3D Printing: Civic Practices and Regulatory Challenges

Melbourne Networked Society Institute Research Paper 2-2016

This report is based on research funded through the Melbourne Networked Society Institute to develop empirical findings on the social meaning that surrounds 3D printing.

Acknowledgements

The authors would like to thank all of the interviewees as well as acknowledge the cooperation and contributions of Vivek Ashok Chandrika, Angela Daly, Michael Xiantian Luo, Bernard Meade, Paul Mignone, and Sanjeewani Pathirage in making this project possible.

Citation


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ISBN

978 0 7340 5268 1
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1 EXECUTIVE SUMMARY

3D printing creates new social and economic policy puzzles that Australians urgently need foresight into. This report approaches these puzzles by acknowledging 3D printing as a social practice including experimentation and learning — rather than a mere manufacturing process focussed on problem/solution dynamics. 3D printing involves more than the action of creating a physical object from a three-dimensional digital model by means of additive manufacture. It is an innovative and interactive social practice of learning, sharing, and economy.

This report forecasts key strategic issues for practitioners in industry, government, and education to invest in to position Australia at the forefront future innovations and evolutions of 3D printing practice. We hope to encourage collaborative civic and economic innovations that ensure the imagined 3D printing ‘revolution’ can be transformed into wide reaching material benefits.

Our findings draw from extensive interdisciplinary research that saw the research team analyse data from collaborative learning/maker-spaces; interviews with industry leaders, academics and social commentators; and visualizations/maps of the evolving use of 3D printed objects made through social network analysis (SNA) of the world’s largest public 3D Printed object design repository.

The key empirical findings of our research suggest:

• There are incoherent visions between public expectations for cultural and instrumental uses of 3D printing, which presents a primary challenge to educating new communities of practice. This is particularly pronounced in some institutional settings, such as universities, as they attempt to foster ‘maker’ cultures that are primarily found in more informal and democratic settings.

• There is an inbuilt lack of centralised accountability for the decentralised rights and responsibilities that come with 3D printing. The emerging practices are very difficult to regulate through restrictive censorship regimes of what can be printed. Hardware manufacturers do not want restrictions built into their devices. Online operators do not want new responsibilities for user uploads or downloads.
• There are methodological opportunities for the continued study of 3D printing concerning finding new ways to recognise the important role digital objects, their metadata, and the networks they are shared on contribute to social outcomes. New research on cultures of 3D printing will need to incorporate the ways meaning exists with and through a web of object-oriented connections between digital files, their metadata and how machine-organised ‘visibilities’ make these useful for human users.

This evidence suggests that opportunities for 3D printing in Australia will need to consider how to engage the following pathways to turn 3D printing promises into practice:

**Educational Pathways for rifts in communities and institutions**

To respond to rifts in educational cultures and practices, we consider options that centre on the development of mixed skills and reciprocation norms within teaching and learning provide options for 3D printing teaching and learning. We suggest consideration of the importance of establishing community and peer-to-peer styles of learning within structured 3D printing curriculum.

**Accountability Pathways within decentralised economies**

To respond to difficulties in centralising control of 3D prints and practices, we consider accountability through critical making, transparency and market models that are designed to be ‘better than free’.

**Methodological Pathways for researching networked objects**

To respond to the new types of data available in 3D printing practices, and the importance of how this makes social patterns visible to human eyes, we suggest considering methodological innovations that rely on novel digital research methods that include social network analysis of metadata connections shared between 3D printed objects themselves.
2 CONTEXT: THE SOCIAL HISTORY OF 3D PRINTING

The social history of 3D printing is tied to the technical inventions, intellectual property regimes that regulate those inventions, and the emergence of innovative business and peer-education models that reconfigure the ways invention and regulation shape practice and communities. This section’s overview of the social history of 3D printing gives the context necessary to position to how the experts and learners we have interviewed comprehend 3D printing. Specifically, it will show how the industry and cultures of 3D printing practices have grown, and will evolve in future, up to the point of the current industrial and communal landscape. The chronology of events below is not canonical, but serves as a guide to introduce the key shifts of additive manufacturing processes as they relate to the social practices of 3D printing. Technical shifts of additive manufacturing have followed three phases we identify as availability, utility and finally practicality. These phases mirror 3D printing practices through shifts in economies of pre-production, production, and peer-production.
Centralised Pre-Production
The origin of 3D printing spans back to its uptake in prototyping in what we call the pre-production phase of additive manufacture. Additive manufacturing was first employed to in so-called ‘rapid prototyping’ of one-off models, of great convenience in form, fit and function analysis and testing (Kellock 1989). This phase is directly tied to the invention of ‘stereolithography’ as invented by Charles ‘Chuck’ Hull. Stereolithography was described in its patent as “a system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed” and drawing the object up through “step-wise laminar buildup” of cross-sections (Hull 1986) from a fluid that could be affected to change into a solid in precise geometries. Hull went on to found 3D Systems in 1986 and leveraged his invention to enable rapid prototyping across transportation, health and other industries. As these processes improved, the ability to fabricate models rapidly and cost-effectively met the needs of form, fit and function trials (Wood 1990), as well as industrial designers, architects and engineers at the drawing board stage of bringing products to market (Pham and Gault 1998).

Decentralised Production
Advances in additive manufacturing in terms of printing with metals and other materials enabled a shift to the production phase of 3D printing. Objects able to withstand stress and strain or with unique properties, geometries or aesthetics could be used in part or whole for final end-user products (Bak 2003). Here, another inventor and invention takes some of the credit. The technical processes of Fused Deposition Modelling (FDM) was patented by Scott Crump (1992) as a way to create objects by incorporating a computer controlled “movable dispensing head” with “material which solidifies at a predetermined temperature” to build up the layers of an object in an x-y-z 3D space. Instead of changing the state of a usually plastic-based substrate, FDM meant powdered metals and other novel materials could be fused together in precise geometries. Crump went on to found Stratasys, and utilised his processes for limited product runs in aerospace, automobile and military applications, where customisation and complex geometries trumped economies of scale (Hopkinson, Hague, and Dickens 2006).
These two developments of a technological nature were necessary but were not sufficient to move 3D printing from high-tech research and development into broader society. However, they did enable a shift in practice that moved bespoke (pre)production design from in-house operations to a new modes of manufacture that shifted supply chains and development patterns in niche applications (Krogmann 2012). These pieces created through additive manufacturing were limited to specific industries and remained mostly out of the public eye, in hidden personalised medical-tech devices and deep within airframes. To put this in perspective, while 2011-2014 saw a quadrupling of the additive manufacturing industry to $4.1 Billion US, according to Wohlers and Associates, a leading 3D printing consultancy, these same figures show that 86% of revenues came from industrial, not consumer applications. Adding to the puzzle is that Wohlers and Associates insist that only 8% of 3D printing systems sold are industrial – the rest are desktop-based, consumer-oriented machines. This begs the question: what are people doing with the other 92% of the printers?

**Distributed Peer-Production**

The development that most clearly speaks to 3D printing as a social practice considers the accelerating decentralisation of design and production through peer-production. These public-oriented printers are not designed to fulfil a specific profit-driven economy. This development relied on innovation across the ‘hardware’ of printers and processes, the ‘software’ of object design interfaces and network-enabled sharing, as well as the ‘wetware’ of human interactions towards the design of 3D printing. In terms of hardware, the development of peer-production coincided not with a new manufacturing technology per se. Instead the continuing expiry of additive manufacture patents helped ‘wetware’ configure increasingly inexpensive open source and mass-market 3D printers targeted towards hobbyists and enthusiasts under the general label of ‘makers’ (Moilanen and Vadén 2013).

