MAKER DISCOURSES AND INVISIBLE LABOUR:

TALKING ABOUT THE 3-D PRINTER

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DECLARATION

I declare that this thesis is my own, unaided work, except where otherwise acknowledged. It is being submitted for the degree of Master of Arts in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

Johannesburg, May 2016

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ABSTRACT

The technology of 3-D Printing is afforded extensive coverage in the media. Discourses surrounding this technology are charged with ideas of revolutions in manufacturing, democratisation of technology, and the potential to change the face of consumption and production. This technology is being marketed to the consumer and hobbyist. The consumer-grade 3-D printer is a result of the labour of a loose-knit worldwide community of hobbyists known as the "Maker movement". This movement, a convergence of the traditional "Hacker" culture and Do It Yourself (DIY) is constructed around ideas of affective labour. That is, labour performed for the sole purpose of enjoyment of doing so, and for a sense of well-being and community. The explosion of "affordable" 3-D printing as a technology is a result of this affective labour, yet little mention is made of any forms of labour in popular media discourses surrounding this technology.

In this paper I construct a history of the Maker movement while theorising the forms of labour inherent to this movement using the Autonomist Marxism of Michael Hardt and Antonio Negri as a framework. Then, working within the field of Cultural Studies, and drawing on Actor-Network Theory (ANT), I perform Multimodal Critical Discourse Analysis (MCDA) on a small sample of texts to illustrate the occlusion and obfuscation of labour within these discourses of the consumer 3-D printer.

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CONTENTS

ACRONYMS

ANT Actor-Network Theory

CAD Computer Aided Design

CDA Critical Discourse Analysis

CNC Computer Numeric Control

CS Cultural Studies

DIWO Do It With Others

DIY Do It Yourself

FDM Fused Deposition Modelling

GPL GNU Public License

MCDA Multimodal Critical Discourse Analysis

MIT Massachusetts Institute of Technology

NC Numeric Control

OS Open Source

TMRC Tech Model Railroad Club

1 INTRODUCTION

1.1 Tea, Earl Grey, Hot.

Science fiction has both technically and narratively heralded tools such as the *Cornucopia machine* or the *Replicator*. They are presented as markers of technical advancement that have removed both the burdens of physical labour and the need for production line labour. This machine can hypothetically produce anything, requiring nothing more than an instruction or blueprint and a supply of raw feedstock. The title of this section (from *Star Trek - The Next Generation*) refers to Captain Jean-Luc Picard's often quoted and iconic drink order. The machine he orders his tea from is not just a voice-operated vending machine, but a true replicator - a machine that can construct anything at a molecular level. However, there is another equally significant aspect to this scenario: At this point the technology is so pervasive that he uses it for the simple and mundane activity of making a cup of tea. In reality, science and technology have far to go before reaching this level, although, as I will argue, *3-D printing* is being framed as headed in the direction of this fantastical technology.

The topic of 3-D printing has been prevalent in mainstream media in recent times, and a cursory Google News search returns over 700 news items for a one-month period in late 2015. The technology is being lauded as *game-changing* and *revolutionary*, with applications ranging from prosthetics and medical devices to motor cars and jewellery (Campbell et al.). Hyperbolic discourses are common with new technologies, yet in the case of 3-D printing, both the ubiquity of this discourse and its application to such a wide range of fields makes it of great interest.

1.2 The 3-D Printer

The 3-D printer is based on the notion of a machine that is given a pre-written set of instructions and produces something in response, automatically and repeatedly. This concept can be traced back as far as the late 18^{th} century, where such technology was used in France, in the form of the *Jacquard loom*. This mechanical add-on for a fabric loom allowed the loom to produce a pattern in the fabric being woven. The pattern was introduced to the loom on a punched card (Essinger). Despite this early innovation, most machinery and machine tools remained in the hands of artisans and trained operators until the late 1940s. Research around this time led to the development of Numeric Control (NC) systems, rudimentary controls retrofitted to lathes, milling machines, and other machine tools, which could reproduce parts from paper tape or punched card patterns (in much the same way as the Jacquard loom). This ultimately evolved into Computer Numeric Control (CNC) systems, using digital files transferred from the design computer directly to machinery on the workshop floor. These machines all had (and continue to have) certain things in common: they took a significant amount of skill and experience to program; they were expensive; and they generally took the form of machines that used *subtractive* manufacturing technologies — that is, they removed material from the stock (the starting block or chunk of metal or other material) — they used blades, drills, milling bits, wires, and other methods to do so.

The 3-D printer approaches the manufacturing problem from a different angle. Rather than milling or cutting away what is not needed from a block of metal or plastic, it builds up an object from layers of material. The most common technique involves extruding a thin stream of melted plastic from a nozzle and building up the object in question layer-by-layer.[1] Other techniques are used for different materials, such as metal or ceramic, but the fundamental concept of constructing an object layer-by-layer remains the same. 3-D printing is relatively new. One of the first patents related to this technology dates from 1985, and as a new technology it has been expensive and dependent on operators and programmers with arcane and sophisticated skill-sets. These factors mean it has remained within the scope of the military and industrial manufacturing complexes, where it has been extensively used for rapid prototyping — not production itself, but for producing once-off prototypes of objects or components without the time-consuming, risky and expensive requirements of re-tooling or shutting down fabrication processes. The materials used in their construction have little intrinsic strength, and the time taken to produce them (ranging from 20 minutes for a copy of a whistle, to tens of hours for something like a flower vase) currently is prohibitive for mass production.

The 2009 expiration of a commercial patent (Crump) on the FDM or *squirting plastic* method of 3-D printing has meant these printers have shrunk in size and cost. They are now being marketed to and acquired by individual, home users, who may be characterised as *hobbyists*, *tinkerers*, *DIYers* or *makers*. Despite these being simplified, consumer oriented machines, they share the same fundamental principles with their bigger and more expensive industrial counterparts. This includes the requirement for these arcane and sophisticated skill-sets.

It is this version of the 3-D printer that forms the core of this research, and this phenomenon is the nexus of particular rhetorics of technology in culture. Mythologies are already beginning to accrete around this particular manifestation of the 3-D printer. These include the assertions that they will: herald a "new industrial revolution"; that it is a "disruptive technology"; that it will lay the groundwork for the "democratisation of technology" and allow the average consumer to "reclaim the act of manufacturing". Crowd-funding sites such as Kickstarter and Indiegogo are illustrative of its popularity and are raising funds for a plethora of 3-D printing related projects. At the time of writing this (late 2015), Kickstarter listed 300 campaigns related to 3-D printing, the largest of which was funded to the amount of USD 3.4 million. Indiegogo listed about 600 campaigns. Formal funding for 3-D printing

1 This is known as Fused Deposition Modelling (FDM).

related companies has at times been reminiscent of the heyday of the dot.com bubble, for instance, Google has invested USD 100 million in a 3-D printing startup.[2]

1.2.1 *The 3-D printer as artefact of the Maker movement*

The primordial form of the hobbyist/low cost 3-D printer as it stands today is the *RepRap*. This was a project founded by Adrian Bowyer *et al* at the University of Bath in 2004. The initial driver for this project was to explore the possibility of self-replicating machines. That is, a machine that can produce all the parts necessary to build another instantiation of itself. Bowyer describes this aim as follows: "As the machine is free and open-source, anyone may – without royalty payments – make any number of copies of it ether for themselves or for others, using the RepRap machines themselves to reproduce those copies." (Jones et al. 177). Bowyer and his team released their designs under an Open Source licence, and this captured the imaginations of scores of hobbyists. These hobbyists refined and modified the basic concept in a myriad of ways and contributed their changes and improvements back to both the RepRap project and numerous other online repositories. Most consumer-grade 3-D printers on the market owe their heritage to both the RepRap project and the makers who contributed to the design.

1.3 MAKERS

The loose accretion of hobbyists responsible for this popularisation are part of a global movement known as the *Maker movement*. Makers can be located around the intersection of traditional DIY and technology. Their aims are to make things, tear things apart and see how they work. This is often done to try and make something better, and is linked to claims of resistance to traditional hegemonic structures of production and consumption (Anderson, *Makers : the new industrial revolution*; Gershenfeld; Ramocki).

As I will argue later, this figure of the Maker carries echoes of an earlier archetype from the history of technology, namely the *Hacker*.[3] The earliest documented practices of this nature go back to Massachusetts Institute of Technology (MIT) in the late 1950s (Levy 3), where the ethos was one of exploration and play. According to Steven Levy — chronicler of early hacker culture — knowledge gained from disassembling and remaking devices and consumer objects could then be used to create something better since "nothing annoys a hacker more than badly designed systems or objects, and they considered it their right to fix everything and anything that they considered broken" (28). This drive surfaced again in groups such as the *Homebrew Computer Club* in California in the 1970s, from which companies (Apple, amongst others), and entire industries (like that of the PC, or home/ consumer computer) grew.

2 Carbon3D.

3 The original Hacker - experimenter, tinkerer and programmer, not the "Hacker" - or "cyber-criminal" as appropriated by the mainstream media.

I approach this topic with the diverse interests and skills of an experienced computer programmer and electronic hardware technician and *tinkerer*, and a modeller, woodworker and Maker. Through the lens of these interests and skills, and with a growing interest in the relationship between technology and culture, the unbridled excitement being constructed around this technology caught my interest. However, I became sceptical of the rhetoric and myth-making that was invoked, and ultimately have been disappointed in the initial promise of the media discourses surrounding 3-D printing technology. These are specifically the reductionist and romanticised depictions of what the technology is capable of, and more importantly, that the capital in the form of skills, experience, and foundational labour required to make use of the technology is under-represented or obscured.

1.4 STRUCTURAL FRAMEWORKS

My initial observations indicated that the manner in which 3-D printing technology was being mobilised in the media and popular imagination was both consistent yet exaggerated. This required a suitable framework within which to analyse these discourses, and a language with which to describe them. Looking towards Cultural Studies, I found appropriate tools for my research and analyses. Theorist Stuart Hall describes the informing tenet of Cultural Studies as the position that texts and practices are not by default provided with meaning that is entirely and only dependent on the intentions of the author. In other words, the meaning always has to be explicitly expressed, but this expression is shaped by the social and historical context of the discourse (Storey 5). In addition, Toby Miller details the overall landscape of cultural studies as:

> . . . magnetic. It accretes various tendencies that are splintering the human sciences: Marxism, feminism, queer theory and the postcolonial. The "cultural" has become a "master-trope" in the humanities, blending and blurring textual analysis of popular culture with social theory and focusing on the margin of power rather than reproducing established lines of force and authority (Miller 1).

Further to this, and in a similar vein, semiotician Roland Barthes' seminal work on *myth* posits the idea that myths are recurrently deployed to present an ideology as though it were a universal truth, rather than the message intentionally constructed by the author (Barthes). These theories proved useful in understanding the mythologising of the technology and those who produced it.

Cultural Studies, however, is seldom used in discussions of technology, or for that matter, physical artefacts. The problem in Cultural Studies, according to Melchionne is that

> Humanities academics are more bookworms than busybees, more readers of texts than creators of artifacts. As a consequence, the formation of the object domains and theoretical constructs of Cultural Studies has been marked by the favoring of artifacts that can be treated as texts (Melchionne 254).

Cultural Studies' domain of analysis has traditionally been television, film, popular music and printed texts, and as such, despite the products of DIY themselves being cultural artefacts, they lie somewhere outside of the scope of Cultural Studies, being neither mass market commodities nor traditional artworks. Given these shortcomings in current approaches to Cultural Studies, an approach that is aware of the position and importance of an artefact as banal as a printer leads towards the ideas of John Law (Law, "On the subject of the object"). Law calls this approach ANT, and the analytic process consists of reading and contextualising a technological object as the product of an entire "network" of actors – those who in some way inform its structure, shape, or intention.

Law's seminal work on this matter is "Aircraft stories", describing the *TSR2* military aircraft project as a product of both Cold War era England and a change in governments, and how the project and the object itself were shaped (and ultimately scrapped) in response to the actors and pressures of the time. Cultural Studies is rooted in a critical and contextual understanding of a text as well as those multiple texts that surround it, and Actor-Network Theory allows one to extend Cultural Studies' notion of the artefact as text in a way that delineates the web of meaning which determines how an artefact signifies.

I have used references to fantasy and science fiction throughout the argument. This is not just because I am a fan, but as an intentional move to connect discourses of imagined futures with vocabularies of technology deployed in the present. In talking about technology in culture, I acknowledge that discourses are not just a response to real technology, but are also shaped by the imaginary. Cultural Studies does not necessarily favour one over the other as both have the potential to shape discourses equally. I intend to weave these two aspects together over the course of this dissertation.

Given that I am looking at the 3-D printer, not as a technological device in itself, but as an artefact of a particular group or culture, this combined approach helped locate the actors and drivers involved in the creation and deployment of this technology. The version of the 3-D printer examined in this research is targeted at the consumer who identifies as a maker. In light of the above discourses, this reveals numerous tensions in the construction of the maker/consumer identity. Foremost is the claim made by makers that they make as an act of resistance to current models of production and consumption, yet they are consuming products of that system in order to resist it. In many cases, the products being marketed to the maker community are built to designs that were, in the first place, developed by members of the community itself and originally released under open-source licences. It is for this reason that I am focusing on the concept of labour as a critical theme in this research. Vincent Mosco, (in Fuchs and Sevignani 230) notes that "labour remains the blind spot of communication and cultural studies" and that therefore "labour needs to be placed high on the agenda or projects for the renewal of cultural studies". This project does not aim to explore the phenomenon of labour in the practices surrounding the 3-D printer, but rather to consider the representations (or rather the lack thereof) in discourses that circulate and construct the myth of the maker and the 3-D printer. My motivation for this focus lies in the turn of the new economies towards knowledge and information work and increasing trends towards co-option and exploitation of these forms of labour (Terranova).

To summarise: I am performing Cultural Studies based research, informed by Actor-Network Theory to explore critically how the hobbyist-grade 3-D printer is constructed within the popular imagination. I am focusing primarily on both labour and skills capital within these discourses.

1.5 METHODS

The structure of my analysis takes the following form. Firstly, I consider the figure of the hacker and the evolution of this key trope since the 1950s, and through the period in which the Personal Computer "revolution" took place. The connection between the Hacker and the Personal Computer provides a rubric for examining the parallels with the maker and 3-D printing technology, and the ways in which these comparisons might also fail. The myth-making and rhetoric deployed regarding these technologies is strikingly similar and is in need of historicisation. Langdon Winner notes the lack of historical context in many studies of emerging technology saying: "In fact, no well-developed comparisons of that kind are to be found in the writings of the computer evolution. A consistently ahistorical viewpoint prevails" (Winner 102).

In response to this lack of historicity, I have sketched the narratives of the rise of both the Maker and Hacker movements and the objects and people central to their respective discourses. Not only do these narratives provide historical context, but they are an integral part of the process of resolving and understanding some of the myth-making and rhetoric attached to 3-D printing technology.

I examine a small selection of diverse texts from mainstream media, and illustrate the primary discourses and myths constructed around 3-D printing technology. Certain themes are recurrent and these speak to how this technology is positioned within the collective imagination. One of these themes generally notable by its absence, is that of labour. That is, who does the work of making the 3-D printer function and to what end? Discourses and myths constructed around 3-D printing technology tend to obfuscate or misrepresent what is required to produce items with these machines. The printer itself produces the object, but no small amount of work and skill is required to conceptualise, design and produce the file required by the printer to print the aforementioned object. To produce usable original objects requires, to re-use an earlier phrase, "arcane and sophisticated skill-sets". These skill-sets include understanding of design and shapes, proficiency with complex 3-D Computer Aided Design (CAD) software, knowledge of file-formats, mechanical maintenance of the machine, and many more. The discourse constructed around 3-D printers often represents this process as "just click print", reducing the whole conception, design and pre-printing process to nothing more than the click of a button.

1.6 THE ISSUE OF LABOUR

The subject of labour within the Maker movement has received little coverage within academic or allied literature. As a key figure in the Maker movement, Chris Anderson approaches the possibilities of this sort of technology in a rather breathless and utopian manner (Anderson, *Makers : the new industrial revolution*). Anderson considers everyone to be a latent entrepreneur. The rhetoric of revolution is evident in his statement that "... the Third Industrial Revolution is best seen as the combination of digital manufacturing and personal manufacturing: the industrialization of the Maker Movement." (49). Anderson, despite also being a maker minimises the skills required to use these machines and the labour involved, and presents it as a "... simple menu option [that] compresses three centuries of industrial revolution into a single mouse click" (34).

This motif of a "revolution" or the "next industrial revolution" is repeated frequently albeit with different nuances by different thinkers and writers in the field. Dale Dougherty, another key figure in the Maker movement, in "The Maker Movement" and Mark Hatch in "The maker movement manifesto" both promote the idea of revolution. Neal Gershenfeld (who is MIT Professor and director of MIT's *Centre for Bits and Atoms* and author of "Fab : the coming revolution on your desktop–from personal computers to personal fabrication") is more pragmatic in relating the practical issues and potential benefits and uses of these technologies. Likewise Jarkko Moilanen has gone beyond the rhetoric and performed detailed empirical research on usage and peer-production models in hackerspaces. Moilanen providies useful demographic insight into makers, and how they themselves identify as makers (or other) (Moilanen). Joshua Tanenbaum works within the field of HCI (Human-Computer Interaction) studies, but looks toward the DIY and Maker movements for models of expression, collaboration and "democratized technological practice" (Tanenbaum et al. 2603), and presents these movements as potential sites of protest and resistance to traditional modes of production and consumption. A rare work which does look briefly at a number of the mythologised discourses around 3-D printing is Matt Ratto and Robert Ree's paper "Materializing information: 3-D printing and social change". This work examines how notions of authenticity (and thus value) are challenged by more traditional manual craft-workers. Ratto draws on the concept of the latent entrepreneur or latent creative as originated by Anderson, reiterating the belief that anyone can be an entrepreneur or creative. Furthermore this hypothetical everyman already has the skills to do so, and just needs the right tool — in this case the 3-D printer — to unlock these latent talents.

Counter to these proponents of the idea of revolution are a few more critical voices. Langdon Winner in "The whale and the reactor", writing on society and technology from the perspective of the personal computer bubble in the mid 1980s notes that even at that time these themes were not new. He holds that similar discourses are applied cyclically to many new and emerging technologies. Winner examines these discourses of revolution, and how they are driven by political, marketing and other objectives.

1.7 AN OUTLINE OF CHAPTERS

My argument is constructed around the idea that the 3-D printer typifies the relationship between technology and culture as it plays out in the Maker movement. However, before exploring the specific discourses of the 3-D printer, I establish some historic precedent regarding the Maker movement and then construct the foundations of my theories of labour. As such, I have positioned the textual analysis slightly later in my argument.

1.7.1 *Chapter 2* - CONTEXTUALISING THE MAKER MOVEMENT

In this chapter I outline the historical narratives of the Hacker movement from its documented roots in the 1950s, and note the key players and their philosophies, motivations and influences. The early history of this community, mostly based at the Massachusets Institute of Technology (MIT) provides key insights into both the development of the hacker ethos and much of the discourse and terminology, and is where the term *Hacker* was coined. I continue this history with a look at the *Homebrew Computer Club* of the 1970s, and how this ultimately led to the development and rise of the Personal Computer. I then look at the birth and rise of the Open Source software movement, fuelled not just by the rise of the personal computer, but also by various figures within the hacker community. Finally, I argue that the Maker movement is not only a product of the hacker philosophy, but also draws from the Open Source movement, and reflects the pragmatism of DIY practices that have, for various reasons, been on the rise since the 1960s.

1.7.2 *Chapter 3* - LABOUR AND THE SIXTH WAVE

This chapter begins with an examination of the dominant forms of labour within the Maker movement (and by association, the Hacker and Open Source movements). I then locate these within the context of the current late Post-Fordist economy and the turn away from manual labour towards intangible labour or *knowledge work*. I sketch a brief history of the post-industrial and preceding industrial eras. A trope that is commonly deployed in discourses of 3-D printing is that of a "new industrial revolution". Given that the first industrial revolution marked both the uptake of new manufacturing technologies, and the associated major shift in modes of labour, we should expect to see similar patterns in the case of 3-D printing. As such, an examination of the first industrial revolution comprises the first part of my history. The second part consists of the next significant shift in technology and labour, the Post-Fordist move towards immaterial and intellectual labour, and at this point I reiterate how these forms of labour are inherent to groups such as the Makers. Most of the theory covering immaterial and intellectual labour is a result of the work of the Italian Autonomist Marxists: Michael Hardt, Paolo Virno and Antonio Negri. These theorists have explored labour in the post-war *Italian Laboratory*, which provides a framework for the non-traditional and post-Fordist economies where permanent, traditional, and physical forms of labour are eclipsed by impermanent and intangible labours.

1.7.3 *Chapter 4* - DISCOURSES AND ANALYSIS

Firstly in this chapter, I describe the theoretical framework which informs my reading and analysis of my example texts. The aim of this dissertation is to present an argument and therefore these texts were chosen to illustrate this larger piece of theoretical work. As stated above, the aim is to explore critically how the hobbyist-grade 3-D printer is constructed within the popular imagination, with the focus on how labour is represented within these discourses. The first part of my theoretical framework comprises an overview of the field of

Cultural Studies and how it approaches the problem of describing and locating a cultural artefact within its social, political and economic contexts. Cultural Studies does not often deal with discussions of technology, so I then look towards the work of John Law and Bruno Latour and ANT (Law, "On the subject of the object"). This is an approach which treats objects as a part of (or function of) social networks. In the case of this research, the 3-D printer is the focus of these networks, and these relationships can be mapped in terms of material (between objects and actors), and semiotic (between concepts). Following this, I describe the range of texts selected, and my motivations for selecting this material, after which I present my readings of these texts. The approach I use in reading these texts is based within MCDA. MCDA is based on Critical Discourse Analysis (CDA), which aims not just to describe discourse, but, being grounded in social history, semiotics and linguistics, attempts to explain how and why it was produced, and the related ideological underpinnings (Tenorio). MCDA allows for the analysis of materials of various forms in addition to printed text, such as images and film.

1.7.4 *Chapter 5* - CONCLUSION

3-D Printing: noun \ˈ*thrē dē* ˈ*prin-tiŋ*\
A process by which end-users (or "makers" as they call themselves) can create insane amounts of plastic nick-nacks, virtually at will and barely any cost, with the push of a button.
— Daily Reckoning

2

CONTEXTUALISING THE MAKER MOVEMENT

In order to contextualise the 3-D printer, I examine how, why, and where it came into existence in its current form. This chapter presents a history of the Maker movement and argues that it is the result of a convergence of the hacker philosophy of enquiry and curiosity and the DIY enthusiasts' pragmatic approach to "getting things done". The meteoric growth of this movement, and those that produced it, the Hackers community and the Open Source movement, can be attributed to the impact of online communication, first *Bulletin Boards* then the Internet.

I begin by tracing the early history of the MIT Hackers and the West-Coast (California) "garage startup" culture, through the rise of the Open Source movement, followed by a brief look at DIY culture. Next, I will tease apart common threads and philosophies from these movements and communities and explain how and why they can be seen to have converged in the Maker movement, and why this movement can be seen as a movement and not just a loose collection of enthusiasts. The final sections of this chapter provide a historical overview of the 3-D printer in its popular form, and a discussion of the 3-D printer as an artefact of the Maker movement. Understanding the roots and philosophies — both inherited and explicitly stated — of this movement is critical to my later engagement with media representations and discourses related to 3-D printing.

