common use
Geometric specificities	3D, 2D, cube, Z-Axis, 40mm	Item designed with specific ratios
Representational of subject content	Art, animal, moon, halo, knot, scan	Item?s function is likely representational
Hardware in use	Makerbot replicator, RepRap	Item designed for specific printer
Software in use	Sketchup, blender, TinkerCAD	Item designed using specific software
Date/time	2013, 2014, July, Christmas	Item produced on that date, holiday-specific
Material specificities	ABS, PLA	Item intended to be printed in this material
Representational of use case	Holder, screwdriver, sensor, tensioner, food, wearable	Item is designed as a functional object.
Affective/emotional	Cool, awesome, love	Item evokes subjective evaluation
Brands and IP	Nike, Warhammer, Canon, GoPro, iPhone, Arduino, LEGO, Pok?mon,	Item mirrors the aesthetics of these brands, or adds to or replaces proprietary parts
Subcultural	cookie, robot, baixar	Tag has context to a specific subcultural group that has origins outside 3D printing

Finally, we noted that patterns of re-mixing objects into new objects, which suggested low factors of sequential evolution. Most users remixed objects only once. This can partly be understood through the design of Thingiverse?s interface, which affords a simple but restrictive ?customizer? tool to re-shape objects in specified ways. However, it can also be understood as a function of the use cases employed: from numerous spot checks on remixed items that did not employ the ?customizer? tool, users tended to remix in order to personalise objects rather than evolve their utility or form in a transformative manner. For instance, the modification of mobile phone cases, which was one of the most common practices as measured by our SNA, often added names or personalised designs.

Rights & Responsibilities: Legal Frameworks & Beyond

This section locates the concerns we encountered from consumers and experts in reference to current IPR to express some common points of guidance to emerging wicked problems connected to 3D printing practices. Our findings are provided here mostly in summary and in a non-proscriptive framing, as the mosaic of law, business terms, geographical and jurisdictional issues that users interface with in their 3D printing practices are diverse and sometimes contradictory. Any guidelines must consider that comprehensive knowledge is untenable in this evolving field that must grapple with what decentralisation of responsibility and the individualisation of risk looks like for persons involved with 3D printing practices.

While our research relied on the necessary legal scholarship and case law to a certain extent (Daly, 2016 [33]; Engstrom, 2013 [34]; Holland, 2009 [35]; Lemley, 2015 [36]; Scardamaglia, 2015 [37]; Weinberg, 2016 [38]; Weinberg & Knowledge, 2010 [39]), these approaches are not sufficient to convey an accurate account of user experience online. Internet intermediaries, with their own policies that deflect responsibility on to use (Mendis & Secchi, 2015 [40]; Seng, 2014 [41]), consumer protection agencies that are coming to terms with shifting realities, and the evolving cultures and technologies of sharing objects online (Bogers, Hadar, & Bilberg, 2016 [42]; Moilanen, Daly, Lobato, & Allen, 2015 [43]; Moilanen & Vad?n, 2013 [21]; Schrock, 2014 [24]; S?derberg, 2014 [44]), together create a complex and often contradictory reality that tests and sometime ignores codified policy and protection.

Weighing these factors, we found that across jurisdictions and services online, risk is often directed towards individual users of 3D printed goods. That is to say, the protections consumers might be used to through state protection regimes are less certain to apply, or be easily accessible as the complexity of ownership, jurisdiction, publisher, and enforceability of IPR create increased uncertainty of outcomes. For instance, user experience of governance in 3D printing cultures is often served through private threat of legal action, opaque website terms and conditions, or a conglomeration of such concerns as rendered through automated ?takedown? mechanisms tied to the America?s Digital Millennium Copyright Act - regardless of the laws of the user faces in his or her host country. Thus, the below guidelines for 3D printing often take the ?worst case? scenarios of a specific jurisdiction or jurisprudence decision in forming a baseline for response to consumer concerns.