The cultural importance of makers and making is being leveraged as a new phase in entrepreneurialism and innovation that can extend economic growth past late capitalism. Chris Anderson (2012) explains the social cache of ‘makers’ through combining his thesis of the endless diversity found in the internet’s ‘long tail’ with the effects of practices of open design and new small scale manufacture technologies.
More recently, online makers’ markets like Etsy.com (the fifth most visited marketplace in the world) and Amazon’s copy-cat website ‘Handmade’ drive consumers to individual crafters/artisans/makers. Such practices can be extremely important in the cultivation of self-identity and culture, both locally and worldwide (Luckman, 2015). Offline, the ‘maker’ phenomenon is mainstreaming insofar as even financial institutions are targeting their services towards this newly perceived identity/market. For instance, a 2015 rebranding exercise for Bank of Melbourne entices new customers to identify with the tagline “we are the makers, creators, crafters, doers ... building to break, so we can build again.” (Bank of Melbourne, 2015).

However, makers as described by Anderson are not sustained by new sources of financial capital. So far, the makers of 3D printing enable and are enabled by forms of sharing and production that specifically diverge from organisational hierarchies and markets. Much of the digital maker economy relates to what Benkler (2002; 2006) describes as commons-based peer-production. This involves the re-use of others’ contributions with minimal restrictions on that use – the communal power of wide experimentation of “building to break, so we can build again” The point is that, according to Benkler – among other commentators that acknowledge what is called the gift/sharing economy – intellectual property regimes that raise the cost of re-using...
information limit the creative utilisation of existing information and decrease innovation. Benkler’s evidence is built through an empirical trace of commons-based peer-production in the software industry and applied to more general economies of information sharing across creative-productive industries. The digital-material hybrid of 3D Printing practices offers a new form of productive and creative practice that appears to be taking on the logic of commons-based peer production. Thus one of the policy puzzles of 3D printing is how to construct governance systems that leverage the large-scale, widely distributed creativity in online settings. This is further complicated by incumbent intellectual property regimes based on information-scarcity instead of information abundance.

So far 3D printing companies have engaged the challenge of information-sharing through leveraging decreasing or un-defined intellectual property regimes. For instance, the firm Makerbot Industries struck a nerve in the media and the public via claims of selling printer hardware that was designed to be self-replicable. These self-replicating plans were based from the open source ‘RepRap’ 3D printer blueprint outlined by British academic Adrian Bowyer. The prospect of a printer that could print another printer without being regulated by intellectual property regimes meant that it could be cheaply made by anyone and that its own design evolution was open to experimentation and innovation. Likewise, most consumer level 3D prints are not designed by the person who prints the file, but instead come from communities that populate websites with freely shared objects. These objects are usually shared as small .STL files (although other standards exist, including proprietary formats), often stored in 3D printable object repository websites, such as Thingiverse, and can be easily interpreted by printers. STL files themselves cannot be easily modified (technical note: this is due to STL files representing point clouds often composed several million unconnected points, rather than modifiable polygons), but users regularly upload their 3D models to share with other users. The re-use and re-mix of files represents crucial enabler of 3D printing peer-production; the wheel (or any widget searchable through Google) does not have to be re-invented by each maker, but can be modified by each maker.

Communities of makers do not only exist online and are also found in workshops and open DIY spaces that foster creativity through specific sets of cultural contexts. Schrock (2014) describes these community-maintained workshops that allow individual tinkering, social learning, and collaboration
on creative-technical projects as hacker-maker spaces (HMS). According to Kostakis et al.’s (2014) count, these spaces are growing at an exceptional rate, from 40 globally in 2007 to around 1000 by 2013. Kostakis et al. go on to claim that HMSs create a spectrum of collective communities that value and are driven by “sharing, abundance of resources, intrinsic positive motivation, openness, collaboration, bottom-up innovation, community accountability, autonomy, communal validation, distribution of tasks, and common ownership of the results” as well as outright anti-institutional frames (2014: 5). Channelling these productive, but also disruptive, energies into institutionalised education and market innovations speaks to another challenge of encouraging 3D Printing as practice.

The Empire Builds Back

Yet innovation is moving past hobbyists and community based sharing regimes to more integrated yet limiting models of production and consumption. One example we encountered was Pirate3D, a start-up based in Singapore that models itself after Apple in terms of product design, vertical integration, and ease of use. It offers its customers glass and aluminium printers that come with simple cloud/tablet based design tools within a walled garden of printable objects. At the same time, large tech-sector market players are vying to enter the market. 3D printing insiders suggested that these incumbents would transform the industry through two shifts: further lowering entry points of use and cost, and further increasing available scale of parts manufactured. Two examples of technology incumbents ensuring their importance in 3D Printing’s futures are Hewlett Packard and Microsoft. Both firms plan to do so at the intersection of openness and proprietary.

Hewlett Packard Inc. has a strong 3D printing focus that leverages its 2D printing expertise to build new technical efficiencies and innovations into 3D printers. This is in addition to creating markets that offer precision printing services to consumers via third parties. To help ignite this industry, HP Inc.’s CEO Dion Weisler is making a radical change from its 2D consumer printing business model by opening the market for new types of ‘ink’ for its 3D printers to third parties. Microsoft’s move is to engineer itself into 3D printing at the level of file-type. Next to .DOC, .XLS, and .PPT, files, the Redmond based technology firm hopes to standardise a .3MF file-type that carries information for structure, colour and future extensibility that is currently unavailable in STL, which is currently the most popular file standard. The extent that
.3MF will allow actors to limit the sharing of objects through digital rights management, or more generally follow Microsoft’s demonstrated strategy to embrace, extend, and then extinguish open standards (in what the US department of Justice defined as monopolistic practice) is currently open for debate. Of interest, Microsoft’s coalition of willing hardware manufacturers (including Stratasys, 3D Systems, and HP Inc.) suggests that “code to read or write 3MF is available as open source” while the source code of the standard itself is, currently, available on GitHub (3MF Consortium, 2015).

These brief examples show how the social practices of 3D printing are evolving through the interplay of sharing economies that decentralise design at the expense of strict intellectual property regimes, as well as manufacturers and incumbent technology firms that seek to reorient these flows into proprietary profit streams.

Note that these two poles are not always diametrically opposed. Even Benkler’s canonical example of Free and Open Source Software sharing sees successful hybrid firms like Red Hat, which have learned to market services for the free and open software they share with clients. Red Hat turned annual revenues of over 1.5 Billion USD in 2015 under a business model that acquires closed proprietary platforms and opens them up, charging for customer support, training and enterprise integration. A similar model for 3D printing would also have to account for open creative design. However, some 3D printing firms have moved to close their once open practices. Makerbot presents a well-known example of changing intellectual property expectations when it stopped sharing the design files for its printers even though commons-based peer production practices had, ostensibly, created and refined some of the parts that of the printer.

Explaining the current context that surrounds 3D printing in this section sets the stage to how the experts and learners we have interviewed comprehend the industry and how cultures around 3D printing will expand, evolve and abut the current industrial and communal process of additive manufacturing. Specifically, it allows us to understand the context from which learning practices and cultural expectations of 3D printing are situated. So what comes next?
3 RESEARCH DESIGN

Our inquiries began with the theoretical realisation that 3D printing is a social practice that will present new and unique social and economic policy puzzles for Australian society. The subsequent research was designed to focus on empirical findings that could highlight the challenges that are present in the practice of 3D printing, and provide insight into how to leverage future evolutions of these practices into productive forms. In order to comprehensively study the practices of 3D printing we formed the following three-stage reflexive research design to draw data towards bettering educative, social and research directions for 3D printing practices.

The report draws from extensive interdisciplinary research that saw members of the team embed in collaborative learning/maker-spaces, interview industry leaders and social commentators, and map the evolving uses of and relations between 3D-Printed objects by thousands of users through techniques of social network analysis.

Our methods were employed within three distinct but connected stages of research.

1. Reflexive literature review based on participant observation in an experimental university-sponsored short 3D printing course, followed by mixed qualitative/quantitative survey and interview work to respectively map and explore user practices and educational expectations in 3D printing;

2. Interviewing industry leaders, academics and social commentators based on the above learnings, and embedding within an international 3D printing expo, to gather further participant observation data on industry trends and cultures;

3. Quantitatively mapping the evolving uses of and relations between 3D-Printed objects by thousands of users through advanced techniques of social network analysis to further understand the practice of sharing 3D printed objects, and how technology affords specific patterns of sharing.