2.1 ORIGINS AND INFLUENCES OF THE MAKER MOVEMENT

2.1.1 *Beginnings - The* Ur-Hackers

MIT is the starting point for this historical review. Steven Levy's "Hackers", Glyn Moody's "Rebel code : Linux and the open source revolution", and Katie Hafner's "Where wizards stay up late: The origins of the Internet" each cover different fields, but converge on MIT around this period as the nexus of something significant. MIT has a reputation for academic, research and technical excellence[1] that is engendered by a rigorous selection process and a fiercely competitive atmosphere. Levy recounts the anecdote that students are told in their freshman welcoming lecture "Look at the person to your left . . . look at the person to your right . . . One of you three will not graduate from the Institute". This fostered intense competition amongst students to ensure that one was not one of those three. However, according to Levy, certain students saw this as an opportunity to find allies: "Maybe they [the

1 MIT alumni include Robert Metcalfe (inventor of ethernet), and more directly relevant to this discussion, Limor Fried (Well known maker, founder of "Adafruit.com"), and Andrew "Bunnie" Huang, hacker, maker and chip designer.

person to your left. . . And right. . .] would be of assistance in the consuming quest to find out how things worked and then to master them" (Levy 7). To these students, this quest often seemed more important than obtaining an actual degree.

Levy opens by setting the scene at the MIT Tech Model Railroad Club (TMRC) , which was (and still is) a student organisation for those with a love for model trains (Levy 6). Around this time (the late 1950s), the club was split into two distinct factions. One group was more interested in building the model trains, creating scenery for the layout,[2] and concerned with issues such as attention to train paint schemes and how to create the best miniature trees. The other was the "Signals and Power Subcommittee", which consisted of students who were more interested in the inner workings of the layout, or "The System" as they called it. Their obsession was the collection of electronics and mechanics that actually controlled the trains on the layout - their speed and direction, the switches (allowing trains to switch between one set of tracks and another), signal lights, and anything else they could think of. Levy describes it as "something like a collaboration between Rube Goldberg and Wernher von Braun" (7). An interesting choice of wording, given the tensions between the hacker /tinkerer exemplified by Rube Goldberg, and the military-industrial complex[3].

They spent their hours, days, and weekends building and rebuilding the System, often using parts donated by the telephone company, scrounging for other parts at scrapyards and developing their own subculture with its own language. A project undertaken for the sheer pleasure of doing so, and not necessarily towards a practical end was known as a *hack*[4]. To be a true hack, though, "the feat must be imbued with innovation, style, and technical virtuosity" (Levy 10). A hack must be seen as an elegant solution to a problem. Incidentally, the terms *hack* and *hacker* first appeared in print in this context in the 1959 TMRC Dictionary (Samson).

The complexity of the System led the hackers of the TMRC to investigate the newly available computers installed on campus to find a way to keep track of, and ultimately control, the sophisticated and labyrinthine mess of wires, switches and relays underneath their train layout. They would sneak into the computer labs after hours when they were not being officially used, and run their code (in the form of paper tape, at first). Then they would take the results and work on them the next day (Levy 23). Ultimately, a number of the "Signals and Power Subcommittee" members spent more time working on abstract problems on the computers than they did "messing" with the train layout or switching system. I call these hackers the *Ur-Hackers*, the first of the original hardware and software hackers.

These hackers worked on the principle that the best way to learn about something was to take it apart — whether it be a kitchen appliance, a piece of electronic equipment, or soft-

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2 A "layout" traditionally consists of a section of terrain, modelled by hand out of papier mache, polystyrene, plaster, etc. with railway lines, miniature towns, and so on, on which model trains are run. They can range from tabletop size, to an entire room: "The clubroom was dominated by the huge train layout. It just about filled the room, and if you stood in the little control area called "the notch" you could see a little town, a little industrial area, a tiny working trolley line, a papier-mâché mountain, and of course a lot of trains and tracks. The trains were meticulously crafted to resemble their full-scale counterparts, and they chugged along the twists and turns of the track with picture-book perfection." (Levy 7)

3 Particularly given the period - the start of the Cold War, and the fact that much research at MIT was military funded.

4 This term was already known at MIT, used to describe practical jokes, often on a huge scale, played by students. http://hacks.mit.edu.

ware. This knowledge could then be used to create something better and more interesting. According to Levy, nothing annoys a hacker more than badly designed systems or objects and they considered it their right to fix everything and anything that they considered "broken" (Levy 28). This drive, and more importantly, the ability to demonstrate proficiency and skill was the mark of a true hacker and not their qualifications or degrees, age, or any other "bogus criteria" (31). It is worth noting that the term *hacker* is often used with negative connotations and is used to describe "cyber" criminals and practitioners of morally and legally suspect online activities. This was not the original meaning of the term and this dissertation makes use of this earlier iteration of the term as articulated by Levy. A significant product of this way of thinking is distilled in the tenet "Information wants to be free". This philosophy was absorbed by the software people in MITs computer science department, which will be a significant player in the Open Source movement, as seen in the next section.

2.1.2 *Phone Phreaks and the Homebrew Computer Club*

This fundamental ethos was also playing out on the West Coast of America. A popular pastime amongst college students and engineers on the somewhat more liberal West Coast, particularly in Berkeley similar areas was "Phone Phreaking". Some enterprising individuals had discovered that by playing a certain tone into a telephone, one could invoke the telephone companies' maintenance system, and make free calls, both local and, importantly, long distance. This was a boon to broke college students wanting to call home or just to play with and explore the system. Sterling describes phone Phreaks as those "... who 'explore the system' for the sake of the intellectual challenge" (Sterling 58). A sophisticated party trick was to call the public telephone right next to the one you were using, by routing the call through as many nodes around the world as you could. It was then discovered that the toy whistle that came as the gift in a box of cereal ("Captain Crunch") played the exact tones necessary. This performance of resistance is something we will see repeated in both Maker and 3-D printer discourses later in this dissertation.

Later, various people made little electronic boxes ("Blue Boxes") that played this tone (and others used within the telephone system), thus eliminating the need to go hunting for a cereal-box toy. One of these people was Steve Wozniak, who went on to be co-founder of Apple Computer. Around this time (early 1970s), a group known as the "Homebrew Computer Club", holding its meetings in Stanford, was popular amongst electronic hobbyists. The stated mission of this club was to get computers into the hands of average people. They played with computer hardware that was demonstrated and lent to them by various companies and designed and built their own (Watson 134). As with the aforementioned performances of resistance, the idea of making technology available to everyone is something we also will see in discourses surrounding the 3-D printer.

One of their members was Steve Wozniak, who, by his own admission, really just wanted to show off what he could do. However, as he states, his philosophy is strongly aligned with what would later be known as Open Source. His assertion was that "the theme of the club was 'Give to help others.' It was an expression of the hacker ethic that information should be free and all authority mistrusted. I designed the Apple I because I wanted to give it away for free to other people" (Watson 135). The Apple I would later become the first product of Apple Computer, which he co-founded with Steve Jobs.

Levy describes Jobs – co-founder of Apple and Wozniak's friend – as also possessing a similar ethos of enquiry and curiosity:

> His dad, Paul—a machinist who had never completed high school—had set aside a section of his workbench for Steve, and taught him how to build things, disassemble them, and put them together. From neighbors who worked in the electronics firm in the Valley, he learned about that field—and also understood that things like television sets were not magical things that just showed up in one's house, but designed objects that human beings had painstakingly created. 'It gave a tremendous sense of self-confidence, that through exploration and learning one could understand seemingly very complex things in one's environment,' he told [an] interviewer" ("Steve Jobs, 1955 - 2011 | WIRED, Project Website").

This account foreshadows connections to come in discourses regarding makers and the 3-D printer. Most notably the idea of home and domestic space and the 3-D printer's place within these spaces.

The "Homebrew Computer Club" and its atmosphere of enquiry, "how does it work", "take it apart", and "I can build something better" is reminiscent of what was happening at MIT in the early days, and was influential in the formation of the West Coast and Silicon Valley technology culture.

2.1.3 *Richard Stallman & The Open Source movement*

The Open Source movement[5] has its roots in academia. The University of California, Berkeley was an early adopter of AT&T's operating system, Unix. Ken Thompson, one of Unix's designers started working on improvements and additions with a few graduate students, notably Bill Joy, who would later go on to found Sun Microsystems. Unix and its code was owned by AT&T[6], a publically regulated monopoly. It was tied up in anti-trust court, and as a condition, was legally unable to sell software on the open market. They could, however, make software available to the academic community for the cost of distribution media, in other words for the price of a tape or floppy disk. Berkeley distributed their improved version under the name "BSD Unix", and the terms of licensing were fairly basic: you could do anything you wanted with the software or the source code as long as you provided appropriate attribution and understood that there was no warranty. Originally this (and other similar freely distributed software) was mailed around on disk or paper tape. Later, it was shared via early email and UUCP on the embryonic Internet (at the time known as the ARPANet) (DiBona 28).

5 Source code (also referred to as source or code) is the version of software as it is originally written (i.e., typed into a computer) by a human in plain text (i.e., human readable alphanumeric characters) ("Source code definition by The Linux Information Project, Project Website").

6 American Telephone and Telegraph, at the time the world's largest telephone company. Broken up in 1982 by the Justice Department due to their monopolistic practices.

This discussion of freely distributed software leads back to the starting point in this chapter: MIT. Richard Stallman was a programmer in MIT's Artificial Intelligence Laboratory in the early 1970s. Due, in part, to the aforementioned culture surrounding software sharing and development, there was a thriving hacker culture in the lab (DiBona 48). However, in the late 1970s and early 80s this culture was starting to collapse as a company had hired most of the programmers who had been working in the lab. Another factor was that the companies that provided their computer hardware (and operating system software) did not distribute source code with their machines. In some cases one had to sign a non-disclosure agreement simply to get a copy of the operating system. This was completely counter to the hacker ethos, where one needed to be able to see the "innards" of the machine and software in order to understand it and where sharing information and code was the norm. Stallman recalls that "The rule made by the owners of proprietary software was, 'If you share with your neighbor, you are a pirate. If you want any changes, beg us to make them.' " (49). Stallman apparently had a visceral and emotional reaction to this. He reasoned that the best way to rebuild the community of hackers was to write software, in this case, an entire operating system and corresponding user software, and to release it freely. He left MIT and started the GNU[7] project, later rolled into the Free Software Foundation.

The principles upon which he built GNU are as follows:

> The term "free software" is sometimes misunderstood – it has nothing to do with price. It is about freedom. Here, therefore, is the definition of free software. A program is free software, for you, a particular user, if:
>
> 1. You have the freedom to run the program, for any purpose.
>
> 2. You have the freedom to modify the program to suit your needs. (To make this freedom effective in practice, you must have access to the source code, since making changes in a program without having the source code is exceedingly difficult.)
>
> 3. You have the freedom to redistribute copies, either gratis or for a fee.
>
> 4. You have the freedom to distribute modified versions of the program, so that the community can benefit from your improvements.
>
> (DiBona 50).

In 1991, a Finnish university student, Linus Torvalds started the *Linux* project - an attempt to write a Unix-like operating system capable of running on any home PC. Note that there was already a similar system available, also freely, in the form of BSD Unix, but by virtue of its origin, it consisted largely of proprietary code from AT&T. Torvalds wanted Linux to be free from any commercial and proprietary code, and freely available and open to anyone to modify or contribute to (Moody). In the twenty years since the first usable kernel was released, it has become the "poster child" for Open Source. From Torvalds working on the

7 The name GNU is a self-referential acronym, meaning "GNU's Not Unix". Stallman's operating system was to be called "HURD".

system alone, to over 10 000 contributors and 1000 companies contributing to the kernel[8] alone ("Linux Development Report, Project Website"). Linux, in some form, is now found in every corner of the tech world, running on everything from mobile phones – in the form of *Android* – to micro-satellites, unmanned aircraft, and desktops.

In 1997 Eric Raymond published "The Cathedral and the Bazaar", discussing two models of free software development; the *Cathedral* model, in which the development is limited to a select group of programmers; and the *Bazaar* model, in which the code is developed openly, with the Internet as a collaboration platform where anyone can watch and contribute. His arguments in favour of the latter include the motto "given enough eyeballs, all bugs are shallow[9]", and a number of "Lessons for creating good open source software", with entries such as "Every good work of software starts by scratching a developer's personal itch", and "To solve an interesting problem, start by finding a problem that is interesting to you." (Raymond 38). The first idea is common in the world of programmers. "Scratching a developer's personal itch" indicating that there is a problem that needs to be solved, and so the developer will write a piece of software to do so. Both of these ideas, as we will see, are quite common within the world of hackers and programmers (and DIYers too). Affect, and more specifically, *affective labour* is an important theme in the discourse of 3-D printing. We see this idea here, framed in terms of working on something for the enjoyment and other intangible benefits in a series of interviews with Torvalds. He noted that "I thought it would be fun" as one of the reasons behind his initiation of the Linux project, and he states that "Most good programmers do programming not because they expect to get paid or get adulation by the public, but because it is fun to program." He then goes on to make the connection to affective labour in the arts by adding "... artists usually don't make all that much money, and they often keep their artistic hobby despite the money rather than due to it" (Ghosh).

Moreover, as with Stallman and GNU, and by extension DIY, and in the stated ideals of the Maker movement, the idea of resistance to current modes of production and consumption is a goal of Linux and Open Source. In this instance their target is Microsoft, the producer of the *Windows* operating system, and known for producing unstable software and monopolistic market practices. Torvalds states explicitly "If Microsoft ever does applications for Linux it means I've won", implying that Microsoft's response to the critical mass and ideological pressure of the Linux project would demonstrate a significant shift in the power dynamics between these two ideologically opposed entities. One finds this discourse in online discussions between Linux developers and users on sites such as "OSNews.com" or "Slashdot" (Ghosh).

2.1.4 *The DIY Imperative*

Andrew Jackson, in "Constructing at home: Understanding the experience of the amateur maker" defines the range of activities performed by practitioners of DIY as primarily within the realm of home maintenance and improvement. The term is often used to describe a far

8 The "core" of the operating system.
9 With enough people looking at a piece of code, someone is bound to pick up problems that others may have missed.

wider range of practices, and as such has led to a body of literature that is "fragmented and decentered" (Jackson 7).

The practice of much of what we today know as DIY has roots in practices of domestic self-reliance. As recently as the early 20th century most people were still repairing their own houses and fixing their own plumbing. This self-reliance has been subsumed by specialisation in modern society, and the specialists inherent in the post-manufacturing economy of services.[10] Stacey Kuznetsov thus defines DIY as "... any creation, modification or repair of objects without the aid of paid professionals." (Kuznetsov and Paulos 295).

There are multiple driving forces and circumstances behind this need. Gelber suggests that due to the rise in industrialisation in postbellum America, portions of the male population had anxieties regarding loss of autonomy and manual competence (found in the artisanal and farming traditions)[11], and as a result, there was a movement towards reclaiming the domestic sphere as a site of masculinity (Gelber). In the 19th century the home and activities related to the home were traditionally female dominated and very little work inside and around the home was performed by men. Only after 1900 was any home-related work undertaken by men in any significant manner (70). The conventional and ornate aesthetic associated with Victorian era furnishings and interior design made way for more utilitarian, simple and robust styles such as "Craftsman[12]", and "Bungalow" that placed emphasis on physical, craft-like skills. In addition, besides starting to perform work in their home, many men were starting to find space within the home for a small workshop or at least space for a workbench (77). Under this emerging rubric men tended to claim the basement. This was already male-dominated space due to the man of the house's duty to clean and stoke the central-heating furnace. The gendering of activities in the home was echoed by contemporary writer and civic reformer Charles Lummis (in Gelber 74) when he states "Any fool can write a book but it takes a man to dovetail a door." This masculinisation of a formerly feminine territory speaks to an interesting and relevant phenomenon. The domestic sphere was in this case a site of labour, in that *affective labour* was at this point traditionally feminine, in the form of child-care, housework, arts and crafts, and took place within the workplace of the home. Both this labour and the workplace itself were now being "de-feminised", but the association with affect remained.

Between the turn of the century and the 1930s, the number of privately owned houses grew exponentially. After 1920, so did the number of privately owned automobiles. Almost half of the workforce at the time consisted of skilled manual workers, who worked on their own homes extensively. Gelber articulates this poetically, stating: "And in lovely symmetry, the working men who bought the inexpensive cars produced by Ford's workers spent their free time building shelters for this first generation of cheap automobiles" (Gelber 82).

It was also during the early 1920s that DIY became more mainstream and allowed for shared ideas and frameworks with the popularity of *Popular Mechanics* magazine, and its collection of pragmatic, useful, and sometimes bizarre ideas and plans for labour-saving devices for the home, and the advent of organisations such as the "Home Workshop guild" of the early

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10 Manufacturing jobs in the USA account for around 14%; the remaining 86% is in service related industries.
11 He notes that before the Civil War only 12% of Americans were formally employed by someone else but by 1910 it was more than 66%
12 After Gustav Stickley, the American proponent of Morris' Arts and Crafts movement

1930s. Gelber positions DIY as a contradictory and enigmatic pastime calling it "leisure that was work-like and chores that were leisurely", and asserting that it "produced outcomes with real economic value that might actually cost more in time and money than the product was worth" (Gelber 82). Furthermore, it was rationalised as "money-saving, trouble-saving, useful, psychologically fulfilling, creative, or compensatory" (83). DIY was now a hobby premised on affective labour. It was performed independent of other rationalisations, for enjoyment, a sense of satisfaction, and even a sense of community.

The use of the term Do It Yourself can be traced back as far as 1912, but the earliest prominent use of this phrase, according to Gelber, was on the front cover of *Business Week* in June 1952, where it was positioned as a growth industry worth in the region of 6 billion dollars annually. DIY had been steadily rising in popularity since the end of the war and the subsequent explosion in housing and returning manpower (Gelber 92). In "Do-It-Yourself: A Walden for the Millions?" Roland cites a later (the late 1950s) shortage of skilled workmen and subsequent rising labour costs as a factor in the rising popularity of DIY (Roland 154). Sarcastically, he characterises some young couples performing DIY on their own home as "so unconcerned with total cost or interest rates that they provide a veritable syllabus of ways to make two dollars do the work of one". This evidences a similar motivation for both DIY-ers and hackers of doing this work for enjoyment. Roland acknowledges the power of affect in driving the DIY-er, pointing out that "In specific, concrete jobs carried through from beginning to end, they find the satisfying feeling of individual identity and measurable accomplishment they fail to get from their everyday routine in an office, the assembly line, or behind a counter" (154).

2.1.5 *Convergence of these forces - The Maker movement.*

At first glance, there appears to be little difference between the DIY community and makers, after all, both groups are all about making, fixing, and improving things. Technology writer, entrepreneur and vocal advocate for the Maker movement, Chris Anderson, acknowledges this problem and asks "What exactly defines the Maker Movement? It's a broad description that encompasses a wide variety of activities, from traditional crafting to high-tech electronics, many of which have been around for ages." (Anderson, *Makers : the new industrial revolution* 25). Amateur design and craft researcher Andrew Jackson, writing about English makers, narrows the focus neatly by defining the makers' ethos as fundamentally the same as that of DIY-ers, but defining and distinguishing them as "Makers of things, rather than maintainers of dwellings and spaces. They make for pleasure rather than necessity, and their making is rooted in a kind of homegrown inventiveness that some writers are beginning to regard with nostalgia" (Jackson 9). McFedries (in Landes 1) defines the Maker as "[A] high-tech tinkerer who lives to take things apart, modify... them to perform some useful or interesting task, and then (sometimes) put them back together." Taking these loose definitions as a starting point, I will develop a more detailed profile of the Maker movement. There are a number of further factors that distinguish makers from *tinkerers* or general DIY enthusiasts.

The most important marker of makers is their relationship with technology. The instantiation of the Maker movement discussed here is evidenced in developed countries, or more specifically, the class fraction that holds a privileged social and economic position, with adequate disposable income and resources, and access to equipment and components (Tanenbaum et al. 2605). Access to the Internet is a major factor. Dougherty credits this with the cohesion of the movement: "Today's makers enjoy a level of interconnectedness that has helped to build a movement out of what in the past would have been simply a series of micro-communities defined by a particular hobby or activity" (Dougherty 12). Kuznetsov agrees that it is this "emergence of new sharing mechanisms" that have contributed to "renewed interest and wider adoption of DIY cultures and practices" (Kuznetsov and Paulos 295).

Many makers are formally employed within the engineering or software industries and so are familiar with the various tools and practices of these disciplines. High-tech tools such as 3-D printers, laser cutters, machine tools, oscilloscopes, and so forth, are integral parts of their toolkit. The advent and rapid adoption of the "Maker Space" or "Hacker Space"[13] concept within the last ten years[14] has accelerated and widened access to these tools. The "Maker Space" is a venue, normally set up as a workshop, where for a small monthly (or per session) fee, anyone can have access to both the aforementioned tools and the expertise of experienced hackers, makers and engineers. These spaces have a history going back as far as 1995 (C-Space, in Berlin), but became popular around 2008, with the founding of *NYC Resistor*, *HacDC*, and *Noisebridge*. NYC Resistor member Bre Pettis later started MakerBot Industries which is a significant turn in the history of maker-driven 3-D printing.

Both Kuznetsov and Dougherty credit this availability of and access to tools as a key point in the rise of the movement (Kuznetsov and Paulos 295; Dougherty 12). It is not just the availability of tools that is important, but the materials for making, hacking, and taking apart (a favourite maker and hacker pastime). Tanenbaum points out that "Our current economy thrives on regular obsolescence, generating a surplus of 'disposable high-technology' that greatly lowers the costs of hacking and experimentation" (Tanenbaum et al. 2605). The emergence of China as the global power in low-cost manufacturing has meant that the market is flooded with cheap, easily modifiable and easily disposable parts and components. Access to these parts is simplified by the existence of online stores or aggregators such as *AliExpress*,[15] *DHGate*[16] and similar sites, where the hobbyist can compare prices from different manufacturers, and order online direct from the manufacturer, in most cases with free worldwide shipping.

Like the DIY community's *Popular Mechanics* magazine in the 1920s, various magazines have emerged to feed the growing maker market. *Make Magazine* appeared in 2005, published by maker advocate and activist Dale Dougherty, with the intention of focusing on DIY and 'Do It With Others (DIWO), thus emphasising the shared and collaborative nature of the movement. Likewise, in a more physical realm of interaction and sharing, the same group of enthusiasts that started *Make Magazine* started a global trend of "Maker Faires". These

13 Hacker Spaces have a spiritual ancestor in the German CCC Hacker collective, and so concentrate on software and Information security, but with much in common with Makers. For the purposes of this paper, I won't distinguish between these two concepts, particularly for the European spaces. The American spaces discussed are pure "Maker Spaces".

14 C-Space, in Berlin, goes back as far as 1995. Metalab in Vienna (2006) is widely credited with being the first Maker/Hackerspace model to be widely copied

15 www.aliexpress.com

16 www.dhgate.com

are gatherings, usually in large cities, of makers, allowing people to exhibit their wares, sell, buy, interact through workshops and lectures, compete, and immerse themselves in the atmosphere of "making". Starting from relatively small beginnings on the West Coast of the USA in 2006, by 2013 there were 98 international Maker Faires. The two flagship Faires in the San Francisco Bay Area and New York City drew 195 000 visitors over a combined six days.[17]

The factors outlined here talk to ideas I presented earlier regarding both the hacker and the DIY communities. Foremost is the sense of collective community, either by sharing one's own work through online discussions or magazines and being able to see what others are doing, or at physical gatherings. On a larger scale is the ability to focus on shared visions and aims for the movement.