Guiding responsible 3D printing practice

IPR factors into 3D printed goods through various copyright, patent, design, and trademark law. Copyright serves artistic works as they are expressed in some medium - not their ideas or functional objects that users might design and are granted immediately to the author/creator. Legal scholarship from the UK and the USA suggests 3D printing design files will probably be protected under copyright, but design ideas within the file (rather than its actual code) will probably fall outside copyright protection unless the object to be printed is artistic in nature (Copyright, Designs and Patents Act; Simons; Bradshaw et al. in Daly 2016: 26-27 [33]). Note that if artistic works are ?industrially? produced, copyright protections may no longer apply and the design should be registered under design law (see below). Showing how evolving socio-technological practices provide wicked problems for the law, Weinberg (2016 [38]) suggests that 3D scans of objects and people will struggle to meet copyright thresholds due to lack of originality and instead suggests that any governance regimes will require consideration of access. As our respondents intrinsically knew, controlling access to uploaded material is in itself problematic.

Patents also present an avenue for IPR to interface with 3D printing practices. Patents are not for artistic works but are instead meant to protect novel functional inventions that are not obvious. Users that 3D print objects to solve common household problems could technically infringe a patent; even if they are unaware the patent exists. Note that Australia and the US do not have exceptions for individual, personal, or unwitting use of patents, while the UK does have an exception for private, non-commercial purposes. Using others? patents for your own experimentation is allowed in Australia and the UK (Daly 2016: 30 [33]). Although technical infringement of patents in home use may occur, the legal avenues of proving this are at present quite slim. Patent law makes patented designs - by definition - public. The extent these designs are used in domestic inventions or household processes has never been a major prosecutorial concern of rights holders.

Design and trademark law is complex, but will be increasingly germane to 3D printing practices. Like patents, trademarks and (some) designs need to be registered and provide complex rights. Design and Trademarks concern IP that is separate from artistic and inventive function but speaks, respectively, to what makes a product look the way it does and to its origin. The current state of trademarks and design in 3D printing offers incentives for, as Scardamaglia (2015, p. 24 [37]) puts it, the ?expansion of intellectual property laws to further ... restrict the continued use of new and emerging technology?. We believe that the attitude being identified by Scardmaglia is already apparent in the tone of public commentary from some legal firms, particularly in terms of how to protect designs from being copied for 3D printing, even when the practices being outlined in briefs widely found online, in some instances, manifest non-infringing uses.

As an important final consideration in terms of liability, most consumer protection laws are built around financial transactions or the business operations of the party to be held liable, which have the additional role of providing a chain of transitions of ownership. In contrast, it becomes quite onerous to sue for damages if a 3D printed object is defective due to a design that was shared freely rather than paid for. The terms and conditions of websites often make users wave rights concerning safety and liability, even if this touches on concerns of negligence from the designers of 3D printed objects. The extent that online intermediaries can evoke safe harbour for 3D printed goods here is untested.

In this short space, we analysed expert opinion towards relevant issues for 3D printing practices as they are playing out in law and practice. The above commentary is meant to reflect the weakest link for rights and responsibilities that users encounter online, and provide a starting point to understand the decentralisation of power and responsibility in 3D printing. What future practice looks like is dependent on a mosaic of intersecting claims of regulation, technology, jurisprudence, and changing social norms and cultural practices.

Conclusion

How 3D printing will reconfigure socio-political power and the capacity of regulation in terms of social communications practices that enable decentralised manufacturing is still complex and contradictory. If the general idea of promoting the progression of science and useful arts through granting exclusionary rights for a finite time to authors/inventors is to be upheld in a digitally networked age of mass self-manufacture, the tenets of its execution must adapt.

Balancing adaptations across industry, government and consumer concerns will require recognising the necessary precedents and pervasive expansion of IPR in digital communications. However, this frame is not sufficient to capture emerging 3D printing practices for the digital economies of the present and future. Evolving cultural practices, functioning business models and greater penetration of technologies will also play a role in determining pathways forward. One pathway suggests incumbent rights holders will hope to target nodes that spread their IP or enable its infringement, rather than the users who consume and reconfigure it (Holland, 2009 [35]). Focussing on such contributory infringement, or ?secondary infringements? will draw in many new stakeholders to the debate, and expose the various generative and non-infringing uses that 3D printing practices have in society. However, this will also make visible the limitations of intellectual property in the contexts of decentralised control.

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