The processes of these stages are described in brief below.

The first stage identified existing methods and understandings within prior research. We assessed academic works from engineering, education, design
studies, and social research, as well as materials intended policy creators in library, university, and educational settings. We also identified a number of research projects that had conducted survey-based research into practices of use in other national settings (Moilanen and Vadén (2013), Kostakis, Niaros and Giotitsas (2014). The data-gathering for this prior research was conducted before the significant growth in consumer 3D printers that became available in mid-2014 and focussed on specialized hobbyists and expert practitioners, if not professional engineers, which left room for our own studies. We sorted these materials for their application to the social aspects of 3D printing practices and identified previous research trends which we could align our research with. From these themes and structures, we designed a parallel quantitative/qualitative approach for active research in an educative event that was focused on 3D printing.

Stage one also involved exploratory work during the first University of Melbourne “DigiSmith” 3D printing workshop, with researchers embedded in the workshop engaging participants in informal discussions regarding experiences and expectations as well as a review of relevant literature. This period allowed the researchers to develop the scope and direction of an interview and survey-based inquiry into participant experiences, while also reflexively considering the pedagogical design of this and future programs. Questions to informants regarding the prospective importance of various Australian industry sectors were integrated into the survey in order to map participant expectations about personal 3D printing, and its carry-on effects into the future. A final set of questions were designed to examine normative preferences regarding claims of intellectual property that surround 3D printing. This was followed by a second round of participant observation during the second DigiSmith workshop, followed by semi-structured interviews and follow up surveys with participants. This round of research enabled us to learn about the experiences and motivations of people participating in 3D printing workshops. Our intention was to gain an understanding of the current practices of use, as well as ways of teaching and learning 3D printing, including curriculum choices in terms of content and practice.

The workshop we selected ran two separate short courses on 3D printing. While involvement was open to anyone who expressed interest 3D printing, the groups were limited in size. Attendees were interviewed by conveners to gauge interest and commitment to the course. As a result, the participants we interviewed and surveyed were not representative of the Australian public,
but did present a purposive sample of the evolving sample 3D printing educators and students. Participants of the first workshop included twelve attendees, and allowed us to carry out semi-structured interviews with individual participants (n: 9) over the first three days of the Winter School workshop, while surveys (n: 11) were completed anonymously online on the fourth day of the workshop. Due to the small survey our analysis does not provide statistically significant comparisons to Moilanen and Vadén’s work, however the results still enable us to learn from the experiences and motivations of people participating in 3D printing workshops, especially when set against the previous representative findings.

Embedding in learning practices of new and experienced 3D printers allowed the team to experience and navigate how much of the learning, experimentation and product development of 3D printing is caught between twin traditions of industrial design and countercultural garage-workshops. As 3D printing becomes a more common subject for tertiary and secondary schooling, educators can take lessons from these twin histories. Our findings suggest utilising the productive tensions between classical lecture-discussion-application based models of learning, and problem-based learning and more radical forms of peer-to-peer learning that is common to 3D printing social practices.

Stage two involved targeting key informants across industry and academia, both inside Australia and internationally. Industry insiders from firms including Stratasys, and consultancies such as Wohlers Associates, provided key insights into the direction and goals of the commercial 3D printing business. We also targeted smaller 3D printing startups that are struggling to bring their products – and customer/user experiences – to market. Together, these interviews shed light on the consumer expectations and commercial challenges involved with 3D printing, including issues of accountability and freedom to print and share object designs. Other key industry informants were opportunity sampled from within the international Inside 3D Printing Conference (Melbourne), and offered expertise on education, law, safety, and 3D printing participant cultures. The research team’s own observations of the Inside 3D Printing conference, catalogued through detailed field notes and further participation through public reporting on the goings on, further accentuated our understanding of the cultural space that surrounds the technology, business models, and the various motivations, concerns, and hopes of participants. We were fortunate to be able to schedule many these interviews
in situ at the Inside 3D Printing symposium held on the 26–29 May 2015. These (n: 8) interviews gave us expert testimony on changes and expectations for the technology across many subject areas, while provided an atmosphere and lived experience of the industry. We also targeted specific start up services and companies inside and outside of Australia (n: 2) that offered insights unavailable within the larger corporate understandings of the industry. We concluded this phase of research by seeking out social and academic commentators to help us reflect on the trends, cultures and theoretical constructs we had formed.

Stage three employed statistical and social network analyses on a large dataset that represents the sharing activity of 3D printed objects from the world’s largest 3D printable object repository site, Thingiverse. Doing this allowed us to obtain a perspective, based on real-world data, about what people are actually printing, and how they’re managing the publicity of their files in open access spaces. Applying the methods of Social Network Analysis (SNA) to 3D printing is a novel (and as far as we are aware, unique to our project) way of understanding 3D printing practices through the website Thingiverse. The community of Thingiverse sorts objects through ‘tags’ of meaning that allowed us to create a map showing the relationship between different types of 3D printing practice. We were able to identify themes and clumping behaviours, implying specific focuses between specific groups of users. This method allowed insight to a number of limited categories of use that were not apparent during our interview phase and allowed us to get a novel, data-based perspective on the use of 3D printing independent but complimentary to other research approaches.

The goal of stage three was to map out existing practices of use within the 3D printing community by extracting a large amount of available data from Thingiverse, one of the biggest international 3D printing file repositories. Because the community on this site self-report about their use of 3D printing through a file-tagging system, we were able to extract this data and map it through social network analysis tools to create generalisations about the use and the users of 3D printing. By treating it as roughly representative of current civilian use of 3D printing, we could make estimates regarding how Australians who are interested in 3D printing might begin to engage with the technology.
The method proceeds through several stages:

In conventional SNA, data is first scraped from a database by a script (conventionally written in Python, but both free and commercial applications exist for this as well). In our case, our Python script was programmed to load a range of web pages from Thingiverse, and then assess each webpage for specific predetermined datapoints related to the object. In our case, these were the creator’s name, the creation date, the intellectual property license type, an internal Thingiverse ID number, number of comments, number of views, the number of collections the object was a part of, the number of times people had self-reported a successful print job with the model, the remix information, the tags used, the number of likes, the number of times it had been downloaded. The script was set to run ten times on ten separate virtual machines, in order to ensure data coherency, and we estimated a degree of precision above 99.9% for all available objects.

All data were stored in an SQL database, which was then cleaned. ‘Data cleaning’ is a process where duplicate or corrupted entries are removed, and data is standardized for importing into other applications. In our case, we were aiming to standardise our data so that it could be imported into different graphing applications, in our case Gephi and R. This cleaning process was relatively straightforward. In the case of Gephi, we merely limited the number of variables being imported for each datapoint, so that we could effectively manage the relational data, and limit memory overheads. Because we assessed a number of variables in R, we retained all available variables during our analysis.

After cleaning, our next phase involved the algorithmic sorting and re-sorting the data into different maps of connections, with algorithms changed to highlight different variables or connections, depending on the points we were seeking for analysis. This then moved through a recursive process, where we would visually analyse the different arrangements we were able to create, and then reassess the data under new sorting algorithms. Finally, we created a number of maps that usefully displayed information about the Thingiverse network, and conducted visual analysis on the elements involved.