2.1.6 *Maker motivations*

I have presented some background into the emergence of the Maker movement and argued that it is motivated by shared principles and material forces that warrant it being called a movement. I now move on to a key aspect of this movement which is the idea of motivation, and in particular, the ephemeral and intangible motivations for this labour. These can be loosely categorised under the headings of learning, affect, and ideology, and these intangible motives are important for the ongoing and often intensive labour that takes place within, and is required to sustain the movement.

2.1.6.1 *Learning*

Kuznetsov cites "learning new skills" as being the second most supported motivation for doing DIY work. He supports this claim with data drawn from a survey of 2600 individuals over a number of communities that could be classed as makers. He then goes on to propose that "DIY is a culture that aspires to explore, experiment, and understand" (Kuznetsov and Paulos 300). This reflects one of the original hackers' motivations, as explored earlier in this chapter, the quest to find out how things work and then to master them. Lande endorses this view in his assertion that makers demonstrate a "propensity toward lifelong learning" (Lande 1). The frequent tendency of makers (as mentioned later) towards *experiment* rather than production of workable solutions supports this.

2.1.6.2 *Creativity and Affect*

I have argued above that the earlier more traditional DIY movements are often driven by creativity and affect. Kuznetsov relates that the "vast majority of [. . .] respondents contribute to DIY communities not to gain employment, money, or online fame, but to express themselves and be inspired by new ideas" (Kuznetsov and Paulos 301). Mark Hatch, in

17 *Maker Faire Africa* was held in Johannesburg for the first time in 2014, however statistics are proving difficult to obtain.

attempting to distill the maker ethos into a manifesto, theorises that creativity and creation are both fundamental to "what it means to be human" (Hatch 25). In addition to the act of creativity, another motivation is that of enjoyment and pleasure from the act of making itself. Despite the end result from the act of making being some sort of tangible outcome, Jackson finds that "...it is clear that in the cases considered the possession of the final artifact tends to be eclipsed by the pleasure and satisfaction gained from the making process" (Jackson 13).

2.1.6.3 *Community/Participation/Resistance*

Historically, communities have accreted around shared ideas of DIY. These include the TMRC at MIT in the 1950s, The Open Source /Linux communities and their numerous factions, and the "Home Workshop Guild" of the 1930s. These communities vary in their purposes and structure (politically and physically) with some being more oriented towards activism and others towards the sense of community. Some meet physically, others never meet physically at all. The hacker figure is often marked as a loner or a "romantic individualist" (Coleman and Golub), yet has the need for some sort of community of practice, at the very least for pragmatic exchange of ideas and the need to show off their handiwork. Despite these conflicting traits, the hacker thrives in the context of online communities, and the Internet has been critical to the development of these communities of not just hackers, but also makers (Kuznetsov and Paulos; Kreimer; Coleman). The original, *Ur-Hackers* from MIT, and their contemporaries were the first generation of hackers/makers/tinkerers to enjoy the communication and collaboration facilities offered by the embryonic Internet.

An important aspect of involvement in these communities that is often emphasised is that of sharing or giving back. That is, in the spirit of Open Source agreements such as the GNU Public License (GPL), you should "pay back" or "pay forward" any changes, modifications or improvements you have made to the software code or hardware design of the project you are participating in. Interestingly, Kuznetsov finds this is not as common as expected as only 51% of her respondents agreed with this as being a factor (Kuznetsov and Paulos 299). Data on participation in other maker projects such as Open Hardware and similar endeavours is scarce for now. Looking again at the Linux community, one set of current statistics puts the number of Linux users at 7.5 million, yet the number of contributors to the core Linux code base is only in the low thousands, with most of these in fact being paid employees of software companies ("Linux Development Report, Project Website").

In addition to the sense of community and sharing, many activity based groups hold some form of political point of view in common. For instance, Bratich finds this in communities of knitters, weavers and practitioners of other handicrafts (Bratich and Brush). They have much in common with the Maker movement in their attitude to craftsmanship and often convene to discuss political issues while they work on projects.

Tanenbaum contends that DIY practice is "a form of nonviolent resistance: a collection of personal revolts against the hegemonic structures of mass production in the industrialized world" (Tanenbaum et al. 2609). This aligns with discourses in the Open Source movement regarding attitudes towards commercial software companies and reflects common discourse from within the Maker movement. The Maker movement's activist role is that of resistance to these "hegemonic structures" and modes of consumption (Anderson, *Makers : the new industrial revolution*; Gershenfeld; Ramocki). These resistances feature as ideas of reclaiming methods and technologies of production from the military-industrial complex, and re-imagining and redeploying these in a hobbyist context. Easier access to these technologies and tools has realised the possibility of "democratisation of manufacturing" (Tanenbaum et al. 2604). Modes and methods of production previously only available to large companies and industries are now within reach of the hobbyist. Not only is this a case of direct access to the tools, but also easier access to infrastructure. Anderson characterises this as such:

> The tools of factory production, from electronics assembly to 3-D printing, are now available to individuals, in batches as small as a single unit. Anybody with an idea and a little expertise can set assembly lines in China into motion with nothing more than some keystrokes on their laptop. A few days later, a prototype will be at their door, and once it all checks out, they can push a few more buttons and be in full production, making hundreds, thousands, or more" (Anderson, "In the next industrial revolution, atoms are the new bits" 4).

Anderson and others are characterising this trend, and by extrapolation, its proponents, as part of a "new Industrial Revolution" (a discourse which will be examined in later chapters of this dissertation). Anderson suggests that "one-person enterprises ... can get things made in a factory the way only big companies could before" (Anderson, "In the next industrial revolution, atoms are the new bits" 4). This democratisation of manufacturing and (latent) entrepreneurship is increasingly being referred to in terms of "citizen empowerment". Ratto attributes this to "Individuals ... afforded digital tools, either through affordable 3-D printing hardware or streamlined outsourcing, [able to] to engage with the act of making directly." (Ratto and Ree 7).

2.1.6.4 *Nostalgia*

Tropes of utopianism are recurrent themes in discussions of technology. Kling (in Sivek 190) notes that utopian ideas are common in discourses on the role of computers in society, and Sivek cites the use of many concepts of American ideology — bordering on nationalism — in publications such as "Make Magazine", namely the idea of technological determinism and utopianism (Sivek). Hand-in-hand with these notions of futuristic technological utopias are feelings of nostalgia for the way things were done in the past. This is reminiscent of Romantics William Morris[18] and John Ruskin and their drive to preserve traditional modes of craftsmanship (Thompson). Even within this zeitgeist of advanced digital technology, there is a move back towards traditional craftsmanship and bespoke artisanal production of certain goods. This can be seen in the profusion of artisanal coffee roasters, craft breweries, handmade clothiers, and even artisanal light bulbs. Sivek quotes an article from Make Magazine:

> Technologies from the dusty attic of the past can have as much mystery, excitement, and allure as those we imagine are just over the horizon. Today's amateur

18 Also a follower of Marxian theory and proponent – with specific limits — of mechanisation in the workplace.

> techno-historians don't just want to read about the gadgets of yesteryear, they want to build them, to interact with their constituent parts, right down to the rivet heads and hand-blown triodes (Sivek 200).

Similarly nostalgic, Melchionne presents the notion that the ideology of craft relies on an ethos of "rugged individualism" and "personal responsibility for one's own material surroundings" (Melchionne 249), echoed by Roland's notion that DIY is a "Walden for the Millions" (Roland).

Throughout this history of the Maker movement and its direct predecessors, commonalities have surfaced that are connected to the concept of work, participation, personal involvement and ideological investment. There are many ways to explore these tensions and relationships. I have elected to trace the concept of labour in its various aspects of affective and immaterial labour in relation to the 3-D printer as a technological artefact integral to and indicative of the Maker movement. Secondly, despite the Maker movement being all about making things, much of the work involved, particularly in the context of technology, computers and software, does not produce anything tangible. This phenomenon has garnered increased attention and is known by the term *immaterial labour*. Thirdly, there is the issue of what one might call the "distancing" of labour. This is the idea that an object might be 3-D printed or fabricated "here and now", but the computer file, and by extension all the labour of conception, creation and design (in the case of the 3-D printer, the CAD work), was done "there and then" at a time and/or place distant from where the object is physically produced.

This is not the place to go into the development of machinery in detail; rather only in its general aspect; in so far as the means of labour, as a physical thing, loses its direct form, becomes fixed capital, and confronts the worker physically as capital. In machinery, knowledge appears as alien, external to him; and living labour [as] subsumed under self-activating objectified labour. The worker appears as superfluous to the extent that his action is not determined by [capital's] requirements.

— Marx "Grundrisse" , 695

3

LABOUR AND THE SIXTH WAVE

The 3-D printer and the Maker movement are a product of specific sets of economic, social and technological markers and influences. Technologies are "crystallizations of socially organized action." (Sterne 367). In other words they are shaped by those who conceive of them, use them and talk about them, and this shaping occurs as a function of how these individuals or groups are themselves shaped by influences on and within society of the period. One of these critical aspects of "socially organised action" is labour, and this research focuses on the different forms of labour involved in 3-D printing technology and the Maker movement. The qualities and dimensions of this labour are also structured by the period (Bourdieu would call this *Habitus* (367)). This chapter examines and characterises the primary forms of labour inherent in the Maker movement, and locates them within a historic context.

Labour, in Marxian terms, exists in dialectical tension with capital, and the relationship between these two elements is essential to the argument presented in this dissertation. In this chapter, I characterise the dominant forms of labour in the current socio-economic era termed the "late post-Fordist" economy.[1] A key marker of this economy is that a significant portion of labour performed by the workforce is unrelated to physical production of goods. For example, 86% of labour in the USA is currently situated within the non-physical and service related industries ("U.S. Bureau of Labor Statistics, Project Website"). These new forms of labour and types of workplace have been theorised and discussed by a number of thinkers active within the Italian Autonomist Marxist movement – see (Hardt, "Affective labor"; Negri and Hardt; Virno). Their work will thus inform the core of my framework regarding forms of work and labour in this late post-Fordist era. I review the primary modes of labour and the major social and industrial points of inflection of the last two centuries to show the origins of the particular forms of labour manifest in the Maker movement and the discourses surrounding the 3-D printer in particular.

The period immediately preceding the industrial revolution in Europe marked the first major transition in labour in recent history. It was characterised by the shift from decentralised artisanal, agrarian and craft-based labour to more formal and centralised factory-based work. Marx's "A Fragment on Machines" was influenced by this transitional era (McLellan), and so this provides a frame for my analysis of labour. In the previous chapter I argued that 3-D printing and similar technologies that promise the democratisation of manufacturing are heralded as the "next industrial revolution". This recurrent invocation of the industrial revolution suggests that it is necessary to identify any parallels between that period and the current period. The shift in dominant modes of labour was afforded by various tech-

1 Given the definition of economy as "the wealth and resources of a country or region, especially in terms of the production and consumption of goods and services", I argue that the use of the term in this research is acceptable without the requirement of delving deeper into economic theory. This is after all, not an economics paper.

nologies such as advanced iron-making, the steam engine, and so forth sets a precedent for similar shifts throughout Western history. The rapid growth of factory-based work due to mechanisation culminated in what is arguably its most formalised manifestation, Fordism. Henry Ford, his production line, and the associated fragmentation of labour, and his drive for absolute efficiency dominated Western manufacturing until the late 1960s.

The next significant turn was one towards intangible labour. This was marked by the Fordism /Post-Fordism transition that heralded a change in not just forms of labour, but changes in the workplace. As labour shifted from manual, production-line based labour towards intellectual, intangible and sometimes precarious work, new workplaces opened up. The nature of the workplace changed from the *public*, such as factories, to the *private*, for example home offices, and other less centralised and formal workspaces.

Economist Nikolai Kondratiev theorised these shifts as cyclic and although the relevance of his ideas to modern economics has been argued by a number of modern economists, *Kondratiev Waves* are a convenient method of classification and ordering of these stages of transition, beginning with the Industrial Revolution and working forwards until the current era (Solomou; Korotayev, Zinkina, and Bogevolnov).

3.1 THE INFORMATION REVOLUTION AND POST-FORDIST THOUGHT

According to Amin, "There is an emerging consensus in the social sciences that the period since the mid–1970s represents a transition from one distinct phase of capitalist development to a new phase" (Amin 1). This new phase has been described by various terms such as *post-modern*, *post-industrial*, and the *fifth Kondratiev wave*. For the sake of consistency in my arguments, this dissertation will use the term *post-Fordism*. Stuart Hall describes this as simply "...A broader term, suggesting a whole new epoch distinct from the era of mass production" (Hall 24). According to Hall, two of the significant markers of this era are a shift from physical work towards information technologies, and a more decentralised labour organisation allowing for more flexible work conditions and organisation.

There are a number of differing approaches to, and speculations regarding the effects of the post-Fordist move (see Elam, (in Amin 43), Peck and Tickell (in Amin 280), and Harvey (in Amin 361)) but the fundamental features of the Post-Fordist economy are generally agreed upon. Bell, in "The coming of the post-industrial society" characterised this move as "a shift from a goods producing to a service economy; a move in occupational distribution away from manual labour to the pre-eminence of professional and technical work". Dyer-Witheford agrees that increasing levels of automation and the subsequent replacement of production line workers by "cybernetic systems and continuous flow processes based on automatic control" is the core marker of this latest phase (Dyer-Witheford 87).

Sternberg has gone further by breaking this epoch down into eight potential new ages, the final three elements are of particular interest in this research (Sternberg). These ages are:

1. The information age.

2. Post-modernity.
3. The rise of global interdependence.
4. New mercantilism.
5. A new age of corporate control.
6. Flexible specialisation.
7. New social movements, and
8. The rise of fundamentalist rejection of technocracy and consumerism.

As a result, (human) labour is moving from handling and processing of materials to supervisory and service functions.[2] Two important aspects quoted by Hall, and reiterated by Sternberg as *the information age* (item 1 in the list above) — which involves the generation of wealth through the exercise of knowledge and trade in information activities, and *The age of flexible specialisation* (item 6 in the list above), marked by new methods of production, decentralised production, and increased flexibility of workforces and working conditions (Amin 2). This is often referred to as the *New Economy*. Castells positions it as "A new economy [that] emerged in the last quarter of the twentieth century on a worldwide scale. I call it informational, global and networked to identify its fundamental distinctive features and to emphasise their intertwining " (Castells 77).

Sternberg's seventh "age of New social movements" is shaping this new economy (Sternberg 1029). He theorises that in the industrial age workers involved in manual work on a production line directed their loyalties towards the company, military, national identity, and so on. He suggests that now they are aware of and have access to a much wider range of concerns and identities. He identifies these as gender, environment, sexual preference and so on (1030). There has been a resultant groundswell of new social movements due in part to the combination of this factor and access to information, and the use of social networking to further causes and connect like-minded people (Bratich and Brush; Chun; Dyer-Witheford). Sternberg solidifies this idea by stating that:

> Despite their diversity, the social movements share a common thread – the open, participatory ethic (Sternberg 1030).

This idea forms a significant thread of this research - the concept of an ethos which supports and is built upon openness, sharing of ideas and resources, and is situated within the context of a post-Fordist, information-based society. Despite difference of interpetation there is consensus that networking technologies such as the Internet and its various applications have resulted in a recent explosion in innovation and invention (see (Korotayev, Zinkina, and Bogevolnov; Devezas, Linstone, and Santos) for more detail on these various arguments). It appears that we are approaching a sixth Kondratiev wave, consistent with what Castells describes as following from earlier similar bursts of technological innovation. These were revolutionary in that they were marked by a "sudden, unexpected surge of

2 This is not the case for all economies in the current period, China being an example.

technological applications [which] transformed the processes of production and distribution, created a flurry of new products, and shifted decisively the location of wealth and power" (Castells 34).

3.2 THE INDUSTRIAL REVOLUTION

However, I return to England of the late 18th century to begin my review of labour. Around this time a series of innovations drove a major change in the cotton industry of the period (Landes). The inventions of Arkwright and others (including the cotton gin, the spinning jenny and the flying shuttle) (Freeman and Louçã 158) afforded massive savings in time and costs (from the producer's point of view) in processing raw cotton. Landes describes these innovations under three headings: The substitution of machines for human skill and effort, the substitution of inanimate sources of power such as steam, and the use of new and more abundant raw materials. These changes would expand rapidly into other industries. At the time this shift started Europe was still essentially an agrarian society. Various forces in the fourteenth and fifteenth centuries (mainly the plague in the late 14th century) had resulted in shifts in power relationships between landowners and serfs (Brenner 38), and most were now free peasants either renting land from landowners, or freeholders. The old model of indentured labour, where villeins were allowed to work some land for themselves, but as payment needed to pay both rent and labour to the landowner to whom they were legally bound had mostly fallen away.

To some extent, the peasants were now free wage workers. As for the primary employers of the period, according to Bryer, social relations of the landed and merchants had begun to merge, and as a result capitalist farmers began joint ventures in exploration, commodity production and trade (Bryer 30). Marx (in Bryer 30) recognises the period from about 1750 onwards as the rise of this capitalist farming with the landowners (the capital holders) primarily employing waged labour. The nature of this labour was mostly manual — farmwork in the form of ploughing, tilling and harvesting, woodcutting and so forth.

On the other hand were the skilled artisans – involved in fields such as masonry, glass making or fabric weaving, and who had some measure of protection afforded by their guilds. Production by these trades was marked by the fact that in producing an object or artefact, the artisan was in control of every step, from selection and procurement of the raw materials right through to finishing and distribution of the article. There was however a steep price for guild membership, as (prior to 1563) the accepted length of an apprenticeship was seven years.

This shifting configuration of technological labour, skills capital and social position is worth noting, as this is the dynamic I will be examining closely in the context of the Maker movement and the 3-D printer. However, before the current era there was another adjustment in this dynamic due to the uptake of mass production and the production line.

3.3 THE AGE OF MASS PRODUCTION

3.3.1 *A Brief introduction to Fordism*

In the years during and immediately after the height of the English Industrial Revolution, most production was still in the form of craft production. A notable exception was an attempt by noted textile designer and early contributor to the English Socialist movement, William Morris. Morris was vocal in his resistance to methods of production starting to take hold in English industry of the period. He was not anti-machine although many others in the period were (Kinna 494), but supported machinery inasmuch it could free up the worker to perform more meaningful, "thoughtful" work. Morris was attempting to streamline the production of hand-made goods, like textiles, stained glass, metalwork and similar decorative arts through basic assembly-line techniques. This turned out to be untenable, though, as the requirement to produce goods in a timely and efficient manner conflicted with his aim to allow workers to retain individual agency (Thompson). This is an early example of the emergence of artisanship as a form of resistance. We have seen these seeds bear fruit in discourses evident in the Open Source movement and even more so with the Craft and Maker movements. This is a core theme in discourses surrounding 3-D printers that resists not just the mechanics of mass production but also the principles of consumer culture.

While affording some of the advantages of (what we now know as) the production line, this did not come into widespread usage until Henry Ford and the Ford Motor Company flipped the switch on the first iteration of the all-too familiar production line in 1908 marking a significant point of inflection in the histories of both manufacturing and labour.

3.3.2 *The year of our Ford, 1908*

The production line in various forms had been running in slaughterhouses for some years (Clarke 4), and in making and packing tin cans over thirty years before Ford (Giedion 115). Ford saw this as a means toward streamlining production and making a luxury item — the automobile — into a commodity that anyone could afford. The driving forces behind his move from craft production to large-scale industrial production were the relative scarcity of skilled workers, particularly at the scale he needed, and the strength of their organisation in the form of the craft unions and guilds (Clarke 1). This movement was marked by a number of features, namely:

- The decomposition of tasks, that is, breaking a large task down into a number of smaller tasks to be done by less-skilled workers.
- Specialisation of tools, or creating tools for a specific function on the production line.
- Assembly of these tools into a machine.

- The subsequent assembly of machines into a machine system, in other words a production line.

This decomposition[3] of tasks also broke the traditional means of controlling labour on the factory floor which was to pay skilled workers per piece produced, and thus meant the need for supervision and other methods of worker control. This also put much more direct control of workers back in the hands of management. (Clarke 4)

Two aspects of Ford's innovation had significant impact on the labour force: the deskilling of previously skilled work, and the radical separation of production from final assembly. The added factor of his injection of scientific and technical progress into the labour process had (and still has) ongoing effects. From both a labour and social point of view, the rigid distinction between skilled and unskilled work allowed this difference to carry over into the workforce at large, leading to the differentiation in the form we still know today with a small force of skilled workers – and the associated larger group of unskilled labourers. Ford understood, however, that this deskilling of much of the work force and the requirement for lower wages for less-skilled work, also led to a corresponding decrease in buying power in the market. This resulted in the working class not being able to afford the very products that were aimed at them. It is no accident therefore, that hackers, the Open Source movement and the makers have common cause in their resistance in terms of their motivations to learn (reskilling), affect (in response to the fragmentation of tasks), community and the collective as compensation for industrial processes, and finally open resistance to the principles and practices of the late capitalist model.

3.4 Models of labour and value

Despite the strong academic tradition theorising labour in previous eras, there are fewer options available which adequately covered new and non-manual forms of labour in the current era. However there is a renewed interest in Marxist thought led by Žižek and others in light of the recent global financial crisis (Žižek). For instance Dyer-Witheford cites Derrida in asserting that rather than Marxism being rendered obsolete by the information age, certain of Marx's themes become more apparent, for example the internationalisation and automation of production (Dyer-Witheford 8). The extent could not be foreseen by Marx, but the forces of globalisation, pre-eminence of the media and tele-work all have direct bearing on the Marxian concept of *general intellect* (11). This concept originally had implications for the elimination of workers from the factory floor (by automation), and global transport and communication networks binding the world market together. Fuchs, in his work on digital labour, asserts that Marxism provides the most comprehensive framework for these discussions:

"When discussing what work and labour are, Marx offers the most thorough analysis that is available. In encyclopaedias and dictionaries of economics, entries such as labour, labour power, labour process or labour theory are therefore often predominantly associated with Marx and Marxist theory" (Fuchs and Sevignani 239).

3 Actually, Marx, in his essay *Machinery and Modern Industry'* (Capital, Vol. 1) described this process quite well.

Marxism can be seen as a multiplicity of themes and ideas, often (in the spirit of dialectics) in conflict with each other. Dyer-Witheford characterises this as "...Not so much of Marxism as of 'the Marxisms' " (Dyer-Witheford 8). To develop my argument I will focus on a very specific set of these Marxisms: those theorised by the Italian Autonomists. The primary thinkers in this area are Michael Hardt and Antonio Negri and their work "Empire". Some theorists have described this area as more *post-Marxism* than Marxism itself (Hall et al.; Thoburn), although within this research that is more a semantic issue than anything else.

The hobbyist 3-D printer and the Maker movement typify these post-Fordist forms of production and labour. Secondly, the emergent discourses surrounding the 3-D printer in the hands of hobbyists and Makers are very similar to the Autonomist dialogues on affective and intellectual labour. I have already introduced aspects of these motivations and ideologies in Chapter 2 when discussing the Makers and their predecessors and influences. Notwithstanding the correspondence between the Maker movement's principles and mythologies and the ideological underpinnings of the Autonomists, there is a problematic irony in that despite labour being central to these parallels, it is rendered invisible when talking about the 3-D printer and the Maker movement.

The following section is not an attempt to perform a Marxist-centric analysis of these issues, but rather to surface some of the important discourses and ideological cornerstones that inform this critical reading of this labour in a post-Fordist context. It is not my intention to argue whether or not these ideas are valid, but rather to point them out in advance of the textual analysis I perform in Chapter 4.

Traditional Marxist thought models capitalism as a steady, linear progression through multiple stages, ultimately ending in a monumental crisis due to declining rates of profit. Marx was of the opinion that the estrangement (which he refers to mostly as alienation) of the worker occurred exclusively where the worker did not own the means of production, this being the capital, or tools and resources in the factory owned by the capitalist class. Therefore the worker was cut off from the value produced by his own labor. This concern and the associated response is evident in the Hacker, DIY, and Maker movements discussed in Chapter 2, where the labour performed by these groups can be seen as an attempt to reclaim some of this agency and its value. Marx cited this as the contradiction of capitalism, the conflict of other, historically overt forms of production such as slavery and feudalism being occluded by a "cynical" ideology of social and technological progress. Hardt, Negri and the Autonomist (or Post-Operaist)[4] Italian Marxists, operating in the industrial labour turmoil of 1950s Italy, discarded this in favour of the idea of attack and counterattack, crisis and response. Dyer-Witheford (in Murphy and Mustapha 137) describes how, in the late 19th century, capital's response to the residual craft power of the artisanal labour employed in new factories was the deskilling regimes of Taylorism[5] and Fordism. Here we see a productive positioning of the idea of craft deployed in opposition to the idea of deskilling. We can read adherence to the principles of craft as a sort of resistance to the atomisation, alienation and fragmentation of the mass production process.

4 "Post-workerism."
5 Scientific Management: in which tasks were broken down and redesigned according to time and motion studies before then being taught to workers on the line.

As a response, the newly created assembly line mass worker began organising into unions, and so on in a repeating cycle of crisis and response. The premise of Autonomism is that this constant and cyclical series of struggles between labour and capital mutate and reshape each other through each cycle. Within these struggles, the driving argument behind the force of labour is that, whereas capital is dependent on labour, labour is not necessarily dependent on capital. To this end, Dyer-Witherford states that "Labour does not need capital. Labour can dispense with the wage, and with capitalism, and find different ways to organise its own creative energies" (Dyer-Witheford 137) and is thus potentially autonomous from capital and the traditional hegemonies of structure and power within industry and production. Thoburn describes this as marking "... the passage from apparently orthodox concerns with class, capital and the economy, into a post-Marxist concern with the possibilities of agency, popular practices and new social movements" (Thoburn 75).

Hardt and Negri's Autonomous Marxist thought provides a convenient and timely lens through which to view facts and perceptions of labour and value in the Maker movement.

In traditional Marxist thought, valorisation refers to the idea that workers add value to capital assets and resources through application of their labour. This is also often referred to as the creation of surplus value. In order for the owner of this capital to make a profit – he needs to ensure that the worker spends longer effectively working for free, that is, *surplus labour*; rather than working to secure the value of his labour power in the form of *necessary labour* (Marx, *Capital : Volume I, Der Produktionsprozess des Kapitals* 325). Cleaver describes it as "the way in which capital subordinates, transforms and utilizes human productive activities for its own purpose: endless command over society." (Cleaver 9).

In contrast, the idea of self-valorisation is explained by Negri as "the possibility of not working hard, of living better, of guaranteeing the wage" (Murphy and Mustapha 90). Cleaver expands this to also mean to not just ensure one's own wellbeing within (or outside) the workplace, but to find time and space to become involved in projects autonomous and external to the traditional workplace. This talks directly to the need seen in both DIY and the Maker movement for affective labour — hobbies and labouring for the betterment of self and living conditions, and personal growth and empowerment.

Similarly, an important concept in the context of traditional Marxism is that of alienation. Kai Erikson deconstructs the factors behind alienation in an industrialised capitalist economy (Erikson 2). Firstly, invariably both the products themselves, and the means by which these products are produced both end up being owned by someone else other than the worker. Secondly is the aspect of division and fragmentation of labour. This is when the process of production is broken down into smaller and smaller pieces and the worker tends to use less of their skill and knowledge in performing their small task. The worker thus tends to lose any sense of the bigger picture of the production process and its logic (Braverman 317). Thirdly, the labour of a worker ultimately becomes just another commodity, in the manner of manufactured goods. According to Marx , "Labor not only produces commodities; it also produces itself and the workers as a commodity and it does so in the same proportion in which it produces commodities in general." (Marx, Estranged labour)

These factors serve to distance or alienate (or estrange, as some translations of Marx use) the worker from the product of his labour. In some cases this was intentional given the drive for higher efficiency by Taylorism and Fordism and the desire to shift agency and control of the production process away from the factory floor towards management. Braverman writes that "the labor process has become the responsibility of the capitalist. . . It thus becomes essential for the capitalist that control of the labor process pass from the hands of the worker into his own . The transition presents itself in history as the progressive alienation of the process of the production from the worker" (Braverman xiv). In contrast, the utopian discourses seen regarding Makers' user of the 3-D printer position the Maker as resisting these factors by owning the process, and therefore having skill and agency over the entire process of production. These discourses are suggesting that the Maker is trying to remove themselves from this process of alienation and commodification.

3.4.1 *Affective Labour*

The affective manifestation of immaterial labour was theorised early on by Mariarosa Dalla Costa and Selma James, Autonomist Marxists who recognised the role of the reproduction of labour power, and the associated unwaged labour in the home (Fortunati 145). Negri defines affective labour as ". . . immaterial, even if it is corporeal and affective, in the sense that its products are intangible; a feeling of ease, well-being, satisfaction, excitement, passion — even a sense of connectedness or community" (Negri and Hardt 96). This is precisely the kind of intangible reward seen in the Hacker and Maker communities, illustrated by Linus Torvald's earlier statements (see Section 2.1.3) on why he started the Linux project for fun and a sense of community. Hardt and Fortunati reiterate the traditional place of affective labour as being in the home, related to childcare and homemaking (Hardt, "Affective labor"). However, Fortunati argues for the de-feminisation of affective labour (Fortunati 14), in that much theoretical, symbolic and artistic work shares common traits in being undervalued, often unwaged, and heavily reliant on emotional and social wellbeing and rewards in lieu of traditional wages.

3.5 THE GENERAL INTELLECT AND BIOPOWER

At the time Marx wrote "Grundrisse" in 1857, the generation of wealth depended primarily on workers directly expending physical labour. He suggested that at some point in the future of capitalism this would change, that wealth creation would depend on the "development of the general powers of the human head" (McLellan 694). He went on to describe this in various forms, including *social intellect*, and *the general productive forces of the social brain* (709). This is commonly described within Autonomist Marxist theory as the *General Intellect* redefining Marx's original idea of this being "power of knowledge objectified in the physical machinery and plant of the factory" (Ray 3). This is by no means a leap of faith if one considers that the physical machinery and plant of the new social factory is in fact the human brain. Arviddson describes this as ". . . putting to work commonly available, socialised competencies" (Arvidsson 17), emphasising again the idea that it is not just the individual's cognitive abilities and labour that contribute to this workforce, but the power of social connections and networks. The emphasis on the social in these terms is important given the post-Fordist turn towards knowledge-based labour, and the reliance and intensive usage of communications technologies for not just everyday communication, but collaboration. Tiziana Terranova, who writes extensively on unwaged intellectual labour amongst internet communities quotes Tapscott in describing the digital economy as a "new economy based on the networking of human intelligence" (Terranova 37). She goes on to theorise the Internet as highlighting "the existence of networks of immaterial labor and speeds up their accretion into a collective entity. " (42). Returning to to my earlier examination of the Maker movement in Section 2.1.6, one can see how the ideas of collaboration and sharing apparent within both the Maker community and the Open-Source community seem to reproduce many of these ideas.

3.6 THE NEW WORKPLACES - THE SOCIAL FACTORY

Where traditional forms of manual labour require physical presence, whether it be a farmhand (who, by nature, has to work at a farm), or a factory assembly-line worker, who obviously has to work on the assembly line situated in a factory, these new forms of labour are more flexible. Aided and driven by the pervasive penetration of communication and data processing technologies this labour may take place anywhere. Negri calls this concept the *Factory without walls*, and describes it as a function of labour being deterritorialised, dispersed, and decentralised (Negri 89). Dyer-Witheford extends Negri's earlier idea to position the worker as part of a *post-Fordist proletariat*, and if the "... mass worker had labored on an assembly line, the socialized worker was at the end of a fiber-optic line" (in Murphy and Mustapha 139). Dyer-Witheford goes so far as to call those who work within this context "Cyborgs", in that the combination of human and computer is required to perform this work (in Murphy and Mustapha 139).

Negri argues that workers within the factory are learning the skills and knowledge required to use the tools of global industry, and at the same time, are learning how to use these same tools outside of the factory. With the knowledge and skills having dispersed outside the traditional factory into the very fabric of society, capital has gained even more access to human resource. Negri states that "Work (production), education and training (reproduction), and leisure (consumption) all become points on an increasingly integrated circuit of capitalist activity" (Negri and Hardt). This is an important point to remember later in Chapter 4 when I discuss the struggle between distancing from, while being co-opted by, traditional industry. Hardt describes modernisation and industrialisation as transforming and redefining all elements of social life. When agriculture was modernised into industry, the farm became a factory with all of the inherent discipline, technology, wage and power relations, and in a similar manner society was gradually industrialised and ultimately "society became a factory" (Hardt, "Affective labor" 91).

Negri has devoted considerable effort to exploring the role of information and communication technologies. He states that his *factory without walls* can also be seen as an information factory, a system whose operation depends on the "growing identity between productive processes and forms of communication". Dyer-Witheford embraces Negri's idea of the post-

Fordist proletariat and how its relationship with high-technology differentiates the worker in this case from the Fordist-era worker (Dyer-Witheford 112).

Despite having names of Greek shepherds (Polystyrene, Polyvinyl, Polyethylene), plastic, the products of which have just been gathered in an exhibition, is in essence the stuff of alchemy. At the entrance of the stand, the public waits in a long queue in order to witness the accomplishment of the magical operation par excellence: the transmutation of matter. An ideally-shaped machine, tubulated and oblong (a shape well suited to suggest the secret of an itinerary) effortlessly draws, out of a heap of greenish crystals, shiny and fluted dressing-room tidies. At one end, raw, telluric matter, at the other, the finished, human object, and between these two extremes, nothing; nothing but a transit, hardly watched over by an attendant in a cloth cap, half-god, half-robot.

— Barthes, "Mythologies", 97

4

DISCOURSES AND ANALYSIS

4.1 METHODOLOGIES

This analytical chapter has dual aims. On the one hand it provides a detailed reading of the themes, mythologies and discourses that position the technology of the hobbyist 3-D printer in its social context. The second aim is more complex. A major aspect of this dissertation is the complexity and politics of invisible labour. However, the term itself points to the fact that labour is seldom mentioned in discourses — invisible labour is by definition, invisible. Can one describe and characterise the lack of something? To deploy another science-fiction trope, the Invisible Man[1] could only be seen by his hat and gloves — we could see the secondary effects, not the phenomenon itself. However by means of the methods of CDA I will lay open the constructions and representations in the discourses that surround the 3-D printer in the popular imagination proffered by the commercial media.

The primary methodology used is MCDA. Traditional Critical Discourse Analysis is centred squarely within the concept of social semiotics, and draws from various theoretical sources, including Habermas and the Frankfurt School's Critical Theory[2] (Habermas) and various aspects of Marxist thought, most notably Gramsci (Gramsci, Nowell-Smith, and Hoare). Critical Discourse Analysis aims not just to describe discourse, but, being grounded in social history, semiotics and linguistics, also attempts to explain how and why it was produced, and the related ideological underpinnings (Tenorio). The additional dimension of multimodality in MCDA is motivated primarily by the character of the material under investigation. Advertisements and magazine articles are multimodal media where graphical and visual, and verbal/textual modes of communication coexist and inform each other. Multimodal Critical Discourse Analysis provides "a set of tools that [allows us] to study the choices of visual features just as Critical Discourse Analysis allowed us to study lexical and grammatical choices in language" (Machin and Mayr 7), and thus the tools to show how images, photographs and other graphics work to create meaning.

Discourses comprise ideas, values, identities and sequences of activity, and MCDA examines how semiotic choices used in text and visual forms of communication can signify these even though they are not explicitly present. Therefore, much like the Invisible Man, the messages that frame the 3-D printer and speak to the Maker movement can be read in terms of silences, absences and substitutions. Levine characterises Multimodal Critical Discourse Analysis as:

1 Claude Rains, 1933.

2 Critical Theory has a long tradition of examination of technological determinism and ideas of reification of technology and its effects (Ellul and Neugroschel; Winner)

> The recognition that all discourse is multimodal. That is, language in use, whether this is in the form of spoken language or text, is always and inevitably constructed across multiple modes of communication, including speech and gesture not just in spoken language but through such 'contextual' phenomena as the use of the physical spaces in which we carry out our discursive actions or the design, papers, and typography of the documents within which our texts are presented. (LeVine and Scollon 1)

David Machin and Andrea Mayr's approach to MCDA provides a useful starting point. Their approach to this form of analysis involves closely examining the following characteristics of material (Machin and Mayr 13):

- Firstly, is the lexical analysis of the text itself, determining how lexical fields[3] are used to signify meanings not made explicit in discourses, and how these can be used to foreground and background issues and elements. For example, what is missing? Is a significant population group missing from this discourse, and why is this?

- The next focus of analysis is the attitude of the speakers: what quoting verbs are used ("Fred whined about his work"). This affects how we are driven to evaluate a speaker and their message. This may also be applied to visual elements, such as the gaze in a photograph, for instance where are the participants looking - at the viewer (photographer) or elsewhere?

- The third area of interest is the representation (visually and linguistically) of people and all aspects of identity, and how various aspects are foregrounded and backgrounded, and how this foregrounding or backgrounding act as resources for conveying or suppressing power. Machin suggests that we "... can ask if some participants are represented as always engaged in actions that have a material outcome, whereas others are always engaged in mental-type processes that may suggest they are more thoughtful and humane, or, on the other hand, simply less able to act" (Machin and Mayr 12). Uses of metaphor and rhetorical tropes should be noted, as should linguistic strategies of concealment, that is, implying meanings without them being explicitly stated, or presenting issues as fixed and accepted, when they are quite obviously arguable.

4.2 MYTHOLOGIES

In analysing these texts, there are a number of factors to be aware of. Firstly, is that outside of specialised industry this is a relatively new technology. Therefore, I have looked closely at the language and metaphors used to construct this technology in the eye of the consumer. Especially whether new language and terminology is being deployed, and how pre-existing language is being deployed. Furthermore, what images and metaphors are being used to represent the technology? According to Barthes, the primary characteristics of constructions of *myth* are as follows: Myth is a type of speech, it is a "mode of signification, a form", and since it is a mode of speech, "everything can be a myth, provided it is conveyed by

3 Words acquired their meaning through their relationships to other words within the same word-field.

a discourse" (Barthes 107). In addition, Barthes notes that in this case, "speech" is not just spoken word, but can be taken as any mode of communication, being written text, images, cinema, and so on. Myth is a semiological system. As a "signifier" talks about the "signified" within semiotic language, Barthes positions myth as a "metalanguage", this being a "second language" employed to "speak about the first" (114)

A study performed by Pierre Bourdieu on the sociology of amateur photography is pertinent in explaining how existing language is deployed to talk about new technologies. Given the "naming" of the device as a "3-D printer" (by no means a natural or self-evident choice), the associated usage of printing metaphors is instructive. Fredric Jameson examined this study and noted two compelling findings: Firstly, was the "need to justify this practice for which society had not yet produced any codified role or status", and the subsequent solution to this problem with the photographers "borrowing" aesthetic discourses and terminology by "reproducing painting's apologia in all its variants" (Jameson 207). Similar reproductions and cooptions of language have been theorised by Langdon Winner (Winner) regarding discourses of revolution and change brought about by technology. I will examine these thoughts in due course.

4.3 Preliminary analysis

The range of texts selected for analysis consists of articles from online and print publications, and advertisements from print publications. I have extracted key examples that typify the prevalent discourses surrounding 3-D printing and the Maker movement, and shed some light on the invisible aspects of labour. The small sample of texts selected are intended to provide an illustration of discourses and ideas theorised and discussed in this dissertation, and as such this cannot in any way be considered to be a corpus analysis. The texts selected span the time frame from late 2012 until mid-2015, and all except one are from American-based publications. The sole South-African text is an advertisement from "Dion Wired". At the time of my preliminary research and selection of sample materials, all articles examined from similar local commercial publications and sources were syndicated and localised international stories, and so the only uniquely local material available was the aforementioned advertisement. The initial analysis pass involved an open coding process, looking for commonalities within the material, then creating a tentative set of labelled categories for ideas and discursive techniques used within the material. I then performed a second pass of selective coding, taking the categories from the first pass and finding all instances of these deployed in the texts (with a certain amount of reflexivity in altering and refining the categories from the first pass of coding) and identifying further sub-categories and themes. This is not intended to be a statistical analysis and the texts were chosen to illustrate a number of tropes that surfaced via historicisation of the Maker movement and its antecedents (Chapter 2). The result of this process is outlined in table 1.

The above readings of my texts revealed two primary groupings of discourse. First is the deployment of existing discourses and mythicisations of technology, including:

- Aspects of science-fiction and futurism, utilising ideas of "replicators" or "cornucopia machines", utopian ideals of automation and robotic labour freeing humans from the need for labour (and allowing them to concentrate on creative endeavours).

- Borrowing status and credibility from "hackers" and similar technocratic figures, while also using this to anchor the binary opposition to ease-of-use of the technology.

- Rhetorics of disruptive technology and revolution. Foremost is the idea that this technology is changing the way goods are manufactured and potentially undermining the established structures of business and manufacturing.

The second grouping involves the construction of new representational strategies and discourses around 3-D printing technology. What we see in this are:

- Ideas regarding the domestic space. Positioning this technology within the home through both textual or visual language of location, and by describing the 3-D printer as an appliance or home entertainment device. This includes connecting the technology with "play", either through the use of the machine, or using the machine to produce toys. In a related manner, the discourse of play is often used when describing the technical and skills capital required to use the 3-D printer, using phrases such as "child's play".

- Locating the technology within a particular target market. I use the term "target market" here with caution, as these texts suggest that the actual market to which these machines is useful is unknown, therefore in this case it is primarily the demographic of the consumers of the medium in which the particular text has been published. As seen in the demographics quoted from media kits and other data at the start of each reading, this is the well-educated, affluent middle class. A portion of this target can be termed "early adopters", who buy new technology well before it is mature and stable, and often with unknown application, hence the preponderance of "tchotchkes"[4], "trinkets" or, as Elizabeth Royte, the author of one of the example texts states, "cheap plastic crap".

- The idea that 3-D printing technology will allow for the "democratisation of technology". This is inextricably linked with the idea above of disrupting markets and traditional manufacturing, but with the added rhetoric of "reclaiming the act of production" for the proletariat, and with the potential for everyone to have one of these machines. This idea is often deployed through invocation of chain stores such as Walmart or Best Buy. I have also included explicit references to workers and ideas of cost and value of labour in this section.

- The idea of latent creativity, entrepreneurism and innovation. This discourse centres around the implicit assertion that everyone has the skills, ideas and motivation, and just needs the right tool or machine to allow these traits to manifest.

4 A "tchotchke" is a 1960s Yiddish word describing "a small object that is decorative rather than strictly functional, a trinket." This term is deployed often in discourses of 3D printing, and as such I thought it was a useful piece of terminology to represent many of the objects described.

Whether these new strategies will solidify with respect to the 3D printer is yet to be seen because discourses and tropes evolve given shifts in context, and in turn can cause shifts themselves. However, through a systematic analysis of these clusters, I make the argument that the types of discourses deployed tend towards the sustained occlusion or deflection of representations of labour.

The following table outlines the presence of each of these discourses in each text analysed.

Deployed technology myths					
Sample text	Item 1 – Advertisement: The "UP!" 3-D printer	Item 2 – Advertisement: Dion Wired	Item 3 – Article: "Shaky start, but 3D printing revolution underway"	Item 4 – Article: "The New Makerbot Replicator Might just Change your World"	Item 5 – Article: What Lies ahead for 3D Printing?
Science-fiction, futurism, technological utopianism	Not present	Present	Present	Present	Present
Romanticisation of hacker, nostalgia, borrowed status from hackers	Not present	Not present	Not present	Strongly present	Not present
Disruptive, revolutionary, association with Open Source	Not present	Not present	Present	Strongly present	Not present
Emergent Discourses					
The Domestic Sphere & conflation with work-space					
Location	Present	Present	Present	Present	Present
Language of appliances	Strongly present	Present	Present	Strongly present	Not present
Toys, Fun, Play	Present	Present	Present	Strongly present	Not present
Childs play, "plug and play", "press a button"; skill level	Strongly present	Strongly present	Not present	Strongly present	Not present
Target Market					
Middle class, affluent	Strongly present	Present	Not present	Strongly present	Not present
"Cool", early adopters, unknown usage, tchotchkes	Strongly present	Present	Strongly present	Strongly present	Present
Democratising technology, workers, free, "designs for free"	Not present	Present	Strongly present	Strongly present	Strongly present
Innovation, Creativity, Entrepreneurship (latent)	Present	Present	Present	Strongly present	Present

Table 1: Results of first-pass analysis

4.4 SAMPLE TEXTS

4.4.1 *The "UP!" 3D printer, Make Magazine, Volume 37*

See p.73

The first item analysed is an advertisement for a small 3D printer. The advertisement is from Volume 37 (Q1 2014) issue of *Make Magazine*. This magazine targets the Maker movement, and was first published in January 2005 by Maker Media.The magazine and company were founded by Dale Dougherty,[5] a significant figure in the global Maker community. In 2006, he organised the first Maker Faire, to "celebrate arts, crafts, engineering, science projects and the Do-It-Yourself (DIY) mindset." The readership of Maker Magazine is 80% male, with a median age of 42 years, relatively affluent ($110 000 annual income), and with approximately 77% owning their own home. 76% of these readers are college graduates, with 27% having postgraduate qualifications. 33% have technical job titles in fields involving science, engineering, or research and development. The total readership of Make Magazine (including passed-along issues) is estimated at 300 000. ("Make Magazine Media Kit")

The products in the advertisement appear to be standard hobbyist-level 3D printers. There are two printers represented, one named the "UP! Mini" and the other named the "UP! Plus 2". They both appear to be in the process of (or just having finished) printing an an unrecognisable abstract shape. These printers, plus various items of text occupy the right-hand half of the advertisement. The left-hand half represents a child assembling a stack of building blocks. He is sitting at a table, with a soft-focus view out the window behind him. His gaze is directed at the topmost building block, but also beyond that, towards the printers in the top-right hand corner of the advertisement.

There is a "badge" over the corner of the leftmost printer identifying it as "Best in class" for the "Just Hit Print" class in the "Make: Ultimate Guide to 3D printing 2014". This comparison is in the form of a special issue of the magazine, published in 2014. The upper text on the advertisement reads "You can't stop innovation", with (one assumes) the company name, "Tiertime", and the text along the bottom of the ad reads "UP! Create! Innovate!'. Other than a small logo advertising "PP3DP" and smaller text announcing that the product is available to purchase through *Amazon.com*, the advertisement contains no other details of the product or contact details for the company in question.