Combining the three stages together triangulated our perspectives and drove insight to aspects of 3D printing in complimentary ways. Firstly, we obtained a speculative understanding of user behaviour by novices. This understand-
ing was used as a pilot study into the uses of 3D printing by non-experts, the conventions involved in teaching and learning how to use the technology, as well as an idea about what minimum competencies are required in using a 3D printer. Secondly, we were able to develop an understanding of expert perspectives on the current and future developments within 3D printing. Our expert interviews provided us with an excellent idea of how industry giants and innovators were hoping to change and develop 3D printing in the near future. This gave us an understanding about how the different expectations around 3D printing were likely to change in the near future. Expert perspectives, however, were mainly focused on specialist users, industrial production, or research and development. Because of this, our third research method – Social Network Analysis – gave us data on real, existing practices that were taken from real hobbyist users. As a result, this data gave us concrete information about how many everyday users already engage with 3D printing, and how they do so. Through these different research approaches, we were able to gain a reasonably thorough idea of the emergent elements and complications for 3D printing for non-expert users.
4 OBSERVED TRAJECTORIES

4.1 Rifts in economies of education & production

Our work suggests that rifts in cultural expectations of producing and consuming 3D printed goods are in some ways linked to the split seen in HMS and institutional learning, and more largely, extrinsic and intrinsic motivations to undertake the social practice of 3D printing. The related lack of shared vision between two different camps of 3D printing use presents the primary challenge for educating new communities of practice. In one camp, we have the civic, individually-focused, everyday, cultural, creative, and/or artistic 3D printing practices; in the other camp, we have the pragmatic, instrumental, industry-focused and/or market directed uses of 3D printing. At expert levels, these two camps are not mutually exclusive, but for beginners this divide is significant. This is particularly pronounced in institutional settings such as universities as they attempt to foster ‘maker’ cultures that originate in more informal and democratic settings. Overall, participant-learners we spoke with held interests in the ethics and practices of countercultural movements, such as peer-to-peer sharing practices, and an interest in legal protections for creatives from large corporate entities. At the same time they approached 3D printing with a cultural naïveté that required mapping normative as well as technical ways of going about 3D printing.

We aimed to explore these patterns through how 3D printing industry experts understand the requirements for future growth of the industry. For instance, one knowledgeable 3D printing community organiser, April Staines, suggested this intrinsic/extrinsic divide is produced on gendered lines, noting perceptions that while men tinker, women make. Staines’ standpoint explains this through the political economy of female home-makers constrained to weighing up the time and cost of designing and manufacturing objects that need to be reproducible to justify the labour.

Terry Wohlers (Lead of Wohlers and Associates) applied a similar argument to most consumers, claiming that they are concerned with only two things: value and the assurance that goods work. In his view, “most consumers” won’t be bothered to re-design, or look for redesigns, of things they are used to buying, let alone ensure new designs are compatible with or take advantage of additive manufacturing. Further, even those consumers excited about 3D printing do not consider the in-depth work it takes, trial by error, to ensure
process controls, repeatability, optimisation, and other steps that are part of additive manufacturing processes. In short, Wohlers assumes consumers will continue to be motivated by extrinsic factors (cost, reliability, familiarity) rather than factors intrinsic to learning to create their own material goods.

The General Manager of Stratasys Asia Pacific and Japan, Omer Kreiger, provides a different assessment. Krieger suggested to us that Stratasys’ successes have come from the surprising creativity of their clients. To help grow these blue-sky innovations (and markets) across extensible networks, Stratasys maintains two different file sharing sites, GrabCAD and Thingiverse. These sites respectively target engineers and everyday consumers, yet both demand that user uploaded objects be available to download for free in Creative Commons or variations of free software licences. The intellectual property regimes embedded by Stratasys in these sharing communities are complex, differentiating vertical (user to Stratasys) and horizontal (user to user) licensing. Moilanen at al. (2015) suggest that the terms create a one-sided relationship when Thingiverse’s parent company Makerbot/Stratasys no longer shares its own intellectual property back with the community and has even been accused of misappropriating the creations of Thingiverse users. Further, while GrabCAD’s marketing suggests “No need to reinvent the wheel! Someone else has solved that CAD problem or designed that bolt.” (GrabCAD 2015), its terms of service suggest limited uses for these wheels and bolts, as “All User Submissions Posted on or through the Services are for non-commercial use only.” (Gracad.com./terms). These limits again speak to the friction between commons-based peer-production and incumbent regimes of intellectual property.

Educating users on these issues are often overlooked in 3D printing practices. GrabCAD’s Terms of service are not easily findable on the site and run over 6,000 words. Thingiverse’s terms of use are also not prominently linked and run over 4,800 words, although this site does provide a wry ‘Terms of Use in Plain English’ greatly abbreviated parallel text that promises ‘understandability’. That these constitutional “terms of service” are not front-and-centre is currently the norm for user experience in many online services. However, as this report expands on below, when people share designs that create material differences in their lives, issues such as accountability, risk, and user rights
should be foregrounded. However, before considering the friction of educating user rights and responsibilities tied to intellectual property, the intellectual capacity required to contribute to communities of production has to be addressed.

**Educational Bridges**

Krieger maintains that learning additive design principals remains one of the biggest challenges to expand the industry and explore related social and business benefits. His experience suggests that this should start as young as possible as children's minds seem to be “100% flexible ... and are not limited like adults” with prior teaching of how to mechanically engineer solutions to specific problems. The entrepreneurial space in Australia is starting to respond to this opportunity. One example is the Australian start-up 'Proto-works' which is currently seeking financing for the developing of mobile 3D printing education workshops targeted at secondary school students. As of 2015 tertiary institutions in Australia do have a few of 3D printing centric subjects, but these are not considered as part of a new discipline of design or engineering in a similar way to specific streams/disciplines such as ‘mechanical/electrical/environmental’ engineering. While educational institutions might be slow to encourage uptake of learning the skills and cultures that surround 3D printing, industry hopes to change this. Krieger stresses the importance of educational institutions creating new 3D printing knowledge. He argues that universities have a comparative advantage in working on 3D printing innovations. Simply put, he remarks that the academy is “more open, [and] happy with failure ... [so] the most interesting stories come from these spaces”. We understand this as showing a 3D printer manufacture identifying the need for research and learning that is not tied to market pressures, and instead motivated by intrinsic goals of the user/learner. How institutions can rise to this challenge defines a major research question of our project. It is to this we now turn.
Cultural rifts

Our research suggests that an education in 3D printing involves as much cultural practice as it does offering practical skills training. Our data was gathered by embedding researchers in the University of Melbourne's “DigiSmith” 3D printing workshops, as well surveying and interviewing the attendees. The DigiSmith workshops took up many of the attributes of Hacker and Maker spaces in its design: workshop setting, populated with experienced makers, minimal cost attendance, and a non-linear learning trajectory. Equally, the workshops made use of institutional university systems: hierarchical ‘sage on the stage’ teaching methods based around lecture/seminar style delivery, uniform software and machinery for all attendees, and group authority was at least partially determined by the university’s hierarchical employment system. The learning environment and the community that grew within it existed both in opposition to and through traditional pedagogies of the university.

We found the space was able to incubate makers in a fashion similar to what Ito et al. (2013) describes as a method for connected learning. Specifically, the course design reflected Ito’s hope to “build shared purpose [and] opportunities for production” (Ito et al., 2013 5) through and with the openly networked resources and infrastructure provided by the university and contributors to the course. DigiSmith also fulfilled more normative productive aspirations of connected learning: course material was posted on GitHub to equitably share openly with future learners, interest driven learning defined what students decided to create with the printers, and the curriculum integrated subjects that would fuel these interests.

The design of the curriculum also included a final problem-based learning (or PBL) project that was designed to empower students to integrate theory and practice in order to apply knowledge and skills towards an original creation. Strobel & Barneveld’s (2009) meta-synthesis of PBL outcomes shows how PBL is an important factor in the negotiation and creation of potential countercultures within learning environments. This suggests that PBL is most effective in long term retention, skill development, and satisfaction for participants. Although we cannot measure the first two claims against our data, our survey and interview data form participants offer evidence that satisfaction for participants peaked during the PBL based learning activities.
Regardless, these three traits of learning are crucial to creating sustainable community ties between learners in and out of the classroom, an affordance that serves both “connected learning” goals as well as enabling community formation outside of institutional regimes. Yet, how a countercultural ethic of knowledge sharing can be sustained within such contexts, and how this effects the production of education, as opposed to its consumption is unclear.