The advertisement, taking up the top half of the page, is positioned above an advertisement for a CNC milling machine used for performing complex metal machining tasks. This machine is from a well known manufacturer of machines for precision, small-scale industrial and technical work (Tormach). The lower advertisement shows the machine, what it can do (there is a series of pictures of products made with it), and has prices for a number of variants in the advertisement. This is fairly normal convention for advertisements of technical products: the desired information being: what its capabilities are, the requirements — both skill and infrastructure — to use the machine, and how much it costs. This advertisement

5 Co-founder of O'Reilly publishers, probably one of the largest publishers of technical books in fields ranging from programming to hobbyist robotics and electronics, and founder of GNN, the first commercial website.

would not be out of place in a trade magazine. The "UP" advertisement, by comparison, has no pricing or additional information about the machines. The fact that one can order this from Amazon.com reinforces that this is an appliance — rather than having to order directly from the manufacturer or a specialist 3-D printer store, one can order this printer and have it delivered with your groceries, books and small home appliances.

The "Mini" version of the printer has a door on the front, and is in sleek satin-finish black. It would appear that this is meant to sit on a countertop somewhere. This is in contrast to the "Plus" model, which looks as though it is aimed at the more technical "hobbyist", with exposed mechanical parts and yellow warning labels.

The setting of the photo in this advertisement appears to be a diningroom or kitchen table, suggesting a domestic space rather than a workshop or even the home office or study. The child indicates ease of use and simplicity in managing the printer, it is"child's play". Taken in combination with the badge indicating this product as winner of "Best in Class - Just Hit Print" in a previous issue of *Make Magazine* implies that this machine is simple to use, and designates the primary target market as not the tinkerer, basement inventor or engineer, but the general consumer. "Just Hit Print"implies that there is no labour required on the end-users' part to use and create objects with this printer. The entire process of conceptualisation and design is distilled into the simple action of pressing a button.

The building blocks that the child is playing with spell out the word "HOME", reinforcing the connection with a domestic space, while creating some tension with the representation of the two models of printer. The first model, the "Mini", with a sleek black finish and a door on the front so the production process can be discreetly shielded and fingers protected from the innards of the machine looks like any object that may be seen in a home office, whereas the hobbyist model has exposed mechanics and yellow "caution" labels.

Both models of printer in the advertisement are printing an unidentifiable object, a *tchotchke*. In juxtaposition with the other advertisement for a "serious" machine tool (the Tormach milling machine), which shows a "real-world" application for the tool advertised, there is no application or end-use being advertised for these 3-D printers. This is a trend apparent in all of the texts analysed where there are an overwhelming number of toys and "ornaments" produced, but little in the way of useful products. The presentation of this advertisement appears to make little effort towards selling a product, given the lack of technical details. The Tormach advertisement is selling a tool to those that need it, whereas this advertisement is selling affect via an emotional appeal to the imaginary and aspirational idea of a tool. The uses to which this tool may be put are not stated at all in this advertisement.

4.4.2 *"Dion Wired", Standalone advertising brochure, December 2013*

See p.74

This item is an advertisement for a consumer-grade 3-D printer in a glossy, newspaper-insert brochure representing the *Dion Wired* brand. The brochure is A4 in size and 67 pages in length. Dion Wired is targeted at the "higher-income" South African consumer, and bills itself as "South Africa's premiere consumer electronics and appliance concept store" for South Africa's "discerning and tech-savvy customers" ("About DionWired - DionWired, Project Website"). The brochure itself is titled the "2014 collection" and combined with a cover photograph of a smartly dressed man and woman sitting on a row of steps, presents more as a fashion spread than a technology and appliance brochure. Other items advertised in the brochure include a R 389 000[6] television, R 30 000[7] refrigerators and 14 varieties of espresso machine.

Examining the context of the advertisement on the page proves an interesting exercise in locating the consumer this is aimed at. Below the 3-D printer are advertised two "quadcopter drones" [8] , a smartphone-controlled toy car, and a wireless plant monitor. These range in price from R800[9] for the plant monitor to R5000[10] for the drone, up to R20 000[11] for the 3-D printer. The 3-D printer is framed as a toy by means of its proximity to the other items on the page. They are aimed at those with significant disposable income, for gadgets of limited utility, or that may be marketed as solutions (however unwieldy and complicated) to an actual problem, for example the wireless plant monitor.

Positioned at the top-left-hand corner is a badge stating that this product is part of the "2014 collection". This is not on every page of the brochure, implying, in keeping with the theme suggested by the brochure title and cover, that this is a "must-have" for this season.

The advertisement in question occupies the top half of the page, and this space is occupied by a photograph of the 3-D printer surrounded by small objects that appear to have been printed by it. The printer itself is similar in appearance to many other hobbyist 3-D printers, but with less of the mechanical innards showing. This positions the printer as a product for those who are not overly concerned with the inner workings of the machine: it is more an appliance than a tool.

The objects surrounding the printer are all brightly coloured in shades of green, orange, red, and blue, and they are models of aeroplanes, cars, houses, and what looks like a small office block. The first impression given by both the objects and the bright, primary colours, is that they are toys. However, given the target market for the product, they may also be seen as aspirational items (houses, cars, aeroplanes), Thirdly, they all seem to espouse iconic designs, they are recognisable as examples of good and aesthetically pleasing design. The aeroplane is a sleek jet fighter, the car is a Citroën 2CV, the house is a Victorian-era mansion. There is no brand or model apparent at all in the text, the title is simply "3D Printing". The opening sentence states "Meet the 3D printer designed for you" – this implies a personal relationship, thus softening the initial connection with the technology, as though this is your own personal robot or assistant. The printer has been "designed" for "you", repeating the idea of "design" and presenting almost as a custom-made device, possibly even a bespoke device with which one can produce bespoke items.

6 USD 25000
7 USD 2000
8 Remote-controlled helicopter-like toys with cameras, in this case controlled by a tablet or smartphone.
9 USD 51
10 USD 320
11 USD 1280

The text continues with the sentence "Turns living rooms and classrooms into creative spaces". The explicit mention of the living room locates this device within the domestic space and then as an entertainment device. The idea that this product "turns" these places into "creative spaces" implies that it takes nothing more than this device to make creative things happen, which occludes any requirement for pre-existing forms of capital – skill, support, ideas, other tools and software – needed to perform these acts of creativity. As seen in the other texts examined, the idea of just pressing a button or clicking on-screen is then deployed: "putting kids and adults just a click away from their imagination". The process is presented as instant and labour-free (which reinforces what was seen in the sleek, no-mechanics-exposed design of the printer that there is no need to know or do anything else). The mention of "kids" again suggests the notions of "toys" and "play", and the device being simple enough for a child to use. Despite the overarching theme of play and toys, the text then states that one can "print practical things" for your home and office, implying that this printer is not just for entertainment, that it can perform useful functions, too in order to prove utility for what could otherwise be seen as a frivolous or un-utilitarian purchase.

To the right of the photograph of the printer is a block of text in smaller type listing its features. The first line talks to the concept of simplicity and no prior skills needed by stating "plug and play simplicity - just plug in and start". Further in it makes the assertion that the "Cube has software that preps your files for printing" reinforcing ease of use, with no labour required on the part of the user: the Cube does all the work for you. The amount of user interaction with this software is an unknown. Finally, the print states that the printer is supplied with 25 free 3-D files "designed by professional artists" – the theme of creativity, design and art is again deployed here, and the possibility of tapping into the capital afforded by printing designs created by "professional artists" in your own living room. Any labour that might exist (that of the professional artists) is firstly distant, and secondly, part and parcel of the commodity being consumed.

4.4.3 *"Shaky start, but 3D printing revolution underway", Boston Globe Online, July 2015*

See p.75

This text is an article on the "Boston Globe" website. According to the "Boston Globe Online" page "Our Audience", the readership is 52% male between the ages of 30 and 59, with incomes well above market average ($ 125 000 per annum). 75% of these are homeowners, and are "significantly more likely" than the market average to have an advanced degree ("Brand – Globe | Corporate Site, Project Website").

Above the article is a photograph showing Michael Perrone, a co-founder of this Boston-based company (Voxel8) standing behind a tangle of wires and equipment, looking somewhat disturbed. The article opens with the statement to the effect that he was standing next to one of the most advanced 3-D printers in the world, but that it wasn't working properly. The printer is then compared with a household inkjet printer, in that these also sometimes fail to work properly.

As should be becoming more apparent as the analysis of these texts unfolds, there is a repertoire of metaphors and discourses that recur frequently and in a fairly narrow range. The tensions between the mythic and the domestic are set up right from the start with the article mentioning the "hype" about 3-D printing, and that by Christmas everyone will have their own "Star Trek" replicators in the basement "spewing out thermoplastic so Santa doesn't have to show up with his sleigh". That this will "serve to put Santa Claus out of business" once again implies that the printer belongs in the realm of toy production, although these machines are now seen as more utilitarian, and less entertainment devices or appliances than they have been in earlier texts.

The mention of the "Star Trek" replicator invokes the science-fiction and futurism trope, and the idea – particularly with reference to the "replicator" — that it takes nothing more than a simple voice command to have something made. This is positioned in opposition to the mythos of Santa Claus and his traditional toys, "handmade" by his workers, whether it be the "elves" of folklore or the manual labourers in a Chinese toy factory. Both of these are invisible to the consumer, and therefore magical and unknowable. This creates a tension between the fantastic future of the 3-D printer and the somewhat more challenging reality.

In this paragraph that is rich with allusions to magical or futuristic manufacture there is also a casual comment assigning the printer to a place in the "basement". As I have pointed out previously, the basement is an evocative domestic space in the home. In Chapter 2, I highlighted this domestic space in relation to the DIY movement's association with masculine home maintenance. The specificity of the basement in early DIY may have shifted, but the basement remains associated with utilitarian functions, such as laundry and heating.

In the phrase "Reality is Rougher" the article points out that 3-D printer manufacturers like Voxel8 expected the business to be more lucrative and easier than it has been. The article recounts how the company *MakerBot*, despite making machines "priced as low as $ 1375" laid off 100 people and closed its three retail stores. The author accounts for this with the curious idea that "people who shop on Newbury street[12] do not have 3-D CAD files in their wallets".

This section of the article integrates a number of points regarding the market segment for the 3-D printer. This market represents a consumer culture and affluence that is at odds with many of the discourses that circulate within the Maker movement. The MakerBot printer is explicitly presented as "priced as low as. . . ". This comment regarding the price point could be disregarded as a convention of the way prices are given except that the reference to "Newbury Street" resonates in a particular way. One of MakerBot's now defunct retail stores is on Newbury Street in Boston, which is presented as "Boston's most enchanting street. Eight blocks filled with salons, boutiques and fabulous dining" ("Welcome to Newbury Street, Boston, Project Website"). The quip that people who shop in Newbury Street don't carry around 3-D models "in their wallet" suggests that MakerBot doesn't know who their market is and what they need. As is apparent in most of the texts analysed, the target market for the 3-D printer and the actual applications for the technology in a consumer market are unknown.

12 The former site of one of MakerBot's retail stores.

The author then introduces a third and central theme by means of the Boston-based initiative called the "Fab Foundation" which supports the foundation and operation of a global collection of "fab labs", which allow students and community members access to various tools, including 3-D printers. Neal Gershenfeld[13], a co-founder of the initiative, calls these labs "a key part of a city's infrastructure, a place for citizens to not just design products and make art, but also to build things that address urban problems." Here the idea of the "democratisation" of manufacturing is invoked. This manufacturing is being used for entertainment purposes, art, and also what could be called "appropriate technologies" to address urban problems. The word "citizens" is telling as it serves to associate the users of these labs with the rights and responsibilities of the civic space and the public sphere versus the private individual. This discourse that invokes the association between the everyman and manufacturing holds echoes of the 3-D printer for the proletariat.

4.4.4 *"The New Makerbot Replicator Might just Change your World", Wired Magazine, October 2012*

See p.79

This item is a multiple page article in Wired Magazine, October 2012 issue. Wired Magazine is a monthly, consumer oriented magazine focusing on technology and technology-related consumer products. It originally branded itself as "The Rolling Stone of technology". In publication since 1993, Wired was backed by academic Nicholas Negroponte, at the time director of the Media Lab at MIT, and claimed Marshall McLuhan and his theories on media as significantly influential in its editorial content as well as design ethos. Wired was originally edited by Kevin Kelly – former editor of Stewart Brand's "Whole Earth Catalog" [14]. Bought and transferred to Conde Nast publishers in 1998, it is in the company of magazines such as "Vogue", "GQ", "Architectural Digest" and similar high-end lifestyle publications.

The magazine is approximately A4 in size, and is printed in full colour on thick, matte paper (*Post-glossy*), and is square bound. A significant portion of the magazine's content (Each issue is around 280 pages) is advertising. According to Wired's media kit ("WIRED – Media Kit Print | Condé Nast, Project Website"), total readership is 3 million, with 72% of these being male, mostly in the age range of 18–34. They characterise 771 000 of their audience as "affluent", with a median age of 44, annual income of over US $164 000, with over three-quarters having graduated college.

13 See (Gershenfeld)

14 Stewart Brand is an American writer and long-time techno-utopianist. He was involved with the Grateful Dead, Ken Kesey and his "Merry Pranksters", and produced the "Whole Earth Catalog". He later founded the "WELL", the first large-scale online community, was visiting scientist at MITs Media Lab, and has collaborated with various computer scientists and technologists such as Douglas Engelbart (of PARC) and Danny Hillis (Thinking Machines corporation and The Long Now Foundation). You may note a mention of Brand in an earlier footnote regarding Maker Media and O'Reilly publishers.

The article was written by Chris Anderson[15], a significant figure in the Maker Movement and editor-in-chief of the magazine at the time the piece was written. The piece appears to be an excerpt from his (at the time upcoming) book "Makers : the new industrial revolution". That this article was published in this particular magazine, which is a "lifestyle" magazine for affluent, technologically-savvy consumers speaks to the use of the maker trope as a marketing tool, or more specifically, the deployment of the maker as simply another aspect of consumer culture. This is a recurring manifestation of the tension between the stated philosophies of the Maker movement and that makers are both a source of capital - mostly intellectual - and part of the targeted consumer population. The title of Anderson's book repeats the trope of a "New Industrial Revolution" which is frequently deployed with respect to the 3-D printer.

The article opens with a photograph of MakerBot founder Bre Pettis holding up a toy tractor, carefully examining the object. He is facing away from a window, and behind him is a bookshelf filled with various brightly coloured objects, one assumes all 3-D printed. There is also a table in front of him filled with other objects. In a mostly empty space on the table in front of him is a model of what appears to be an aircraft landing gear. On the end of the bookshelf behind him is a sleek, black 3-D printer. The room in which the photograph was taken is apparently in an older building with painted brick walls. The caption underneath the photograph reads "MakerBot co-founder Bre Pettis says his new 3-D printer, the sleek Replicator 2 (shown at right), has a design that's "Darth Vader driving KITT while being airlifted by a Nighthawk spy plane." The opening paragraph then recommends that one takes

> ... the subway to an otherwise undistinguished part of Third Avenue in Brooklyn. Knock on the door. Wait for some stylishly disheveled young man to open it and let you in. You've arrived at the BotCave—the place where 125 factory workers are creating the future of manufacturing.

In the opening moment of this text we have a caption and paragraph setting up two major recurrent themes in close proximity: the languages of fantasy and science-fiction closely associated with that of industrial labour. It is noteworthy that this *is* an instance of visible labour, however the labour is only visible insofar as it is the labour in a factory setting. Starting with the tropes of science-fiction, there is an inference that the factory where these machines are produced is an exceptional location in an otherwise undistinguished area.[16] This, and the use of the term "BotCave", referring to the comic superhero "Batman" and his "Bat Cave" secret lair, is constructing a mythos around the figure of Pettis. This is taken further with the description of their new 3-D printer: "sleek", "Darth Vader driving KITT while being airlifted by a Nighthawk spy plane". The complete overkill in terms of pop culture references builds the mythos of superheroes and their gadgets, while the name of the new printer, the "Replicator" comes from the realm of Science-fiction and is borrowed from the "Star Trek" franchise.

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15 Anderson is author of "Makers: the new Industrial Revolution", and "The Long Tail". He posits that small scale manufacturing, desktop manufacturing and the "democratization of technology" are behind a "new industrial revolution", and that latent entrepreneurship is a significant driver behind Makers.

16 In fact this is in a former industrial area being gentrified, with upmarket venues, food establishments and apartments taking hold ("Third Ave.'s revival in Brooklyn gets worrisome | Crain's New York Business, Project Website").

The opening paragraph's verbal picture of "125 factory workers" is supplemented by a photograph from further into the article depicting Pettis standing on a staircase, on the upper level of the MakerBot premises, looking out over a room of workers. The cover of the magazine issue in which this article is published offers much the same view, with Pettis – looking somewhat pleased with himself – holding one of his printers taking up the entire cover space, and the title "This machine Will change the world".

The first paragraph refers to the *factory workers* creating the future, yet the caption of the photograph quotes company founder Pettis and *his* new 3-D printer. The language also evokes the idea of "creatives" through the use of terms such as "stylishly disheveled young man[17]", and the fact that the workers are "creating" the future of manufacturing, rather than, say, "assembling" or "building". The next paragraph refers again to the "workers", and the machines they are "busy constructing". At last we see a visible representation of labour, even though the article goes on to work against the idea of this very labour. There is significant discursive tension here: the discourse of factory workers, and "bringing affordable 3D printers to the masses that is reminiscent of the articulation of Marx's estrangement or alienation of labour.

While the previous themes have played out in the texts analysed thus far, the next theme is an explicit invocation of the antecedents of the Maker movement in the forms of the Hacker and Open Source movements. The new Replicator is described as being a finished product, not a kit, thus positioning the user as a consumer, not a DIY-er, and "doesn't require a weekend of wrestling with software that makes Linux look easy". This is a reference to the Open Source operating system (see Chapter 2), which has a reputation for being apocryphally difficult and frustrating to set up and administer. The new printer instead has software that allows one to "turn CAD files into physical things as easily as printing a photo". The author has set up a binary here with the almost mythical complexity of using Linux on the one hand and the zero-effort possibility of pressing the "print" button on the other. This serves to distance this iteration of the technology from the complex, technical aspect of the previous generation of 3-D printer and makes it more attractive to those less technically proficient. Anderson, in his mention of the "CAD file" one needs in order to print an object fails to say what it takes to produce that CAD file, both in experiential (skill) and material (software) capital.

Anderson's ideas in this middle section of the article can be grouped into three major themes. First, is his ambiguous relationship with both the philosophical predecessors of the Maker movement and the technical predecessors of the 3-D printer. Anderson paints MakerBot as being part of a "Homebrew Printer Club", along the lines of the "Homebrew Computer Club" of the 1970s (see Chapter 2). The mention of both the Homebrew Computer Club and the Apple II appears to be an attempt to tap into the capital and status of the "old-school" hardware hackers and tinkerers and locate MakerBot in a similar position to companies such as Apple (and by extension, positioning Pettis as a sort of Steve Jobs). Anderson states, with reference to the first generations of personal computers, before the major applications we know today were available, that "All you could do with these early PCs was program them". This is an odd argument: that all one could do was learn how to use them and to learn how they worked. He implies that 3-D printers are currently in that stage of waiting for someone to develop the "killer apps" for the technology. As I have

17 Somewhat ironic as Bre Pettis is currently in his mid 40s.

mentioned above, he is disparaging about those who "wrestle with Linux", yet he invokes the mythos of Open Source and the Homebrew Computer Club. The article continues by referring to the previous generation of printers as "Jerry built contraptions of the past", in contrast with the "sleek, metal, and stylish" Replicator 2. The term "Jerry built" discursively relegates the older printers to the realm of the same "Linux wrestlers" – the technologically competent tinkerer and "geek", while the use of terms such as "sleek" and "stylish" seem to position the new models to be of interest to those who are more conscious of aesthetics than functionality. Anderson mentions that the machines have inbuilt LED lighting which can be controlled to display any hue, "to match the color of your couch". The discourse here regarding style, "sleekness" and the ability to "match your couch" positions the Replicator as a domestic accessory or entertainment device, short-circuiting even the idea of this printer as an appliance. There is a failure to see that both the technical advances and the values of these movements were in fact premised on the very things he dismisses in favour of easy to use consumer appliances that "match one's couch".

Secondly, Anderson invokes the ideas of democratisation of technology through collaborative projects such as Open Source, and talks of things being "free". However, he seems to have misconstrued the core tenets of Open Source, if we look back at Section 2.1.3 and Richard Stallman's ideas on what it means for software (or hardware) to be free: not free as in cost, but free as in open. The idea of just being able to download a design and print it is discussed, in terms of "free design libraries" and "premade CAD files" available to do "just about anything you can imagine". According to Anderson, it is simply a matter of "downloading them, modifying them if necessary, and sending them to the MakerBot to be printed". The matter of "free" in terms of the designs is not unpacked — who makes them, and why? How much time do they spend on them? Are these the same people who spend their time "wrestling Linux"? Why are these libraries free? The author is glossing over any issues regarding the conception and creation of these designs that are being downloaded and printed, and the possibility of the user themselves creating entirely new and original designs to print. There is also no call to action to the prospective buyer/user to return files, material or innovation to the repositories "for free". It seems this usage is one way only.

Anderson's conclusion to the article extolls the virtues of these forms of "digital fabrication" and notes that with traditional modes of manufacturing and prototyping, adding complexity adds significant cost. He lists a number of points to consider: "Variety is Free", "Complexity is Free", and "Flexibility is free", and states that "changing a product after production has started means just changing the instruction code". The idea that these factors are "free" (free as in cost) is problematic. The act of design or modification, in other words the actual labour (which would involve sitting at a CAD workstation, or writing code or other forms of "invisible" labour in this context) is occluded. This labour is only free if time and intellectual labour are seen as having no value.

Thirdly, the article forwards the agenda of making the production process your own. Anderson positions this as the idea that "everyone is potentially an entrepreneur". He suggests the consumer 3-D printer is "... an emerging alternative to the mass-production model", and that "Now we can make the Long Tail of Things—[18] This seems to be Anderson effec-

18 Anderson's theory of the Long Tail posits that the future of industry is not in huge volume production of mass-market items, but in many small manufacturers and businesses filling the many tiny niches for goods

tively positioning the 3-D printer at the centre of Negri's *Factory without walls*, which, as we have seen in the first part of this article, is the home.

The 3-D printer is being attributed with the potential to change the face of, and democratise, manufacturing. The discourses of simplification include phrases like "ease of use", "child's play" and "as easy as printing a photo". However, as appealing this may seem at first glance, there comes a point at which ease-of-use is indistinguishable from deskilling of the user. As such, the individual is losing agency in this equation. At the same time, by attributing this agency to the 3-D printer, the *act* of labour is being occluded.

> This is MakerBot's Macintosh moment. Just as nearly 30 years ago Apple made desktop publishing mainstream, the aim with the Replicator 2 is to take something new to the masses: desktop manufacturing.

Tapping into the mythos of Apple, in this case regarding their pioneering work bringing affordable typesetting to the masses with the Macintosh and laser printer, Anderson compares the MakerBot to the Macintosh, likening desktop manufacturing with desktop publishing. He takes the comparison further by noting that the early efforts of amateurs in desktop publishing were a "dog's breakfast of fonts and clip art. But then they got better[19]." Anderson then equates users' first attempts at 3-D printing with these first desktop publishing attempts, and cites various features of the new MakerBot (such as higher resolution, more colours, the ability to print more complex shapes) that will, in his opinion, accelerate the learning curve.