In one view, productive models of peer to peer learning enabled by digital technologies have been described by Rheingold (2012) as peeragogy and as paragogy by Corneli and Danoff (2011). The end goal, for Rheingold, envisions a point where his role becomes facilitating others to self-organize learning. Corneli et al.’s (2014) recent Peerology Handbook suggests that a synthesis of peer learning and production is available and offers normative political projects related to P2P scholarship.

On the other hand, scholars such as Brabazon (2014) have been explicitly critical of attempts to invest learning with peer-based approaches, noting that, it is cheaper to affirm the value of student-centred learning and deny the expertise of teachers. But the knowledge held by teachers and students is not equivalent. Teachers know more …. They study, think and translate complex ideas into the stepping stones of lesson plans. Students can enact none of these tasks. (2014, p.93)

Despite this, 3D printing is new enough to educational settings that most participants are involved in both sides of the educational process and possess diverse skills and expertise. Because of the transdisciplinary nature of the DigiSmith workshops, approximately a quarter of the class had significant experience with both the hardware and software aspects of 3D printing, with a number of other participants having software skills in 3D modelling. Other participants were able to provide education in the legal status of intellectual property rights in the context of Australian law, while still others were able to demonstrate elements of coding and structural engineering.

We also found that the position of universities in parlaying additive manufacturing into 3D printing practices is diversified across educational, industrial and innovation spaces. In the immediate research context, additive manufacturing has been offered as a service at the University for two years prior to the DigiSmith workshops. However, these services were run by Information Technology Services (ITS) group, rather than a specific faculty or research centre. This service did not contain any formal teaching or curriculum, and instead offered limited consultations on design and materials regarding printer capability. The university also showcased innovative research projects that
had (at least tangential) connections to additive manufacturing in a public exhibit to advertise the capabilities of 3D printing practices for research. The formal agenda and structure of this show-and-tell fulfilled public relations and networking goals, over direct workshopping, skill sharing, etc., and spoke to the institutional cultures of the academy and the trade show rather than HMS. At the industrial level, organisations like CSIRO continue to push technological limits in the name of industry innovation and ‘big science’ frames, but lack the open inclusivity of HMS.

**Rifts within DigiSmith**

We now turn to the specific experiences of the DigiSmith learners, and compare this to previous research on HMS. The comparison highlights rifts in educative contexts for 3D printing. The survey we gave to participants was modelled on similar research by Moilanen and Vadén in 2012 and 2013 of non-corporate users of 3D printers. Across both years of the Moilanen and Vadén survey the top five self-reported use cases for 3D printing were the same: functional models, artistic items, spare parts to devices, research/educational purposes, and direct part production. Our own data suggests that workshop participants overwhelmingly wanted to create “artistic items” with a large subset wanting to use 3D printing for research and educational purposes - this latter result is not surprising given the academic context.

Moilanen and Vadén’s research showed a clear trend towards linking participation in HMSs and being part of a cultural movement (54%), yet our data suggested that only a quarter of participants consciously identified with a cultural movement. We also sought to uncover participant motivations in 3D printing projects through proxies that might signal hacker and maker counterculture, without participants necessarily self-identifying involvement with these movements. Participants gave mixed messages to questions of building autonomous communities. Some felt isolated, with one stating “I could see myself as a part of the community, but not at the same time.” Another participant, however, was extremely enthusiastic, saying, “I want to set up my own workshop for others to come and be a part of a community - sharing tools.” More often than not, participants shared this drive, but also felt the existing structure did not support such outcomes.
The instrumental/extrinsic interests that drove participation were also mixed. When asked about desire to “give back to the community” responses grouped around a neutral response. Yet, when asked about community-building practices, respondents were highly enthusiastic regarding sharing and learning new skills, having fun, and to a somewhat lesser extent, the collaborative elements of the experience.

Importantly, many respondents were interested in seeing the development of legal protections for individual users, at the expense of large corporations. One participant stated that “a company has all the patents on medical equipment [...] but they make it inaccessible for copyright reasons, and people die. [...] I see that as an ethical problem.” Another respondent noted,

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…

Overall, we noted two tendencies that parallel countercultural agendas and hackerspace realities; a lack of financial incentive and complex motivations around sharing the community. Firstly, there was little interest amongst our participants for monetary gain, with less than a third of respondents agreeing or strongly agreeing with the suggestion of financial motivation. A majority did, however, suggest their interest in 3D printing was instrumental rather than intrinsic.

Acceptance of Sharing

Within DigiSmith, peer-based sharing was seen to be an extremely important issue for many people. Our respondents had a strong preference for sharing under a Creative Commons Share-Alike licensing structure, where modifications are allowed, as long as credit is given to previous contributors and the license is kept under the same terms. Interestingly, the survey results might suggest that workshop respondents identified the sharing and printing of 3D objects as sharing others’ work, rather than creating derivative works of their own, even if they worked on modifying objects. This is a key aspect of what Schrock and Kostakis, et al, identify as the meritocratic elements of maker communities and Daly’s (2016) guidance that exact legal status of most aspects of 3D printing are extremely unclear.
In terms of sharing in order to distribute 3D models, respondents tempered some of their acceptance of ‘copyleft’ intellectual property regimes for commercial distribution, but remained proponents of sharing for purposes of distribution overall. The drop off in acceptance of commercialised sharing mirrors the tension in hackerspaces as countercultural elements negotiate the spread of their own values and cultural products to larger systems that might not maintain the original value. Counter-cultures of 3D printing will have to negotiate the paradox of support and autonomy that comes with the peripheral hackerspaces they inhabit, and eventually grow out of, or are subsumed by, larger institutional players.

For the short time that it existed, the DigiSmith community seemed to share an interest in the traditional virtues of Peer-to-Peer cultures. We infer from this that the DigiSmith workshops fosters something of a countercultural attitude amongst its participants, but lacks the firm community grounding that is so important to the countercultural practices of other HMSs. The lack of a coherent shared vision about the cultural or instrumental use of 3D printing presents a primary challenge to education. This is particularly pronounced in institutional settings, such as universities, that seek to foster cultures that are primarily found in settings that are informal and democratic. Our survey and interview data does informs this understanding insofar as it identifies that participants held latent interests in the ethics and practices of countercultural movements, such as an appreciation of sharing and peer-to-peer practices, and an interest in legal protections for creative developers over large corporate entities.

4.2 Limits of centralised accountability

Another aspect that defines the evolving practices of 3D printing deals with accountability. There are significant new puzzles at the level of end user, printer manufacturer, and network provider - and tensions about at which level accountability should sit and how it should (or can) be applied. Some of these issues are familiar and tied to general aspects of what critics like Evgeny Morozov (2014) call ‘solutionism’, or an irrational techno-fetishism that believes that ever-more technology can provide the solution. However, 3D printing technologies and practices bring about a need to engage with decentralising authority and accountability in new ways.
One expert we spoke to saw an example of techno-fetishism in the humanitarian work she has been involved with for over ten years. In her view, recent projects that “send 3D printers to Africa” are anything but successful. Instead of actually fulfilling the ‘teach a person to fish’ parable in additive manufacturing terms, these development projects open issues of appropriateness and accountability that lack needed critiques. Some 3D printing manufacturers do seem to be caught up in imaginaries of their own cultures:

783 million people do not have access to clean water. 3D printed buckets, jars and bowls could better allocate water to families that travel long distances to retrieve water. (Foster-Webster, 2015)

Rather than attempting to re-invent the bucket or end worldwide bowl scarcity, more applicable 3D printed products, such as prosthetics, can still fall to the same criticisms. Although 3D printing a prosthetic limb seems like an elegant, simplified and automated solution to improve the quality and quantity of prosthetics, technical capacity and normative-legal questions do not go away. For instance, the expert we spoke with pointed out fit and feel still need to be validated in the field, that modifying a 3D printed prosthetic is challenging, the longevity of materials used in printing need to be taken into consideration, and issues of accountability if the prosthetic fails become complex; is it the fault of the local stereo-imager of residual limbs? The (open source) algorithms and that transmute the information to STL files? The material supplier? The local printer? The NGO who coordinated these actors? These issues seem to intensify because of 3D printing, rather than have technology provide a ‘solution’. There are measured approaches to testing the empirical outcomes for projects that 3D print objects for development such as the work of the Bill and Melinda Gates Foundation with 3D4AgDev that develops farming tools, and the government of Canada’s funding for trials of 3D printed prosthetic limbs in Uganda.