The article now moves into a third mode. Although this section details the many uses of 3-D printing in industry and commerce which are outside the scope for this dissertation's focus on the hobbyist 3-D printer, there are some discourses that are worth highlighting. After a brief description of how the additive 3-D printing process works, Anderson mentions that "the whole process is almost magical to watch". The use of "magical" here is interesting as on the one hand is the idea that the process is unknown – or even unknowable – and on the other hand, that there is no actual labour involved, the process "just happens", much like the concept earlier of "Just hit Print". The idea of the magical 3-D printer has already been surfaced in the ideas of "Santa's Elves" and once again in this moment of the article it is explicitly coupled with the discourses of home, domesticity and family.

The first paragraph of this section deals exclusively with the material used for printing with the Replicator 2. Described as "ecofriendly", "compostable" and "smells like waffles" and "can be made from cornstarch", all of which would be desirable, or at least not offensive within the home, reinforcing again that this belongs in the domestic space of the home, not even the workshop or garage. The material is described as being sold for "as little as $48 per kilogram", and the metric given being is that a kilogram of material is enough to print "nearly 400 chess pieces". On the other hand,the ABS plastic used by the larger machine is "the same material that Legos are made from" thereby reinforcing the toy connection.

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and services in small quantities towards the "tail end" of the demand curve. See (Anderson, *The long tail: Why the future of business is selling less of more*).

19 But was it the amateurs who got better, or did things get better when these tools got into the hands of existing professionals?

Pettis recounts how their customers' idea of uses for a 3-D printer start as practical - things "around the house", dishwashers, bicycles, but then switches when they have the printer in hand to "jewelry, geometric brainteasers, absurdist sculptures" and toys. On the surface the discourse seems to be referring to the idea that the printer unleashes personal creativity, however it may also be that the user was unable to produce the aforementioned parts to fix things around the house. If the exact part needed is not available for download from the numerous online archives of printable objects, does the user have the needed CAD skills (and time, for that matter) to produce, print, test, modify, and print the needed part? At this point the "magic" theme appears again, with the use of the word "conjure": "Their children ask for wild toys, and the users can conjure these up before their eyes, first on a screen and then in the real world". The importance of the design and CAD modelling process is underplayed here yet is also conflated with other technical skills such as programming: "Indeed, Pettis estimates that when MakerBot first started, half of its operators were programmers, but now he has seen a huge influx of parents". The choice of language here seems to be to distance obscure, arcane complexities and technicalities such as programming (and previously, complex hardware and software setup) from the desired image of the Replicator as simple to set up and use. Amusingly, the role of parent is apparently incommensurate with that of programmer. The "parent", though, comes with themes of home, children and toys, and affect.

Finally, I would like to explore some of the ways the 3-D printer is positioned in the article in terms of commodity culture, consumption, and its market. Anderson uses the phrases "sophisticated early adopters" and "people who just want to print something cool" to distinguish who he sees as the market for these products. This seems, again, to split the users into opposites, but in this case it's not the highly technically proficient and the simple "user". The first of these personae is the "early adopter" — someone who buys new technology mostly before it has found its real purpose (or "killer app") or before it has all the "bugs" worked out, and is still somewhat temperamental. The make-up of the second is less clear.

The following paragraph states that:

> Soon, probably in the next few years, the market will be ready for a mainstream 3D printer sold by the millions at Walmart and Costco. At that point the incredible economies of scale that an HP or Epson can bring to bear will kick in. A 3-D printer will cost $99 and everyone will be able to buy one

The use of "the market will be ready" would tend to suggest two things: that MakerBot is being positioned as a pioneer, and might suggest that the "market", which at this point is still undefined, is still unsophisticated in these matters. Which segues to the reference to Walmart. Walmart is a traditionally budget-oriented "megastore" chain in the USA where one can buy everything ranging from diapers to ammunition under the same roof. Costco is similar, except they sell primarily bulk and palleted goods. The image is being painted here that one could easily walk past the "3-D printer aisle" somewhere between buying peanut butter and toilet rolls, and drop one into your trolley. The phrase that "everyone" will be able to afford one is another reference to "the masses" and the rhetoric of the proletariat.

As an aside, at the time of writing this paper, Walmart does now carry 3-D printers, at least on their web store (I was unable to ascertain whether they carry them on the retail floor). Prices range from US $380 for a basic kit, to US $6500 for the high end MakerBot. This seems somewhat at odds with Walmart's demographics - their average shopper is a white, 50 year old female with an annual household income of just over $53 000.[20] The retail price mentioned is interesting both in the context of the above "average" shopper's income, and that Walmart's lowest-cost normal (inkjet) printers start at just $40.

4.4.5 *"What Lies ahead for 3D Printing?", Smithsonian Magazine (Online), May 2013*

See p.85

This piece is an article from the online edition of "Smithsonian" Magazine, a publication of the Smithsonian Institute in Washington DC. The Smithsonian Institute is the world's largest museum and research complex, consisting of 19 museums and galleries, the National Zoological Park, and nine research facilities ("About | Smithsonian, Project Website"). The format of the piece is simple and clean, with a large photograph (above the fold) of what seem to be 3-D printed scaffolds for a human ear, nose, and finger bone. The title is "What Lies Ahead for 3-D Printing?", with a subtitle stating "The new technology promises a factory in every home — and a whole lot more".

Royte beings by recounting "Wandering the brightly lit halls" of the 3D Systems factory[21], where she "gazed upon objects strange and wondrous". The discourse deployed here would not be out of place in describing a museum. Royte invokes a sense of awe and mystery, but with an element of modernity in the image of "brightly lit halls". The objects she describes seeing are varied and mostly inert, except for a "fully functioning guitar". As she continues, the author briefly describes the 3-D printing process to those who may not be familiar with the technology, stating "if you haven't heard of it, you haven't been paying enough attention", pointing out the pervasiveness of 3-D printing within the mass media. She cites "Scores of breathless news stories and technology blogs" implying that the authors of these news stories are excited about this technology, and these blogs are vocal champions of any interesting new innovations. The commonly deployed rhetoric of revolution is used again here, quoting no less than American President Obama as stating 3-D printing has the "potential to revolutionize the way we make almost anything".

The author then notes that in recent years affordable desktop printers have come within the reach of "self-starting entrepreneurs, schools and home tinkerers". Despite the discourse of an entrepreneurial target market, it seems that nobody really knows who the target market is other than education or the ever-present tinkerer or hacker. The rhetoric of democratisation of manufacturing is noted by the author but is not actually deployed.

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20 Contrast this with the target markets for "Make Magazine" and "Wired" with annual incomes of $120 000 to $170 000.

21 Founded in 1986, by the engineer who patented STL (Another form of 3D printing that builds up objects layer by layer, but by selectively hardening liquid resin in a bath). 3D Systems deals mainly with industrial printers, but has recently branched out into the consumer/hobbyist market.

What is explored in depth in this article is only superficially referenced elsewhere. This is the evident banality of objects produced by the 3-D printer: the *tchotchkes*. Combined with this is Royte's rather more critical view of the technology. Having taken a closer look at some of the "strange and wondrous" objects, or their close relatives, the author now states "just because anybody's ideas can take shape, doesn't necessarily mean they should", after seeing much - "shelf after shelf" of what some people try not to call "cheap plastic crap" – miniature vases, phone cases, jewellery, dolls and skulls. Royte categorises these objects as "lobby tchotchkes" – ornaments, displayed in the building lobby to show potential customers, or more likely journalists, what the company's printers can produce. The printer that has produced these objects is the company's new consumer-grade printer, and her description of this printer — "about the size of a Mr Coffee machine" — again evokes the domestic space. Moreover, the printers are produced in pink, turquoise and lime green, implying that one might, much like the MakerBot above, buy the appropriate colour to match your living room.

At this point Royte acknowledges her "ambivalence towards" the consumer-grade printer and the objects it has produced and is shown the "big guns" in the form of the large industrial-grade 3-D printers. These are described as "refrigerator sized" and "surrounded by monitors, keypads, CPUs". The language describes a more technical space, yet the author is disappointed that the first printer she examines is only printing a piece of jewellery, noting that it's "a lot of machine to print a bauble". The author is not yet convinced of the utility of these 3D printers. The next machine is printing an unknown object. It is "four inches high after 26 hours . . . with many hours to go". Royte points out that 3-D printers are extremely slow, and the success or failure of the printing process will not be evident until this time period is over. Then there is the work of having to remove the excess powder from the object by "excavating" and "exhuming" an object of unknown utility or nature.

She describes the Maker movement as "privileging customisation over commodities", thereby surfacing the tension between production and consumption; maker culture and commodity culture. This juxtaposition suggests that despite the Maker movement's insistence that one of its aims is to "reclaim the act of manufacturing", it is the ability to *customise* an object that is of interest, not necessarily designing bespoke objects from scratch, but modifying existing models (obtained from one of the online repositories, as mentioned earlier in this text). Dale Dougherty of "Make Magazine" is quoted as describing 3-D printing as "Walmart in the palm of your hand". In this instance, much like in the previous text, Walmart is mentioned to invoke not so much the bricks-and-mortar reality of the shopping chain, but rather the myth of accessible mass market, low profit margin retail, and perpetuating the idea that (at some point) a 3-D printer will be able to print anything and be of use to everyone.

Later in the article, Royte moves away from the consumer/hobbyist devices and turns the discussion towards Shapeways, a company that provides online 3-D printing services, giving people access to high end commercial 3-D printers ("million-dollar machines"). Despite the quality and resolution offered by these high end printers, the company PR spokesperson describes most of what they print for customers as mostly *Minecraft* models and *Dungeons & Dragons* dies. In this observation we see the synthesis of several themes. Firstly the "lobby tchotchkes" Royte mentions earlier. In the quote "it's amazing how unsurprising the stuff we make is", doorknobs or "a crib part from a mom in suburbia" we see the return of the home or the domestic sphere as a core association. Underpinning this is the deflation of the idealism encapsulated in the notion that all one needs for latent creativity to be "unleashed" is the right tools.

The article then performs some of the discursive sleight of hand that serves to deflect or occlude labour in different ways. The key to identifying this is the attribution of labour away from an individual and towards and object or objects. Royte notes that "Additive manufacturing would not have flowered without major advances in computer-directed modeling. A decade ago, it took weeks to generate a digital 3-D model, now it takes only hours." She is describing the 3-D *scanning* process – this is not synonymous with the CAD design or manual modelling necessary for producing the files that will generate the 3-D printed object.

As the article continues, Royte states that:

> Multiple scans are aligned and filtered, points are connected to their near neighbors to form polygons, holes are filled and blemishes removed. Finally, with a click of the mouse, the surface of the image is smoothed to form a shrink-wrapped version of the original. Off to the printer the digital file goes.

The passive language used here occludes the aspect of who or what aligns and filters the scans, who connects the points to their near neighbours? The software does this, but the user has to instruct the software which scans to align and filter, which points to connect where, and so on. The last procedure in the process occurs with nothing but a mouse click: the sole apparent act of labour on the part of the user. The author then attempts to further address the problem of creating the digital models, looking at "Geomagic - a pioneer in sculpting, modelling and scanning software". It is worth pausing briefly to point out that there is a return to the concept of "magic" here. Magic, with its inference of work done by supernatural means that circumvents ordinary labour.

Later, Royte rehearses many of the concerns regarding automation: that 3-D printing will create new industries and jobs, but may also displace "skilled craftspeople, artisans and designers who work with raw materials, just as Amazon displaced bookstores, and desktop printers eviscerated mom and pop copy shops". The discourse of "evisceration" in conjunction with the use of "mom and pop" copy shops suggests the nature of these industries as cold, impersonal, and ruthless, versus the warmth, and "human touch". This is an interesting departure from form. In the other texts the 3-D printer has been emphatically constructed with associations of home, parents, toys and play rather than this less friendly face.

The author at this point voices her concern that the speed and supposed ease of producing objects will result in products with a shorter affective lifespan – "fashion obsolescence" and "design fatigue", followed by a "devaluing" of the creativity that went into them. The repeated usage of the idea of "design" calls for closer examination. The traditional usage of the term is taken to mean"the act of specifying the physical or structural properties of an object", but in the context of consumer or commodity culture, we could interpret this as primarily aesthetic design. As seen in previous texts, this speaks to a specific target audience: those who are after a "sleek" and "stylish" accessory, which can be colour matched to your sense of aesthetics.

4.5 DISCUSSION

In discussing the analysis of these texts, I will approximate the the order laid out in the table at the start of this chapter, with exceptions, as certain of these issues are inextricably linked. I rehearse a number of the observations and connections made during the analysis of the text in order to demonstrate how these coalesce into the constructions of discourse and mythmaking through usage and repetition rather than intention. The lack of intentionality by the individual actors notwithstanding, "regimes of truth" (Foucault 51) are produced and continue to function as naturalised.

4.5.1 *Existing discourses: Futurism and Utopia*

These texts repeatedly invoke concepts and discourses from Science-Fiction or other fictional fantasy and folklore. The Boston Globe article mentions "Star Trek replicators" in everyone's basement, putting "Santa Claus" out of business, while the Wired Magazine article constructs a mythos around the figure of Bre Pettis, who is being presented through both textual and visual discourses as a figure akin to a superhero, in his "secret laboratory", the "Bot-Cave", clearly intended as a reference to the "Bat-Cave" of comic-book fame. With reference to Chapter 3 and discussions around immaterial and cognitive labour – the essence of the Maker movement – Gene Ray ("Revolution in the Post-Fordist Revolution") uses similar terminology in describing its practitioners as "... the sexy code-artists, image-wizards and creative entrepreneurs of the new cognitive capitalism"(Ray 4). Other discourses surrounding the technology, rather than the person, serve to construct a similar mythological presentation of this technology as "cutting-edge", or even beyond the frontiers of known technology: technology from the future. Anderson, in the Wired article, describes workers "creating the future of manufacturing". Looking at this in juxtaposition with the "jerry built contraptions of the past" – referring to MakerBot's previous model printer – he creates distance, both temporally and technologically, pushing this new model into the future, not merely the present.

Howard Segal, in his historiography "Technological utopianism in American culture" finds that scientific and technological utopianism is not new and owes heritage to a number of significant utopian works such as Francis Bacon's "New Atlantis" (originally published in 1627). The utopia in this case is a society built around the collective aim of understanding nature through science and thus conquering nature through technology for the benefit of mankind. Marx supported the potential for automation and technology for the emancipation of the worker, and to some extent the ideas were later attempted in the ill-fated machinery of the Soviet Union (Spufford). From the turn of the century the possibilities of technology (obviously ignoring many of the issues around jobs and labour) were being sold to the man in the street through events such as the American Worlds' Fairs in the 1930s, with buildings designed by futuristic architects such as Norman Bel Geddes, and exhibits (usually sponsored by big-name companies such as General Motors, Ford or Westinghouse) entitled "Democracity" or "Futurama" depicting the future as a high-technology, highly automated utopia. Kling (in Sivek 190) has noted that these ideas have been repeated in many discourses regarding the role of computers and similar technologies. Through Winner's work on the personal computer, and Poutiainen's examination of discourses around the mobile telephone we can see that these discourses and tropes are by no means new (Poutiainen).

This is echoed by those who originally created this technology, as Noble states, with reference to the MIT academics behind CNC technology:

> NC was always more than a technology for cutting metals, especially in the eyes of its MIT designers, who knew little about metalcutting. It was a symbol of the computer age, of mathematical elegance, of power, order, predictability, of continuous flow, of remote control, of the automatic factory (Noble 114).

The idea of technological utopianism looks forward in direct contrast to that of nostalgia. As discussed in Chapter 2, the maker philosophy tends to reify traditional modes of work and craftsmanship, the artisanal, and the handmade. This is seemingly at odds with the rhetoric often deployed regarding the 3-D printer that underplays what we have learned about manufacturing and crafting over the last thousand years or so. This rhetoric is echoed, albeit secondhand, in the Smithsonian article. The author suggests that 3-D printing will create new industries, but, as with any "labour-saving" technology, will displace existing jobs, specifically "skilled craftspeople, artisans and designers who work with raw materials". It is significant that one of the only explicit mentions of labour and work in the articles examined is in a negative sense, that is, that these reified skills and arts may be lost or further marginalised.

4.5.2 *Existing discourses: Revolution and Disruption*

Rhetorics of "revolution" are common in technological discourses. These are often limited to ideas that the technology will change the world, change you, or change the nature of manufacturing (as opposed to a more comprehensive notion of revolution as social disruption). Winner, writing in 1986 about personal computers, notes that "A somewhat similar gesture has become a standard feature in contemporary writings on computers and society. In countless books, magazine articles, and media specials some intrepid soul steps forth to proclaim 'the revolution' "(Winner 98).

Discourses from the sample texts repeat this theme frequently. The title of the Wired Magazine article is "The New Makerbot Replicator Might just Change your World", and quotes passages from the author's book "Makers: the New Industrial Revolution". He later describes the idea of a home 3-D printer as "revolutionary". The "Boston Globe" article also uses the word "revolution" in its title, and the "Smithsonian" article uses the term a number of times, including to quote American president Obama on the revolutionary potential for the 3-D printer. The advertisement for the "UP!" 3-D printer uses the title "UP! Create! Innovate!", which in this context, presents as an emphatic call to action. This concept of revolution is linked with the idea of "democratisation" of technology, and the paucity of languages of work and labour used in the texts analysed. The Wired Magazine article refers to the "workers" assembling the 3-D printers and the aim of bringing 3-D printers to "the masses" while the Boston Globe article refers to "citizens" being empowered through making.

4.5.3 *Emerging discourses: Democratisation*

For the sake of clarity, this idea needs to be unpacked, and can be done so into two primary components. First, is the suggestion that the 3-D printer can, will be, and in fact needs to be made available to anyone and everyone, regardless of socio-economic standing. Pettis, in the Wired article, is quoted as harbouring the aim of "bringing affordable 3-D printers to the masses". Later on, the author of the article states that "soon", these printers will be mainstreamed and sold at discount chain-stores. This idea is subtly proffered with numerous comparisons between the 3-D printer and the inkjet printer, a device which is pervasive and almost so cheap as to be disposable.

The second aspect of "democratising technology" is the concept, as discussed in Chapter 2, of "democratising manufacturing". Within the Maker movement this is often seen as "reclaiming" the act of manufacturing from the hegemony of industry and the established, conventional models of production and consumption. Anderson, in the Wired Magazine article, characterises this as "Desktop Manufacturing", as per Neal Gershenfeld"Fab : the coming revolution on your desktop–from personal computers to personal fabrication". Andersen compares this with the field of "Desktop Publishing", arguing that the Macintosh and the laser printer spurred a "revolution" in publishing, and that the 3-D printer is in a similar position.

The "Boston Globe" article quotes Gershenfeld as stating that labs with 3-D printers are a "key part of a city's infrastructure", allowing citizens to "build things that address urban problems".

Adrian Bowyer, creator of the RepRap project on which most current consumer and hobbyist 3-D printers are based, stated in 2004 that:

> . . . the replicating rapid prototyping machine will allow the revolutionary ownership, by the proletariat, of the means of production. But it will do so without all that messy and dangerous revolution stuff, and even without all that messy and dangerous industrial stuff. Therefore I have decided to call this process Darwinian Marxism. . . ("Wealth Without Money - RepRapWiki, Project Website")

There is a compelling interplay here of ideas regarding "reclamation" of the means of production of goods, and, as Bowyer characterises them, the "messy and dangerous" aspects of revolution and industry. Given the demographics (discussed in both Section 4.4.1 and Section 4.4.4), the idea of "reclaiming" the means of production from the hegemonic powers of industry is problematic for two reasons. Firstly, is that the act of manufacturing *never belonged* to this class in the first place, and secondly, in order to reclaim any of the artisanal skills capital that Makers aspire to would mean looking *down* the socioeconomic ladder to the working class, not *up* towards capital. In other words, this is not a revolution that challenges capital and power from below, but instead appropriates from a more marginal class fraction.

4.5.4 *Emerging Discourses: The Domestic sphere*

Both the imagery and the language used in describing the 3-D printer in the texts locates it within a domestic context within the home. There is a lack of discourse placing it elsewhere, such as a workshop or toolshed, except for the Boston Globe article which mentions the "basement". The descriptions of the design aspects of the MakerBot and the appliance-like design of the other printers suggests that they would fit in the lounge or family room, able to "match the color of your couch". The themes of "play" and "toys" also manifest frequently. In the advertisements examined, the printers are busy printing, or appear to have printed nothing more than toys or "tchotchkes". Pettis tries to mitigate this impression in the Wired article by portraying some of the objects as "absurdist sculptures" – one would like to assume that he is aware of this perception. Anderson, in the same article, admits that the "killer app" for his 3-D printer is toys for his children.

The language of manufacturing, production and industry deployed alongside cues placing the 3-D printer within the home create a tension in the conflation of the domestic and production space, an overlap of work and home/play space. This might be seen as a manifestation of the ideas espoused by Negri regarding the tendency for productive labour to find its way into all aspects of modern life in the current post-Fordist economy (Negri and Hardt 79). There is a compelling connection here with the idea of the "Social Factory", and the shifting nature of the workplace explored in Section 3.6. The new forms of immaterial and affective labour generally take place outside of the traditional workplace. Bre Pettis, in the Wired Magazine article, presents the early adopters of his printers as "programmers", and the later purchasers as "parent". The depiction of the users as mutually exclusive categories again constructs a tension between the workplace and the domestic space, the "programmer" representing the workplace, industry and professionalism, and the "parent" representing the domestic space and the deployment of affective labour.

The previous categories consist of discourses drawn from existing ideas currently in circulation. However, there is also a range of new, emergent discourses constructed around the verbal and visual representations of 3-D printers. I posit that these emerging discourses will continue to circulate the further we progress into the late post-Fordist era that is characterised by affective and immaterial labour.

4.5.5 *Emerging Discourses: Creativity and latency*

All texts analysed mention the aspect of creativity, and suggest that it simply takes the right tool – in this case one of these printers – to "unlock" this creativity. The utility of 3-D printing is mentioned in the context of industrial-grade machines, and their use in medicine, dentistry and industrial design and prototyping, yet these are not the same consumer-grade machines. Technical shortcomings of the home printers, such as slow printing speed, that they're finicky to set up, and so on, would suggest that it is these factors behind the lack of utility or creativity representative of their use. Despite this rhetoric, the Smithsonian article quotes a spokesperson from Shapeways, an online business providing access to industrial-grade machines which do not suffer from (most of) these shortcomings, as noting that the objects sent to them for printing are all remarkable in their pedestrianism, such as doorknobs, gaming dice or the occasional "crib part from a mom in suburbia".

The Wired article refers to "a stylishly disheveled young man[22]" and the fact that the workers are "creating" the future of manufacturing, rather than, say, "assembling" or "building". The Dion Wired advertisements states that this printer turns living rooms and classrooms into "creative spaces". The use of these phrases evokes the idea of "creatives", and the manner in which Bre Pettis is constructed both through discourse and visually, in the Wired article (and the continued references to Apple) serves to position him as both a creative and a visionary, possibly in the realm of figures such as Steve Jobs, co-founder of Apple, who is often painted as a cult figure and creative and technological visionary. This suggests that, in connection with the discourses above referring to the 3-D printer as a household appliance, this is a *lifestyle* choice, it's what one needs to be *a creative*. Other than the ideas discussed above of "latent" creativity, Anderson, in the Wired article, presents entrepreneurship in a similar light: the discourse suggests that it is within the skill set, aims, and even desire of most people (Makers) to start a business aided by this technology. Discourses of creativity are emphasised in every text, suggesting that this is a significant driving force.

4.6 IN SEARCH OF INVISIBLE LABOUR

There is little mention in the articles examined of the labour: skills, time and resources (software) required to actually design an object from scratch. The printers are presented as easy-to-use: The "Up" advertisement implies that it's "child's play", while stating that it was the winner in the "Just Hit Print" class, while the Dion Wired advertisement puts kids and adults "just a click away" and the Wired article states that printing an object is "as easy as printing a photo". In a similar vein, Anderson, in the Wired article, deploys the theme of "magic" when describing the process and usage of 3-D printing. He expresses the opinion that the "process is almost magical to watch", then later in the article states that "users can conjure these up". This use of the discursive terminology of magic is interesting on two fronts. Firstly is that the process is almost approached with a sense of awe — "magical to watch" — this is reflected in the Smithsonian Magazine article as the author mentions "gazing upon objects strange and wondrous".

The second aspect of the use of this language could be best summed up by quoting science-fiction author Arthur C. Clarke: "Any sufficiently advanced technology is indistinguishable from magic." ("Hazards of Prophecy: The Failure of Imagination" 1973). The idea behind Clarke's statement is that for those not familiar with these processes or the technology behind them, they might as well be magic because the processes are effectively unknowable and beyond the ken of the observer. This again serves to distance the observer or user of

22 This is ironic as Bre Pettis is currently in his mid 40s.

the 3-D printer from the processes — and thus the labour. The "magic" of the process serves to effectively render the actual work and workings of the process invisible, much like the earlier mention of "Santa Claus" (who has his toys made by elves) or imported mass-market goods (made by anonymous production line workers in China).

The stated complexity of using a 3-D printer is presented as a binary, an "either-or" situation. Anderson uses the example of the Linux operating system, which (particularly before the advent of more polished variants such as "Ubuntu") was notoriously difficult to install and configure. He juxtaposes this complexity with the notion that printing an object with the Makerbot is as easy as "printing a photo". What is missing is the labour or capital — resources or skills — necessary to design the 3D models needed by the printer to produce an object. All texts offer that there are large online repositories of pre-designed objects that can be downloaded and printed, although a large proportion of these are "tchotchkes", random objects designed to simply show off the printer, ornaments, or toys. There is no mention of who produced these objects or how, just that they exist in these large repositories.

Similarly, temporal factors are rarely afforded a mention. The time required to produce a design prior to printing is enumerated in only one text — that it once took "weeks" to produce a model, and now takes "hours", as is the time required to print the object. An object that was "four inches high" after 26 hours had "many more [hours] to go" until completion. The omission of the time facet is also apparent in the mention, in the "Wired" article, that "variety", "flexibility" and "complexity" in 3-D printed objects are free, implying that the time the designer or creator spends in intellectual labour producing the variety, flexibility and complexity is valued at nothing.

I anticipated some of these findings. This included that the labour required to produce objects with a 3-D printer is underrepresented from the point of view of both time and skills required, and is simplistically presented through the use of phrases such as "just press print". The origins of both the printing technology in this (hobbyist/consumer) form are occluded, as are the origins and labour behind the production of the object files available on online repositories. This suggests that unpaid labour, that is, affective and immaterial hobbyist labour is not seen as having value comparable with that of paid labour, and despite the obvious technical advances being made both in immaterial — software and design, and physical — the printers themselves, there is little to no representation of the work "behind the scenes". As an aside, this is similar to a trend within the discourses circulating regarding "artisanal" products. The emphasis is placed specifically on their origins as non-mass produced, with discourse using phrases such as "hand" made, "home" made, and so on, yet also without representation of the process of labour and manufacture (these factors are often deflected by discussion of affect and aesthetic).

The average American Maker is positioned as generally upper-middle class, white, college educated, and over 40 years of age ("Make Magazine Media Kit"). I offer the argument that many Makers are in a similar situation to Gelber's description. They are professionally employed engineers, scientists, teachers, programmers, and similar professionals, who engage in Making in order to reclaim some agency, and work on projects of their choosing. They want to have total control over its implementation, and do it for both the enjoyment and perceptions of community involvement (Gelber). It may also be seen as a form of (re)reclaiming the domestic sphere.

Braverman predicted that the degradation and deskilling of working life would push people to seek refuge in hobbies and subcultural identities, and that, intriguingly, these activities would soon be recaptured by capital. I propose that these tendencies are becoming apparent in discourses of the Maker Movement itself, and the 3-D printer is one manifestation of that recapture.

4.6.1 *Capital's recapturing of affective labour*

Nowhere is this more apparent than in the case of the MakerBot printer, subject of the Wired article analysed. As mentioned in the introduction, the "primordial" form of the hobbyist/low cost 3-D printer was based on a project founded by Adrian Bowyer at the University of Bath around 2004 (Jones et al. 181). This project, being Open Source, was completely documented online, including hardware drawings, software, and circuitry — everything needed to replicate the printer[23]. This captured the imagination of many Makers, who set about building their own, modifying and improving on the original design. After the expiration of the key FDM patents in 2009, a number of these projects became commercial, including MakerBot. By 2012 there were an estimated 400 variants of this basic design, many of which were commercial products. The MakerBot 3-D printer was one of these commercial products based on the original RepRap project("RepRap Family Tree - RepRapWiki, Project Website").

In 2009 Bre Pettis and others founded MakerBot Industries, and released their first printer in April of that year, under an Open Source hardware license, meaning anyone could both copy and contribute back to the project. Various design iterations occurred over the next few years, with significant input and design work from their community of customers and supporters. In September 2012, on release of their Replicator 2 (The model discussed in the Wired article), they announced that they would no longer be supporting an Open Source model for their designs. In 2014 Pettis then filed a number of patents for innovations which, according to the MakerBot community, were contributed under an Open-Source license by community members, with the understanding that these designs would be free and open for anyone to use (Brown).

The MakerBot case is interesting in the context of the nature of the Maker and Open-Source communities. It is also relevant in the context of this research, as it illustrates the ideas of co-option of the affective labour of Makers and hobbyists, which is then exploited, and ultimately sold back to them. Terranova positions this as the "... moment where this knowledgeable consumption of culture is translated into productive activities that are pleasurably embraced and at the same time often shamelessly exploited" (Terranova 37). Gene Ray, in "Revolution in the Post-Fordist Revolution" posits that "Behind its glossy imaginary, however, post-Fordism brings a qualitative increase in exploitation. The virtuoso is in fact a wage slave chained by data lines and microwaves to networks of open-source production" (Ray).

Hardt and Negri proposed something similar in the metaphor of the *factory without walls* or *social factory*. Negri states that "Work (production), education and training (reproduction),

23 http://www.reprap.org

and leisure (consumption) all become points on an increasingly integrated circuit of capitalist activity" (Negri and Hardt 79), while Braverman suggests that: "So enterprising is capital that even where the effort is made by one or another section of the population to find a way to nature, sport, or art through personal activity and amateur or 'underground ' innovation, these activities are rapidly incorporated into the market so far as is possible. (Braverman 193)".

The emerging discourses of latency — entrepreneurship and creativity — suggest that these have been externally suppressed or undermined, most probably by the exact factors outlined by Braverman — the degradation and deskilling of working life, and Gelber's similar ideas of loss of autonomy and manual competence through deskilling and fragmentation of Fordism (Gelber 77). As a result, the discourse seems to indicate that one can move towards recovering what has been lost through the exploitations of capital by simply being a "hobbyist" or "Maker", but one needs the *appropriate tools* in order for these skills to be regained. Makers make as an attempt to recover some agency, and as an act of resistance to modes of mass production. However, in order to be a *complete* maker, one has again to become a consumer within this field. McKenzie Wark, writing about the Maker Faire, notes this as "... the paradoxical act of artisanal labour as consumption" (Wark 302).

Returning briefly to the history of CNC machines above as an illustration of the nuances of deskilling and labour, David Noble positions early CNC technology as a means of managerial control, that is, circumventing the skilled machinists intelligence, and demoting them to simple machine loader and operator (Noble 108). By keeping design and manufacturing skills off the workshop floor, management (the "capital") hoped to regain control over the previous autonomy of the machinists, and the threat to the flow of the otherwise "automatic" factory. There is a significant difference here, in that CNC was a means to remove control from the factory floor, whereas the 3-D printer was adopted without coercion or remuneration. (Söderberg 129). However, the trend towards simplification and "user-friendliness" of 3-D printers follows the same course of deskilling. As a result, despite the discourses claiming that this technology "democratises" manufacturing and allows the user to "reclaim" the act of manufacturing, this seems to indicate the exact opposite. 3D printing can therefore be seen as an act of consumption of the very material produced by Makers in the first place, co-opted and resold back to them.

Perhaps the single most important and difficult, task confronting the critical student of such rapidly evolving technologies as NC is to try and disentangle dreams from realities, a hoped-for future from an actual present. The two realms are probably nowhere more confused than in the work of technologists. Thus criticisms of existing, or past, realities are typically countered with allusions to a less problematic future; the present is always the "debugging phase", the transition, at the beginning of the "learning curve" — merely a prelude to the future. As such it is immune from scrutiny and criticism. "

— (Noble 124)

5

CONCLUSION

In my introduction I outlined my interest in, and reasons for following this line of research. After a brief overview of the concept of the 3-D printer, I introduced the 3-D printer as an artefact of the Maker movement, followed by a short review of related academic literature. I then constructed a history of the Maker Movement, which can be located at the confluence of both traditional DIY activities, focused on the home, and the technologically oriented hacker community. This community has its roots in the Tech Model Railroad Club at MIT in the late 1950s. The ethos of curiosity and exploration amongst their student engineers converged with the embryonic field of computer science, and with the influence of figures such as Richard Stallman ultimately led to the Open-Source movement. The philosophy of this movement is that "information wants to be free" and as a consequence computer software and data should be made freely available, distributable and modifiable. The beginnings of Open Source were in the field of software, but the movement has now expanded to include electronic and computer hardware. This is one of the primary influences behind the Maker movement. The other is the concept of DIY. Early DIY activities, according to Gelber, notably in postbellum America, were in part driven by men to attempt to claim previously feminine domestic spaces (Gelber). Similar processes can be seen at work in the Maker movement, particularly in light of the constructions of domestic spaces of the late Fordist era. One important marker of the Maker movement is its relationship with technology, both as a target of experimentation and making and also in the use of technology — such as the 3-D printer — in this making.

I then explored the various motivations at play within the movement. Firstly is the requirement and desire to learn from the act of making. Secondly, makers exhibit a sense of nostalgia for a period (real or imaginary) where artisans and makers had more agency in their work, and an affinity for both the products of this era and knowledge of the methods and crafts used. Thirdly, and closely linked with these utopian ideals of nostalgia is the attempt (or at least the rhetoric demonstrates this) to somehow reclaim the process of making and production of goods from the hegemony of industry. This manifests in strong discourses of revolution. Fourthly, is the focus on participation in communities, either online in the form of discussion groups and blogs, or offline, at Maker Faires and similar gatherings. Finally, and probably most important, is the need to be able to express creativity through making. I explicitly make this connection by linking the Maker movement with various aspects of affect. This construction of the Maker provides opportunities to explore physical, intellectual and affective labour, and I complicate this set of ideas by arguing that the 3-D printer itself is a product of these forms of labour.

Then, in order to sustain and justify my emphasis on labour in the context of the Maker movement, I first looked at the basic modes of labour across the primary industrial and social points of inflection over the last two centuries, using the ideas put forward by Nikolai

Kondratiev as an organising principle. Kondratiev theorised the existence of cyclic shifts in labour and industry — known as *waves*, and others (Korotayev, Zinkina, and Bogevolnov) have extended this work to include innovation as a driving force. I began with the current era, generally known as the *late post-Fordist* era, or, in Kondratiev's terms, the "fifth wave", and the prospect of the beginnings of a movement towards a *sixth* wave. The main focus of this wave is the move from physical production of goods towards intellectual and information labour, or *knowledge work*. This also means that with this sort of work, there is no requirement for the worker to be physically present, and so the workplace extends outside the factory, and all places become potential workplaces. As a result, workers no longer necessarily direct their loyalties toward a company, the military or other focii such as national identity and there has been a groundswell of new social movements with the common thread of an open, participatory ethic (Sternberg 1029).

To locate this post-Fordist era, I examined the preceding industrial era, the ideas of Fordism, and how they came about. In the period leading up to the Industrial Revolution, the late 18th century, most labour was physical in nature. Farm work was mostly waged labour at this point, markedly different to the indentured labour prevalent before the 15th century, and capital was starting to appear as joint ventures were launched by the landed, farmers and merchants. The other primary form of labour was artisanal, in areas such as masonry, glass making or cloth weaving, and was marked by the steep investment required, namely a lengthy apprenticeship. This work was characterised by the fact that the artisan had total control over the goods he produced, from selection of raw material right through to finished product.

In contrast to this, the late 18th century saw the introduction of machinery into the cotton industry in England marking a significant upturn in production and efficiency. Over the next century this spread into most forms of manufacturing, displacing much manual and artisanal labour. The year 1908 marked a pivotal moment in this ongoing process of automation as Henry Ford put the first industrial production line into action. The idea of a production line was already in use in the meat packing industry, but Ford's contribution was to deconstruct the process of production into the smallest possible units. This allowed for an important breakthrough: the fact that the workers performed small, simple tasks of assembly at each stage meant that they did not need to be skilled, and so could be paid less, and they had no control over the process, the control was moved further up the chain into management. This was directly opposed to the manner in which the previous forms of artisanal work happened.

I then position the work of the Italian Autonomist Marxists, namely Michael Hardt, Antionio Negri and their peers as the next stage in the trajectory of labour and more importantly, as a productive framework in which to examine labour in the late post-Fordist economy. The central premise of Autonomism is that labour does not need capital in order to be productive, unlike traditional Marxism, where labour needs capital, that is, the workers need the factory (and the equipment, materials, and control) in order to produce value. Autonomism allows labour to be in control of itself. As a result of this perceived independence from capital, the worker is no longer tied to a factory — the abovementioned post-Fordist *factory without walls*. Much of this labour is immaterial and intellectual in nature, and so is both a product of, and reliant on, the prevalence of communication networks, and a resulting growth in communities and social movements (as suggested by Sternberg, above) formed and linked through these networks.

Another aspect of the Autonomist model of labour is the idea of *affective* labour. This was originally presented by Dalla Costa and James as feminine labour — emotional and reproductive labour — the labour required to support the labour force, and was thus based in the home. Now that the home is being turned into a workplace, and to some extent defeminised, so is affective labour. Affective labour is being redefined as labour that produces affect, that is, "... its products are intangible; a feeling of ease, well-being, satisfaction, excitement, passion — even a sense of connectedness or community" (Negri and Hardt 96). It still shares the traits observer by feminist theorists of affective labour in that it is traditionally undervalued, often unwaged, and dependent on emotional and social wellbeing and rewards in lieu of traditional wages. Given that the workplace is no longer centralised, work pervades even the domestic space and there is little distinction between work and non-work. According to Negri, "Work (production), education and training (reproduction), and leisure (consumption) all become points on an increasingly integrated circuit of capitalist activity" (Negri and Hardt).

In order to cement and illustrate my hypothesis that the labour at the heart of the Maker movement is occluded in the currently circulated discourses, I performed MCDA on a small, selected set of texts including advertisements and article from both print and online sources, and then discussed the findings from these in light of the earlier theoretical examination of labour. CDA aims not just to describe discourse, but, being grounded in social history, semiotics and linguistics, also attempts to explain how and why it was produced, and the related ideological underpinnings (Tenorio). MCDA extends CDA by facilitating examination of texts in different modalities, that is, images and film in addition to written text.

My first-pass reading of the texts revealed two primary groups of discourse, categorised as *existing discourses and mythicisations of technology* and *emerging discourses and representational strategies of 3D printing*. Given these two categories, I then performed a close reading and further refined the findings within these groups.

The first group, *existing discourses and mythicisations of technology*, disclosed discourses of futurism and utopia, often by using concepts from science-fiction and fantasy. The texts referenced figures reminiscent of *Batman* and similar superheroes and folkloric characters, and the 3-D printer was often presented as an instrument from the future, similar to the Cornucopia machine of science fiction. In contrast to this, yet connected, are discourses of nostalgia incorporating some problematic tensions. The Maker movement tends to fetishise traditional work and craftsmanship, and yet implies that with the 3-D printer, we can now forget what we know about manufacturing and crafting. One text in fact states that while 3-D printing offers the potential to democratise design, it does so by "... letting Makers off the intellectual hook as they bypass deep knowledge of materials and process." (Figure 6). Other discourses within this group involve revolution and disruption, that the 3-D printer will change the nature of manufacturing, and in fact bring on a new Industrial Revolution.

The second group, *emerging discourses and representational strategies of 3D printing*, disclosed the following discourses: Firstly, a common theme is that of democratisation of the technology, and thus the act of manufacturing. This is presented as an act of resistance to the structures of industry and manufacturing. The idea of reclaiming the process of manufacturing is deployed frequently. Next I discussed the discourses around the domestic space and home. The presentation, both textually and in images, often placed the 3-D printer within the home, either as an appliance or as an entertainment device. Only one text mentioned a workshop space in the form of "the basement". All texts showed evidence of conflation of the domestic and work spaces; pointing towards Negri's *social factory*. Additionally, ideas of toys and play were commonly used to communicate the skills and labour needed to use the machines as being as easy as *child's play*. The many references to toys or ornaments also demonstrated that these are the primary product of the 3-D printer, as well as the most commonly printed object.

Thirdly within this group of emergent discourses, are those of creativity and latent skills. The 3-D printer is presented as being a means of expressing latent creativity and entrepreneurship. The discourses underplay the need for extant skills, suggesting that the 3-D printer is all that is needed in order to be creative or productive. Similarly, the creative as a figure is often found in close proximity to these ideas, further implying that this is also what one needs in order to construct one's identity as a creative person.

The results of further analysis of my sample texts demonstrated omission of discourses of labour from texts representing this technology. The labour and skills capital required to use and maintain these machines is underrepresented and oversimplified. In this context, themes of "magic" occur frequently, both as a means of overstating the ease of use of the 3-D printer, and as a step towards mythologising both the technology and the processes of printing. There is distinct emphasis on affect as a product of labour, that is, the enjoyment and satisfaction from performing the labour. Rhetorics claim 3-D printing as a means to reclaim the act of production, and thus subvert the traditional modes of consumption and production. In reality, it seems that given a 3-D printer, the act of "Making" is simply another form of consumption.

Other compelling issues were surfaced in my analysis; despite being apparently unconnected with the primary issues of labour, they may yet prove to be of some interest and relevance. Firstly, despite extensive use of discourses of massification and democratisation of production and access to cheap technology, both the prices of these machines (starting at US $400 at Walmart), and that MakerBot's retail stores were in upmarket shopping areas indicate that the reality is far from the discourse. This is reinforced by the statistics from Make Magazine stating that their average reader is over 40, white male, with a university education and significant (over $100 000) income. Secondly, and supported by these conflicting rhetorics, is that nobody actually knows who the target market is for consumer 3-D printers and what they will be used for other than to make, and be, toys.

5.1 LIMITATIONS OF THIS RESEARCH

There were three primary limitations in this research, all of which were the result of conscious decisions. Firstly, the number of texts I analysed was small. This was due to the principles that underpin MCDA which facilitate reading for depth. Discourse analysis is not a method for counting or enumerating occurrences in content, but looks toward a narrow and sustained focus. However, that is not to say that a large scale representative sampling approach of media messages might reveal valuable alternative discourses or patterns in the deployment of these discourses.

Secondly, the explorations of the Open Source, DIY and Maker movements contained references to local figures or histories, although one of the texts was out of a South African commercial publication signalling that at this level, at the very least, there are remarkable similarities. This is a fascinating area to cover for future work, however there were various factors which would have been beyond the scope of this dissertation. These include the complex labour environment due to the legacy of prior regimes of exploitation and segregation; the deeply asymmetrical access to resources complicated by class and racial issues, and the dimension of discourses from the global North colliding with local post-colonial discourses.

Thirdly, there are many other platforms, such as maker spaces and online fora, and texts where the 3-D printer is discussed and where there are a different range of issues and discourses. However, these take the shape of a different kind of textual and participatory practice that lends itself to a different method of discovery, most likely an ethnographic approach, and a different project entirely.

5.2 AVENUES FOR FURTHER RESEARCH

Various contentious issues around this technology, both positive and negative, have emerged in recent years. There has been a pronounced moral panic and resultant legislative reactions regarding 3-D printed handguns in an era of tightening personal weapons control laws. 3-D model files of these weapons can be downloaded from various sites on the Internet (for instance *Defense Distributed*[1]), and the printed guns, although limited in accuracy or useful life (they can only be fired once or twice) are undetectable using traditional security metal detectors, a disturbing notion for many in the age of heightened security and political tension. There is certainly an opportunity for research that considers these processes and their inextricable link with questions of civil liberties and freedom of expression and speech, both in the context of private weapon ownership within the USA, and the legalities of distributing the files that allow these weapons to be printed.

Intellectual property rights are another area of controversy, with concerns that consumer goods could be scanned and copied, or that 3-D models of copyrighted objects could be shared and printed. With large-scale online repositories of 3-D models and online piracy sites such as *Piratebay* now offering 3-D model downloads or *Physibles*[2] this may turn out to be an edge case for rethinking theoretical models for consumption and commodity.

Finally, on a more positive note, the humanitarian aspects of the 3-D printer are worthy of further research. Projects such as OpenProsthetics and others producing prosthetic and

1 https://defdist.org
2 Although not many at this point. At the time of writing (September 2015), The PirateBay listed many thousand pages of movies, but only 6 pages of Physibles.

medical devices are open-sourcing their designs and soliciting input from users, designers and practitioners. There are also some compelling discourses and myth making happening within these areas, and this may be worthy of examination in the context of Lilie Chouliaraki's ideas of post-humanitarianism (Chouliaraki).

The 3D printer is being constructed as a symbol of the future, a proxy for future objects that at this point in time are unknowable. When it is known or decided what these are, I am sure we will print them.

Part I

APPENDIX

Figure 1: "UP" 3-D Printer Advertisement

Figure 2: Dion Wired Advertisement

Figure 3: "Boston Globe" Article

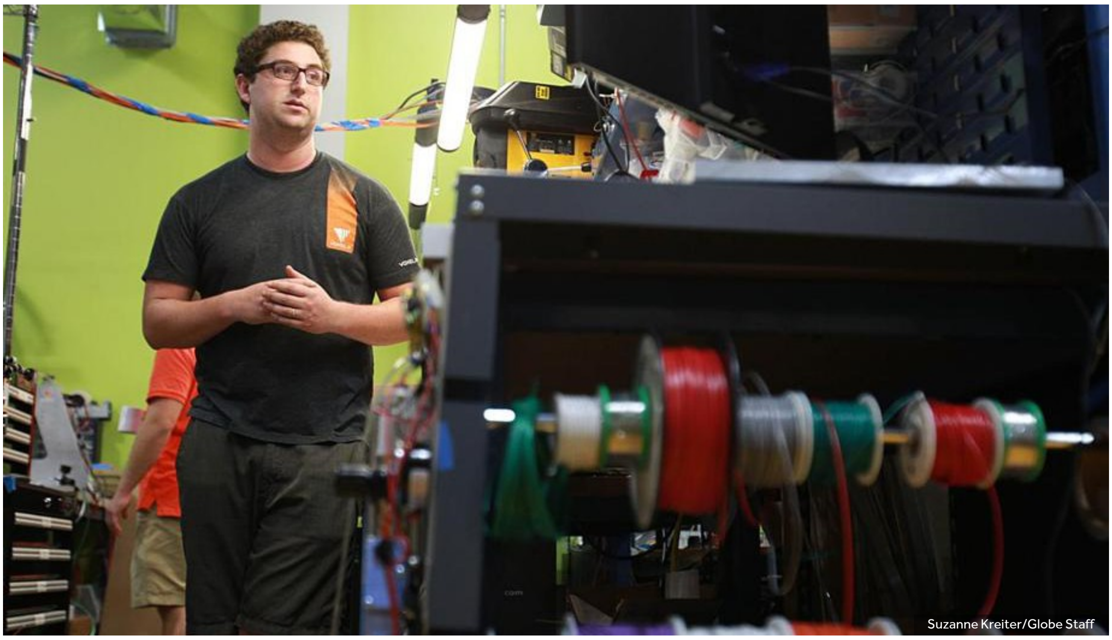
The Boston Globe

beta Boston

Today's top tech event **Click to view**

INNOVATION ECONOMY

Shaky start, but 3-D printing revolution underway



Daniel Oliver, co-founder of Voxel8, a Somerville startup that makes 3D printers that produce objects that incorporate electronics.