“It won’t print - that”

It is not just end-users that have to navigate accountability ‘up-stream’ of their 3D print. Manufacturers of consumer 3D printers face the potential of digitally limiting what their machines can create based on regulations that consider contraband ‘un-printable’. The manufacturers we spoke to were loathe to implement restrictions of what content could be printed by their printers. Some of their arguments were similar to the debate in the 1990s about the “clipper chip”. This chip pitted the US government against privacy advocates for the privacy of any digital conversation. The former hoped to
install ‘secure’ but government-breakable encryption in all forms of digital communication devices, the latter argued this was unconstitutional and unsafe (Froomkin, 1995). In this battle the privacy experts won the day, and the clipper chip is mostly forgotten. However, restrictions on cryptography are again providing challenging conversations for policy makers and manufacturers in, notably in 2016, Apple’s iPhone privacy features.

However, we can look to the history of laser printers to show how such issues have been resolved via digital limitations and market compliance. The advent of consumer grade colour laser printers saw new limits on the privacy to communicate whatever you wanted and represent this in a material form. Specifically, many 2D colour printers new to market refused to print or digitally output facsimiles of a specific type of image: currency. There is some irony of any supposed 3D printing revolution bringing about a post-scarcity world physically, rather than just printing money.

Current 3D print manufacturers seem much less willing to indulge in such restrictions, or have to engage in the debates at all. Some of the reasons are technical. For instance, how does the printer update/determine what it is not allowed to print? Unlike the scarce resource of currency, there are multiple configurations of printing a workable 3D printable object such as a gun, and these could even include original designs to which there is no ‘blacklist’. The COO of Pirate 3D, Brendan Goh comments that any algorithmic restriction of what consumers can print “has to be online”. His logic is that a very large majority of users will find whatever they want to print online, and that in the future even to use 3D printers, consumers will probably be online: either sending files to their local maker-hub, or working on their bespoke printer through software that touches the cloud. While he, and others, recognise that there will always be individuals at the margins that fall outside such restrictions, the vast majority of makers will require online access to share, modify, and print files. The network thus becomes the place to regulate those practices. The normative issues that surround what regulatory implementation would look like are largely outside the scope of this white paper. They do, however, speak to what are seen as largely political debates that the 3D printing industry would be wise to avoid if possible.
Further, technologies like deep-packet inspection that would be required to police the flow of objects around the internet are fallible. Such flows can be hard to spot let alone stop. For instance, in 2013 artist Matthew Plummer-Fernandez created an application that ‘encrypted’ .STL files by changing their physical form to be unrecognisable, but reversible to their original, if a specific algorithmic key was passed on as well.

Plummer-Fernandez’ work was described as an art project, but it shows one of the many approaches that can manoeuvre around internet packet-based regulation regimes. The decentralisation of accountability presents a key policy consideration for future 3D Printing practice.

Overall, the efficacy of centralised restrictions or censorship regimes is suspect in 3D printed futures. There is precedent for heated public debate and failure of digital ‘lock’ policies (see clipper chip, back door encryption debates, etc.) as well as concerns from the tech community that such restrictions impede innovation or are even possible. 3D Printing will prove to be very difficult to regulate through restrictions or censorship regimes focussed on
what can be printed. Hardware manufacturers do not want restrictions built into their devices. Online operators do not want new responsibilities for user uploads or downloads. Control of at the centre is lost.

### 4.3 Challenges in researching networked objects

In terms of methods, interviews provided expert viewpoints onto the current and future trends in 3D printing, or provided qualitative perspectives on the experience of being involved in 3D printing education. These approaches, however, are not so effective at identifying large-scale practices as they currently exist within 3D printing cultures. In other words, experts can help us work out what might happen in the future, but they are not so well-equipped to talk about how collectives of people actually use 3D printers.

Because we sought to identify the knowledge gap that exists between people with no experience with 3D printers and people who are moderately capable, we needed to get past the limitations that interview methods presented. In part these limits are the knowledge limits of experts, and the selection biases in our interviews. While experts are knowledgeable, and our interviewees spoke well about their experiences, we wanted to identify other ways that we might understand how people engage with, and self-curate, their 3D printing experiences.

Our method of getting around this was to use scraping techniques to obtain data from the 3D printing file repository Thingiverse. Doing this allowed us to obtain a visibility into the real-world data of what people are actually printing, and how they’re managing the publicity of their files to each other in open access spaces. This method of scraping and subsequent analysis of visible relations, and how they are made visible, we refer to here as our visual SNA.

The visual analysis component of SNA is a process of identifying different types of irregularities within any given map of relations between multiple entities. This method is generally dominated by finding several key types of pattern:

- Items with a high degree of use
  - Key tags, used frequently (see ‘customized’ in table)
- Items with a low to medium degree of use, but exhibiting a clumping behaviour
- Implies tags frequently used together; spelling variations by community members

- Items with a low degree of use, but in a highly central location
  - Tags that have ambiguous purposes, or tags that are used across a number of different contexts

- Clearly distinct grouping occurring between two clusters in proximity
  - Often identifies proximate subcultural groups: home craft and environmental groups

- Highly central items, whether highly used or not
  - Generally tags that describe a great number of areas (“useful”) or tags which influence the development of a variety of other objects (“first”)

For all of the above points, we ‘drilled down’ on the individual items to examine our findings, and draw more detail as to why the detected patterns were appearing. In some cases, the results were inconclusive – perhaps due to unknown factors, or perhaps due to data gathering anomalies. In other cases, analysis was more fruitful. Some of our more interesting findings are detailed below.

**Remix**

The term remix is borrowed from music cultures, first emerging from African American hip hop and dub music. ‘Remix’ describes the process of using musical work from another artist, and repurposing it in a different context. The themes here have always been about repurposing and recycling, from a perspective of respect (Navas, 2012: 3-7). Within music cultures, this has often meant involved a complex relationship between subtle promotion of others work by musicians and acts of knowledgeable recognitions by audiences. Remix is applicable to cultural practices in 3D printing, but we are still some way from seeing the same nuances as are present in music.

In 3D printing, remix describes the process of reusing the model files from a previous creator’s work. Models, built with 3D modelling software, is relatively easy to modify and reuse, adding or subtracting features, updating simple models, simplifying complex surfaces, and so on. STL files, conversely, are simply 3-dimensional point clouds, which cannot be easily modified. If an author provides their modelling files in some variety of open-access, others may
take these files and remix them, repurposing them for a new use, modifying them for a personal context. These users may then add their own models back into circulation, with models changing and growing over time. Thingiverse reports some information on the remix practice, so we were able to extract this data and analyse it using Social Network Analysis.

Analysis of patterns of remix patterns identified several features. First, by far the most common form of remix was the modification of mobile phone cases. For many common models of phones (predominantly iPhone & Samsung models), generic mobile case structures would be uploaded, which would then be remixed by users to add a personal accoutrement, name, or image to the case. However, this form of remix generally only led to one ‘step’ of evolution in the remix process. Users would generate their own custom phone case, and then there would be no subsequent evolution of that object-form. This is likely due to the personalised nature of these remixes – the strict utility for other users is less than the utility provided by the original generic phone case. As such, the initial SNA methods that attempted to use algorithms designed for cladistics stalled by the fact that there was very little complexity in the evolution path of objects. An additional reason for this low level of evolution is likely to be the fact that the Thingiverse customizer system allows for easy remix of a parent object, but the subsequent descendent objects do not possess the same capacity.

Second, lithopanes are also highly remixed. Lithopanes are opaque plastic sheets, which have images printed into them topographically. When put against a window or light source, the varying thickness of the print becomes semi-transparent, allowing an image to shine through. The item ThingID #74322, which is one of the few non-phone case objects to have a high degree of remix, is a lithopane that allows users to import their own image. Between this, and the phone cases, it is clear that the most successfully remixed items are the most generic – simple plastic plates, or simple phone cases, which can easily be modified to include some sort of personalised design.

Third, fonts are important, but not highly remixed directly. Fonts are one class of objects that had high centrality, but low levels of remix, meaning that while a font might not be remixed all that much itself, several font files have been used by objects which in turn become the basis for a large swathe of remixed items. In particular, the Braille font item ThingID# 16193 has a degree of centrality that far exceeds any other item on the site.
Fourth, ‘collections’ generate artificial remix status, and generally do not lead to subsequent developments. A collection consists of a number of remixed objects packaged into one file, allowing for a single print job to produce a large number of objects. It also simplifies finding, for instance, the entirety of the available Pokémon figurines on the site. While collections represent less than 1% of the total number of remixed objects on the site, they do have a high degree of centrality within the network. Most objects (99%) only declare one originary object as their parent, collections, on the other hand, refer to many objects. As such, they represent a significant role within SNA, while not indicating much in terms of the idea of remix culture.

Finally, remix is an auto-generated state on the site, while remix as a cultural practice has no real reliance on didactic processes of reference, instead relying on cultural knowledge, inspiration, hybridity, and evolution. A key element to remix is the subtle elements that inhere in a text which suggest, rather than inform, about their origins. Thingiverse provides no datafield for the evolution or cultural influences that may have inspired users to create their objects. For instance, brands are tagged, not indicated as remixed. This means is that Thingiverse does not report on remediation as a practice, but instead only as references between database items. Remix within Thingiverse is commonplace, yet often banal.

Tags
In our analysis of tags we were able to obtain information about how many total items were tagged with any particular tag, and we were also able to determine how many of these objects were publicly available from this. By subtracting the known number of publicly available items from the total number of tagged items, we have been able to infer how many items are hidden for any particular tag. Many of the items which have a high privacy rate tend to be scanned items – which we would suggest are likely to be personal items, or scans of people’s bodies. We can see this tendency represented in Table 1. Different tags have highly variable rates of private objects. Of note is the PhotoBooth tag – these are full-body scans of people in preparation for creating a 3D printed model. We can see that a high proportion (98.6%) of items tagged with this tag have been rendered ‘private’. Understandably, many people are not willing to have a full scan of their body readily available to the public. This is similar across all major ‘scanning’ tags: PhotoBooth, scan, MakerBot-Digitizer, Scan 0, Scan 1, Scan 2, and so on. Compare this to the tag ‘openscad’,
which has an almost inverse proportion of private objects (1.8%). OpenSCAD refers to items made with a model compiler that works from written code. This material does not represent the scanning-in of real-world objects, and is thus less likely to be a representation of something personal or private. Furthermore, the OpenSCAD software is open source, and perhaps this ethic has been picked up by its users.

Some tags are automatically produced by specialised 3D printing software or hardware. This is the case of the PhotoBooth tag, as well as Scan 0, 1, & 2. ‘Customized’ is a tag added by Thingiverse to refer to objects that have been customised using Thingiverse software. Customising is a variant of remixing, where objects can only be modified to along a limited number of certain variables. These limitations include things such as height, width, and repetition, but tend not to include complex changes to surface geometry, or including other models into the system. Our research would indicate that the most common use of the ‘customizer’ is to embed personal images onto 3D printed mobile phone cases.

<table>
<thead>
<tr>
<th>Top ten most common tags</th>
<th>First Tag Scrape</th>
<th>Second Tag Scrape</th>
<th>Number of Publicly visible items</th>
<th>Private-class items (2nd Scrape – Public obj.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>customized</td>
<td>393533</td>
<td>463861</td>
<td>187915</td>
<td>59.5%</td>
</tr>
<tr>
<td>Photobooth</td>
<td>16801</td>
<td>16786</td>
<td>243</td>
<td>98.6%</td>
</tr>
<tr>
<td>scan</td>
<td>13838</td>
<td>15050</td>
<td>4366</td>
<td>71.0%</td>
</tr>
<tr>
<td>MakerBotDigitizer</td>
<td>11208</td>
<td>12365</td>
<td>2071</td>
<td>83.3%</td>
</tr>
<tr>
<td>3D</td>
<td>8299</td>
<td>8501</td>
<td>8343</td>
<td>1.9%</td>
</tr>
<tr>
<td>openscad</td>
<td>6473</td>
<td>6808</td>
<td>6686</td>
<td>1.8%</td>
</tr>
<tr>
<td>Scan 0</td>
<td>5802</td>
<td>5798</td>
<td>72</td>
<td>98.8%</td>
</tr>
<tr>
<td>Scan 1</td>
<td>5517</td>
<td>5511</td>
<td>74</td>
<td>98.7%</td>
</tr>
<tr>
<td>makerbot</td>
<td>5443</td>
<td>5545</td>
<td>5432</td>
<td>2.0%</td>
</tr>
<tr>
<td>Scan 2</td>
<td>5397</td>
<td>5389</td>
<td>86</td>
<td>98.4%</td>
</tr>
</tbody>
</table>

Table 1: Analysis of public/private use of tags

Initial observations of tags revealed general categories of tags as per Table 2. While analysis of these categories is ongoing, we are able to address some early observations: qualitative tags cut laterally across all manner of genres of item, as do the hardware and software tags; however, it can be speculated that qualitative tags are more likely to be added by the Thingiverse’s community of users rather than the maker of the object and better highlight social practices. Dimensional information is listed because 3D printer files are generally relational point clouds, and can be modified to easily create different scales.
for printed objects. Further, Tags allow users to identify objects designed to fit together at certain scales. Many of the branded category tags are designed as free replacements for those objects. Notable are the wargaming replacements, such as for the popular Warhammer brand of toys, as are the replacement LEGO pieces. These branded objects are consciously dealt with by amateur producers as having complex legal issues. Many of the other branded objects include things such as fake Starbucks mugs, printable Nike ‘swoosh’ objects, or replacements for expensive camera accessories such as grips or housing.

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

*Table 2: Categorisation of commonly-used tags*
5 POSSIBLE RESPONSES

5.1 Educational Pathways

To respond to rifts in educational cultures and practices found between institutional and HMS logics, we explore options that centre on the development of mixed skills and reciprocation norms within teaching and learning. We find that to better prepare students, and Australia, to leverage practices of 3D printing, consideration of how educators could more successfully establish community and peer-to-peer styles of learning via 3D printing curriculum is key.

At a macro level, institutional engagement with not only HMS, but other public institutions (such as libraries and civic centres) that run informational 3D printing sessions may allow some pedagogical theory and practice to permeate in peer-to-peer spaces that are less along a counter-cultural spectrum. These spaces might be, on the one hand more receptive to ‘institutional’ pedagogy while on the other, still effect peer-based learning with intrinsically motivated individuals.

At the micro level, group problem-based learning projects that are presented and then subsequently remixed by other groups as part of peer assessment afford students the opportunity to grapple with the political economy of HMS and 3D printing more generally vis-à-vis institutional settings and expectations. These learnings could offer formative approaches to the new logics required in grappling with 3D printing economies. For instance, the experience of DigiSmith curriculum design suggests the opportunity to consider both the complex motivations behind sharing, and the power of purpose-driven learning opportunities to enable creative production and community. At the same time it should be noted that, currently, institutional 3D printing learners are mostly intrinsically motivated. As 3D printing practices become (further) institutionalised into mandated curriculum the design of activities, learning may have to refocus on explicitly external motivation and/or substantive assessment.

On the basis of these observations, we suggest that Matt Ratto’s (2011) work on ‘critical making’ offers an important touchstone for educational practice related to 3D printing. Unlike other practice based learning, Ratto frames a project-based approach to learning that is grounded in critical theory and
thinking, but does not necessarily have a pragmatic use. For instance, Ratto has previously asked his students to take three weeks of class to use a provided kit of simple sensors and an Arduino board to create a ‘moral’ piece of technology. The results question how technology can be moral, or whether it should be, but do not propose marketable solutions to a specific problem. While the practicalities of external motivations towards learning may reduce engagement from some students for such projects, the public university continues to offer a unique space and culture to undertake such critical studies of making.

5.2 Accountability Pathways

The challenge of centralising accountability, while leveraging the innovation promise of distributed 3D printing practices, is immense. We hope to open the coming debates here by offering some new directions suggested by our informants and based on the facts on the ground - that are literally materialising before us. Critical Making, Transparency and function IP markets all provide pathways to new accountabilities. Overall, focussing on forms of control, rather than modes of outright denial of prints might be a productive framework to build from. To illustrate this general approach we can return to the 2D colour copier-currency saga. In that case, the solution was not to restrict printing bank notes, but to enable a way to identify which specific printer had printed each note that was undetectable to the human eye. Manufacturers ensured that miniscule unique identifiable marks were printed on every printed page by each printer, regardless of the content. This enabled digital tracing and signalled a more subtle way to control than denying access to print. In the 3D printing context, similar ‘fingerprint’ type chemical markers within materials, added/modified as they extrude might provide a similar path.

Alternative to new forms of secretly tracking prints to specific machines, Jenifer Loy suggests that accountability can come through transparency of what users print. In her work with students and 3D printing communities, she ensures that all users take a screen capture of everything they are going to print before they print it. They can print anything, but there is a record of it. This, she feels, centres accountability in risk management frameworks that encourage the positive benefits of transparency. Issues of privacy in this view, are complex, and seem to accept a connection between increased transparen-
cy and quality of life that is ideologically tied to Silicon Valley. Such views are exemplified in Mark Zuckerberg’s justification of openness and transparency live vis-à-vis Facebook: “more transparency should make for a more tolerant society in which people eventually accept that everybody sometimes does bad or embarrassing things.” (Zuckerberg in Kirkpatrick 2010: 211).

Loy expanded her views on transparency to suggest that appropriateness of what is printed can also be controlled through standards and operator-licences. Making standards known, and encouraging them to be openly arrived at, can remove significant risks from completely decentralised printing practices. In a similar way to how brands once conveyed a promise of quality for consumers, standards and their organisations can convey lower thresholds of risk and higher levels of appropriateness for specific use cases. Similarly, policy options that include licences for 3D Printing do not seem outside the scope of possibility for Loy. Considering the stratified license options for operating motor vehicles (personal, commercial, etc.) on public roads, Loy encourages considering the logic of general licensing options for different capacities to introduce private objects into our public spaces. This approach ties into the traceable/transparent print schedules of users and infers IP controls are not overlooked.

An approach that was popular with our respondents in regard to intellectual property politicised the private/sharing debate within calls for simple and efficient markets. Both industry insiders and startup informants considered the eventual ‘proliferation’ of 3D print IP was inevitable, but suggested for now industry remains the key determinant of how this process unfolds. Many informants recalled the shift of music consumption to the MP3 format in the late 20th Century as a colourful example of what industry can do wrong. Experiments like Thingiverse, its professional equivalent GrabCAD, and new service-oriented ventures point to evolving IP solutions that try to mimic the customer expectations of ease of use and profit models pioneered by services like iTunes and Netflix for digital content. Appropriateness here is measured not by what the market can bare, but what consumer can get for their money that is better than free.
5.3 Methodological Pathways

Applying the methods of SNA to 3D printing is a novel and, as far as we are aware, unique approach to understanding 3D printing practices through the website Thingiverse. Our hope for researchers is to consider the utility and accuracy of exploring such perspectives in future 3D printing research. Our work engaged with what Brügger and Finnemann (2013) call digital born materials. However, unlike Brügger and Finnemann’s study that focussed on ‘web materials’ accessible through a specific interface, we explored evolving collections of connected metadata to allow insights to the relations between objects created by the Thingiverse community over time. To be clear, our research offered more than focus on ‘users’ that help make the community. Instead, we generally followed Rogers (2013), to posit that the researcher must think through any corpus of data in its own digital terms, and adjust research strategies accordingly.

In this way, SNA methods are useful for providing macro-level information about large sets of data, where the data contains relational information between internal datapoints. Generally, these methods are used to map practices in large online social networks, such as Facebook and Twitter, where any one user is connection through relational structures (such as ‘friending’ or ‘following’ other users). These connections are mapped out in network graphs or diagrams which indicate the social connections that exist over large scales. These methods are largely designed to draw out patterns of behaviour from subsets of the entire social network, and these patterns are usually taken as indicative of behaviour across the network as a whole. This is done for a number of reasons: it is usually impractical to store all possible data for a social network; access restrictions imposed on external researchers due to privacy policies and proprietary commercial data on users; and the computationally intensive nature of sorting extremely large datasets. Despite this, SNA regularly deals with ‘big data’ that are an order of magnitude larger relative to other disciplinary approaches. Facebook’s ‘emotional contagion’ research – one of the largest publicly available social research projects – dealt with nearly 700,000 individuals. Our research involved 3D printing object datapoints which have lower complexity than a Facebook profile. However, we still managed to effectively address approximately 420,180 objects, and make informed judgements about the information we found.
SNA methods are almost always directed at analysing the behaviours of individual people through their online profiles. On occasion SNA has been applied to other forms of ‘social sorting’, such as tracking the expression of genes through populations, and tracking animal socialization patterns. Because of the way that Thingiverse operates, we were able to map social patterns that respond to 3D printing technology. The users of Thingiverse self-sort objects into one or many ‘tags’, which indicate a social use for the 3D printed item. This may indicate hobbyist usage, or particular aesthetic or functional purposes. Sometimes these are brand identities, or else measurements for ideal printing, and so on. Because the community would sort objects in this fashion, we could automate the process of identifying which tags shared which objects. We could thus create a map of tags, showing the relationship between different types of 3D printing practice. We were able to identify themes and clumping behaviours, implying different focuses between user groups. We could detect a heavy degree of use in a number of limited categories that were not apparent during our interview phase, particularly wide array of braille-tagged objects, and the significant presence of mobile phone cases, for example. This was most important in terms of how it allowed us to get a perspective on the use of 3D printing independent of our other research approaches.
6 CONCLUSION

The social and economic policy puzzles that are emerging from the practice of 3D printing are complex. This report hoped to develop empirical findings on how best to anticipate and leverage future evolutions of user practice and social meaning around 3D printing to encourage collaborative civic and economic innovations. Our focus was further defined through mapping the ‘facts on the ground’ of the 3D printing practices as they stand, and as key industry, academic and community voices see them evolving.

The report drew from extensive research that saw the team embed in collaborative learning/maker-spaces, interview industry leaders, academics and social commentators, and map the evolving uses of 3D printed objects through social network analysis methods. These mixed methods enabled us to paint a multi-faceted picture of 3D printing practices in Australia and beyond.

The work identified three key foci regarding education, accountability, and requirements for further research on 3D printing. Firstly, the rifts between HMS and traditional educational institutions points to opportunities to explore mixed skills and reciprocation norms within teaching and learning as extrinsic and intrinsic motivations for learners mix. The inbuilt lack of centralised accountability for the decentralised rights and responsibilities of 3D printing practices and outcomes suggest that pathways such as critical making, transparency and ‘better than free’ markets offer some - but not all solutions. Finally, future research into 3D printing practices offers incentives to seek out new types of data available from the communities of makers, in order to ascertain the importance of how object-oriented digital connections make patterns of use visible (or not) to human eyes. In this way, the report forecasts key strategic opportunities for practitioners in industry, government, and education to help position Australia at the forefront of the coming shifts in employment, production, and social life that practices of 3D printing promise.
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3D Printing: Civic Practices and Regulatory Challenges
Melbourne Networked Society Institute Research Paper 2-2016
ISBN: 978 0 7340 5268 1

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