SHARE

By Scott Kirsner
Globe Correspondent
07/31/2015

Michael Perrone was standing at a workbench next to one of the world's most advanced 3-D printers, trying to figure out what was going wrong. The printer, not yet on the market, can produce small objects out of plastic, adding circuitry to them as it goes.

But just as your inkjet printer sometimes misbehaves, the Voxel8 prototype didn't want to spit out the conductive silver "ink" that will form an antenna. The problem seemed to be the building's power and Internet connection getting switched off and then on again, messing with the printer's electronics.

You've probably heard the hype about 3-D printing: it's amazing, and by Christmas we'll each have our very own "Star Trek" replicators down in the basement, spewing out thermoplastic so Santa doesn't have to show up with his sleigh.

Reality is rougher. A mutual fund of publicly traded companies that produce 3D printers is down almost one-third over the last year. MakerBot, a Brooklyn company that makes machines priced as low as $1,375, laid off 100 people in April and shuttered its three retail outlets, including one on Newbury Street.

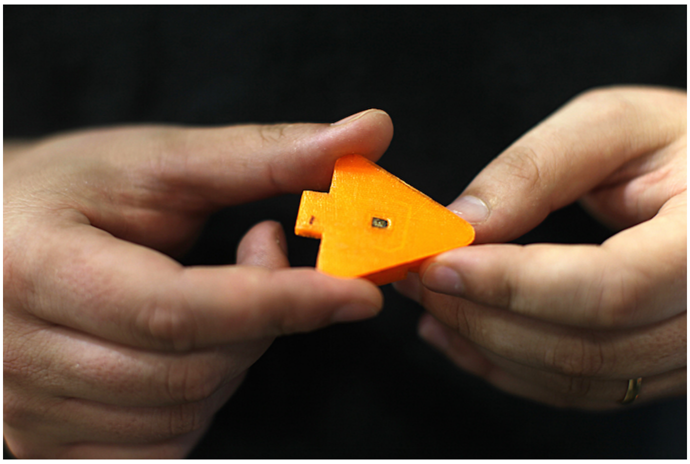
"The so-called mass market for 3-D printing is still pretty early and unproven," says Marina Hatsopoulos, former chief executive of Z Corp., an MIT spinout that helped pioneer the industry. Hatsopoulos quips that "people who shop on Newbury Street do not have 3-D CAD files in their wallets," referring to the digital models that must be created before an object can be produced. And the cost of making something on a 3-D printer at home is still far more expensive than buying something from Walmart, Hatsopoulos says.

Lots of people draw a parallel to the first personal computers in the 1970s, which also required lots of care and feeding. "The PC experience was oversold, too," says Ric Fulop, a Waltham venture capitalist who owns three different brands of 3-D printers. He expects the market for 3-D printers "will be 10 times bigger in 10 years than it is today."

Despite disappointments in the consumer market, a very significant revolution is happening in 3-D printing when it comes to business and educational uses. Terry Wohlers, president of the Colorado consulting firm Wohlers Associates, says he expects sales of 3-D printing products and services worldwide to nearly double to $7.3 billion in 2016 from $4.1 billion this year.

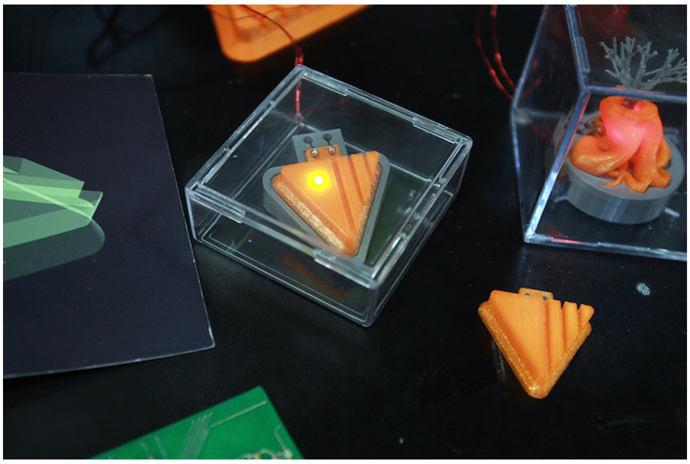
In the Boston area, a number of companies hope to capture some of that growth. MarkForged in Somerville has a desktop printer that can make ultra-rigid parts out of Kevlar and carbon fiber. Another Somerville-based firm, Formlabs, used a dozen of its printers to create several hundred wearable digital bracelets at a conference in June. The bracelets featured different designs, and they lit up when two conference attendees with something in common were close to one another. Woburn-based Viridis3D has a printing system that uses a robotic arm to precisely sprinkle layers of sand that is then hardened with a fixative, creating a mold for casting large parts.

In July, Voxel8, born in a Harvard University research lab, said it raised $12 million, its first significant round of venture capital. (The company was formed only last September.) Co-founder Dan Oliver says that rather than producing flat circuit boards that must be wedged into a finished product, designers in the not too distant future will be able to incorporate circuitry into the product itself. Voxel8's 3-D printer will allow them to do that. One example: a smartphone in which the antenna is integrated into the outer shell, providing better reception.



A 3D printed device with circuitry inside, created by a Voxel8 printer.

Most of today's printers only allow you to use a single material at a time — not unlike when office printers just cranked out documents in black and white. "We think the next big jump is using printers to create finished devices, not just prototypes, with multiple materials in them working together," says Oliver. The company plans to start shipping its printers later this year, at about $9,000 each.



Another electronic device from Voxel8's printer. Some components, like the LED, were inserted by hand during the printing process.

Perhaps the most significant local player in this revolution is a nonprofit called the Fab Foundation ("fab" being short for fabrication). Born at MIT, it supports the creation and operation of a network of more than 500 Fab Labs in 67 countries, outfitted with 3D printers and other tools that enable students and community members to "make anything they can imagine," says Lass, director of the Fab Foundation. (Yes, she goes by just one name.) The first opened in 2003, at the South End Technology Center.

Neil Gershenfeld, the MIT professor who helped open that first Fab Lab, says, "Innovation is a very chaotic, messy process. It doesn't work in sterile boxes. Globally, these Fab Labs bring bright, inventive people out of the woodwork." He and Lass see Fab Labs as a key part of a city's infrastructure — a place for citizens to not just design products and make art, but also to build things that address urban problems, such as sensors that gather data about pollution and adapters that allow bicycle power to run appliances.

This week, several thousand people will participate in the 11th annual Fab Lab Conference & Symposium in Boston. Among the sessions: executives from Google and Amazon.com will talk about making things with robot assistance, and Beno Juarez of Peru will talk about setting up a floating Fab Lab on the actual Amazon.

Gershenfeld is already thinking ahead to the next few decades: "Today, we buy machines to put into a Fab Lab, but we're working very quickly to get to a next stage, where you will go to a Fab Lab to make the machines you need. You'll use a Fab Lab to make a Fab Lab."

Kind of mind-blowing, no?

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TOPICS

Innovation Economy, Viridis3D, Z Corp, Voxel8, 3-D Printing, Formlabs, MarkForged, Makerbot, Fab Lab

Figure 4: "Wired Magazine" Article - cover of issue

Figure 5: "Wired Magazine" Article

CHRIS ANDERSON MAGAZINE 09.19.12 3:15 PM

THE NEW MAKERBOT REPLICATOR MIGHT JUST CHANGE YOUR WORLD

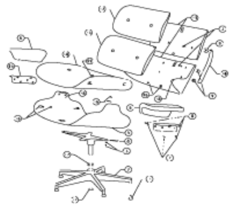
MakerBot cofounder Bre Pettis says his new 3-D printer, the sleek Replicator 2 (shown at right), has a design that's "Darth Vader driving KITT while being airlifted by a Nighthawk spy plane."
Photo: Joe Pugliese

TAKE THE SUBWAY to an otherwise undistinguished part of Third Avenue in Brooklyn. Knock on the door. Wait for some stylishly disheveled young man to open it and let you in. You've arrived at the BotCave—the place where 125 factory workers are creating the future of manufacturing.

The BotCave is home to MakerBot, a company that for nearly four years has been bringing affordable 3-D printers to the masses. But nothing MakerBot has ever built looks like the new printer these workers are currently constructing. The Replicator 2 isn't a kit; it doesn't require a weekend of wrestling with software that makes Linux look easy. Instead, it's driven by a simple desktop application, and it will allow you to turn CAD files into physical things as easily as printing a photo. The entry-level Replicator 2, priced at $2,199, is for generating objects up to 11 by 6 inches in an ecofriendly material; the higher-end Replicator 2X, which costs $2,799, can produce only smaller items, up to 9 by 6 inches, but it has dual heads that let it print more sophisticated objects. With these two machines, MakerBot is putting down a multimillion-dollar wager that 3-D printing has hit its mainstream moment.

more from the

WIRED DESIGN ISSUE



- **Design Wants to Be Free**
- **Glass Works: How Corning Created the Ultrathin, Ultrastrong Material of the Future**
- **How Nerf Became the World's Best Purveyor of Big Guns for Kids**

Unlike the jerry-built contraptions of the past, the Replicator 2s are sleek, metal, and stylish: MakerBot CEO Bre Pettis likens the design to "Darth Vader driving Knight Rider's KITT car while being airlifted by a Nighthawk spy plane." There is also the lighting. Oh, the lighting. "LEDs are part of our core values as a company," Pettis jokes. The new machine will glow in any hue—"to match the color of your couch," he says, "or like something in the movie *Tron*."

You've heard of 3-D printers, but you probably don't own one yet. Pettis thinks the Replicator 2 will change that.

Prototypes of the Replicator 2 print out test items before the machines go on sale in September.
Photo: Joe Pugliese

Constructed of laser-cut plywood, with their internal workings on full display, previous generations of MakerBots were for tinkerers who were as interested in the machines themselves as they were in what they could make. Like the Homebrew Computer Club, which helped hatch the Apple II in 1977, MakerBot was part of what amounted to a Homebrew Printer Club, a global movement of hobbyists taking an existing industrial technology and trying to bring it within reach of everyone. Nearly 13,000 have been sold since MakerBot was founded in early 2009.

And as with the early personal computers, the enabling technology emerged before people figured out what to use it for. All you could do with those early PCs was program them; only later did spreadsheets, word processing, and videogames emerge (not to mention email and the World Wide Web). Similarly, for many owners of the early 3-D printers, simply experimenting with the devices themselves was reason enough to get one.

As the printers got more reliable, though, attention shifted from the machines to the designs they could print. At my house, the killer app for our MakerBots has been toys: dollhouse furniture, board game pieces, models. Print, paint, play. Free design libraries like MakerBot's own Thingiverse and equivalents from Tinkercad and Autodesk mean that there are premade CAD files available to do just about anything you can imagine. It's simply a matter of downloading them, modifying them if necessary, and sending them to the MakerBot to be printed.

Last year MakerBot raised $10 million from investors, including Amazon founder Jeff Bezos, to fund its expansion. It will need all that and more to compete with a host of other emerging low-cost 3-D printers, including Chinese devices and emerging copycat clones. The money is going into R&D, engineering, manufacturing, and a new corporate HQ—everything necessary to take a business that creates kits for hobbyists and scale it into a corporation whose products sell at Target.

This is MakerBot's Macintosh moment. Just as nearly 30 years ago Apple made desktop publishing mainstream, the aim with the Replicator 2 is to take something new to the masses: desktop manufacturing.

A generation ago, people messing around with those original Macs produced some terrible layouts—typically a dog's breakfast of fonts and clip art. But then they got better. When those skills moved on to the web, an entirely new way of publishing was born—and a new industry to go with it. Desktop publishing changed the world.

PolyBend, printed in orange plastic on a Replicator 2 by MakerBot artist-in-residence Marius Watz.
Photo: James Wojcik

Design It, Post It, Sell It

Three-dimensional printers can produce intricate mathematical shapes and whimsical one-off designs. Shapeways, which lets users upload designs to be printed in metal, ceramic, or glass on super-high-end machines, offers a range of such products for sale. MakerBot's home printers can't quite produce these ... yet.—*Paloma Shutes*

Above: Clothoid.A, a lamp shade by Igor Knezevic of Alienology. Printed in nylon plastic by Shapeways ($360).
Photo: Todd Tankersley

Bone Cuff, a bracelet by Nervous System. Printed in stainless steel by Shapeways ($130).
Photo: Todd Tankersley

Thorn Dice set, by Chuck Stover. Printed in bronze-infused stainless steel by Shapeways ($70).
Photo: Todd Tankersley

One Coffee Cup a Day, a series by Cunicode. Printed in ceramic by Shapeways ($50-80).
Photo: Todd Tankersley

Today most people's first 3-D printing projects seem as unimpressive as those first desktop-publishing efforts. But the Replicator 2 line, with its easy-to-use software and optional dual extruder, is designed to accelerate the learning curve to more sophisticated objects by offering higher resolution (two to three times that of previous MakerBots), more colors, more complex shapes, and more reliable output. Add the web's fast-growing libraries of free designs and it's easy to see an emerging alternative to the mass-production model that dominates manufacturing today. Now we can make the Long Tail of Things—perhaps not yet with the same production quality as mass-market fare, but far better tailored for their owner (who also happens to be their maker) and wildly creative. What desktop fabrication represents is a laboratory for the future, not just of manufacturing but of stuff itself.

You might think of 3-D printing as bleeding-edge technology, relevant only to geeks or high-end design workshops. But you may have encountered a 3-D printer already, in circumstances so prosaic you didn't even notice.

Let's start at the dentist's office. Many custom dental fittings are now 3-D printed—like the series of mouth guards, each slightly different from the last, that are used to change tooth alignment over months. After a dental technician scans the current position of the teeth, all positions intermediate to the desired end point are modeled by software and then printed out in plastic. Also, if you're lucky enough to have a dentist who can replace a crown in a single sitting, it's because models are 3-D printed and then the replacement teeth are milled right there in the office.

And that's just the tooth business. Practically every consumer item or electronic gadget you own has been prototyped on a 3-D printer; ditto for the newer buildings around you. Today you can get a custom 3-D-printed action figure of your World of Warcraft character or your Xbox Live avatar. And if you go to Tokyo, you can have your head scanned for a photo-realistic action figure of yourself. (Try not to get too creeped out.)

Commercial 3-D printing works with only a few dozen types of materials, mostly metals and plastics, but more are in the works. Researchers are experimenting with exotic "inks" that range from wood pulp to sugar. Some devices can extrude liquid foods, like cupcake icing and melted chocolate. Soon we'll be able to print electric circuits, potentially making complex electronics from scratch.

When 3-D printers make an object, they use an "additive" technology, which is to say they build objects layer by layer from the bottom up. (By contrast, other computer-controlled machines, such as the CNC router and CNC mill, are "subtractive"; they use a spinning tool to cut or grind away material.) Software first examines the CAD file for an object and figures out how to make it printable using the least amount of material and time. Take, for example, a robot figurine. The external walls will be printed according to the specs, but their thickness can vary, depending on the material; the software will calculate the best thickness to print for sufficient strength while minimizing the amount of material used. Typically the inside of the body is not visible, so there is no need to print it. But without any interior structure, the figurine could wind up too fragile. So the software might make a honeycomb-like support matrix to provide maximum rigidity with minimal material.

The software then "slices" the object into horizontal layers as thin as the printer can handle. As the printer head moves over the build area, it deposits material along the perimeter of the object, with the software picking a path that minimizes the distance the head must move. Then, once a slice is finished, the printer's build platform moves down a tiny fraction of an inch and the head traces the next slice, laying down another layer of material. And so it goes, layer by layer, until the object is finished.

The whole process is almost magical to watch. That's the beauty of digital fabrication. You don't need to know how the machines do their work or how to optimize their tool paths; software figures all that out. We're moving toward an era when, just like with your 2-D printer, you don't have to think about how your 3-D printer works, only what you want to produce with it.

A home 3-D printer is fun. The *concept* of a home 3-D printer, though, is the beginning of a new industrial revolution. That's because those CAD files you created for your Replicator 2 can just as easily drive industrial robots; MakerBots speak G-code, the standard machine control language in manufacturing, just as the first desktop laser printers spoke Postscript, the same language used by professional printers.

So once you have a design on your computer, you can prototype a single copy on your desktop fabricator—or upload it to a commercial manufacturing service and generate thousands. Essentially, you "print local" on your MakerBot and "print global" with cloud manufacturing services ranging from Shapeways and Ponoko to Chinese mass-production facilities found through Alibaba.com. Modern CAD software like the free Autodesk 123D even offers wizards to make it simple to go from one copy to many. All you have to do is click the right buttons, enter your credit card number, and you're in the manufacturing business. The services will even ship the finished goods directly to customers.

Pettis (above) with MakerBot staff in the BotCave.
Photo: Joe Pugliese

Everything about the Replicator 2—how it's designed, made, and sold—is geared to get it into the homes of ordinary Americans. Start with the printing material: The entry level Replicator 2 uses an ecofriendly bioplastic called PLA (polylactic acid), which can be made from cornstarch. Unlike other materials, PLA doesn't shrink very much when it cools, and overall it requires the machine to be less fine-tuned. It's also compostable, and as Pettis says, it "smells like waffles" when it prints. MakerBot's PLA will be available on its website for as little as $48 per kilogram, enough material to make nearly 400 chess pieces. (The Replicator 2X is designed to use ABS plastic, the same material that Legos are made from—it's also nontoxic, but users should make sure to keep the room well ventilated while printing.)

MakerBot is also hoping to radically cut its delivery time to buyers. Previous MakerBots were essentially manufactured only after an order was already in hand, meaning that six weeks or more could go by while you waited impatiently for your machine. That's the sort of thing that devoted makers will put up with, but it won't fly with the general consumer market—especially around the holidays, when people want gifts to arrive by the appointed day. For MakerBot, though, this means a new level of up-front cost before the company realizes any sales. Pettis' goal is to have 2,100 Replicator 2s on hand by the September 19 release date, far more than it has ever stocked of a previous product.

The company is making an even bigger gamble on retail: It's opening a store that same day in Manhattan, on Mulberry Street just north of Houston. Besides selling the new machines, the store will host a mini manufacturing operation so people can see objects being made. "You'll be able to buy MakerBotted things in the store that have been made right there," Pettis says. "I expect tour buses to stop by and kids' faces to be glued to the window displays as they watch products getting manufactured before their eyes."

All of this adds up to a risky time for MakerBot, but Pettis sees the demonstration effect as key: Just as with the early PCs, the appeal of the devices can't quite be understood until they're seen in action. "Before people buy a MakerBot, they think of all the practical applications—all the stuff they can cross off their 'honey-do' list, the things they can fix around the house"—broken parts on the bike or the dishwasher, or a new toothbrush holder to fit a tight space. "But once they have it," Pettis says, "their mind flips a switch. They start printing out amazing things, wonderful things."

They make jewelry, geometric brainteasers, absurdist sculptures. Their children ask for wild toys, and the users can conjure these up before their eyes, first on a screen and then in the real world.

Indeed, Pettis estimates that when MakerBot first started, half of its operators were programmers, but now he has seen a huge influx of parents.

The kids themselves are a given; as I've learned with my own children, they already understand natively how to work with 3-D geometries onscreen, thanks to videogames. (You may not think of *The Sims or Minecraft* as CAD programs, but that's essentially what they are.) Much as the first generation of software entrepreneurs were kids like the young Bill Gates, who grew up with the first machines and intuitively grasped their potential, so the next generation of 3-D-printing innovators may be children. High schools would be smart to bring back shop class but rename it design class, a shift that really would entail just adding a few MakerBots to the school's existing computer labs. How many students wouldn't rather design and print real things than mock up yet another PowerPoint presentation?

But bringing an easy-to-use, reliable machine to market is not enough. MakerBot must also fend off competitors, from the giant 3-D Systems—whose Cube 3-D printer is also targeting mainstream users—to Chinese rivals such as PP3DP, which makes the Up! system. MakerBot hopes that the higher resolution of the Replicator 2 (100 microns, compared with the 200- to 250-micron resolution of the other low-price competitors) and its ability to print sizable objects will make it the winning choice in the $1,000-to-$2,500 price range.

Then there are also the sleeping giants: HP, Epson, and other 2-D printing titans. So far they've been content to either license technology or focus just on high-end professional printers. But how much longer until consumer 3-D volume becomes great enough that these giants awake? Ask Pettis and his response is confident: "By that time, we'll already be way ahead of them."

By all evidence, 3-D printing has reached its inflection point, when it moves from the sophisticated early adopters to people who just want to print something cool. Soon, probably in the next few years, the market will be ready for a mainstream 3-D printer sold by the millions at Walmart and Costco. At that point, the incredible economies of scale that an HP or Epson can bring to bear will kick in. A 3-D printer will cost $99, and everyone will be able to buy one.

That doesn't mean we'll 3-D print everything. The big win of the digital-manufacturing age is that we can have our choice between mass production and customization. Just because you can make a million rubber duckies in your garage doesn't mean you should: Made on a 3-D printer, the first ducky might run you just $20, but sadly so will the millionth—there is no economy of scale. If you injection-mold your ducks in a factory, though, the old fashioned way, the first may cost $10,000—for tooling the mold—but every one after that amortizes the initial outlay. By the time you've made a million, they cost just pennies apiece for the raw material. For small batches of a few hundred duckies, digital fabrication now wins. For big batches, the old analog way is still best.

But think about how many products actually make more sense in batches of hundreds, not millions. For this Long Tail of Things, the only option a few decades ago was handcrafting. Today digital fabricators can bring automated processes and near-perfect quality to the smallest batches.

Digital fabrication also takes the expensive parts of traditional manufacturing and makes them cheap. In mass production, the more complicated a product is and the more changes you make, the more it costs. But with digital fabrication, it's the reverse: The traits that are expensive in traditional manufacturing become free. Consider:

Variety is free: It costs no more to make every product different than to make them all the same.

Complexity is free: A minutely detailed product, with many fiddly little components, can be 3-D printed as cheaply as a plain block of plastic.

Flexibility is free: Changing a product after production has started means just changing the instruction code.

When *Star Trek* captain Jean-Luc Picard wanted a hot beverage, he'd simply tell the *Enterprise* Replicator to make "Tea. Earl Gray. Hot." It's no coincidence that MakerBot chose the same name. The tea itself is still a ways off, but the cup? You can make it today.

Chris Anderson (@chr1sa) is *editor in chief of* Wired. *This article is adapted from* Makers: The New Industrial Revolution, copyright © *Chris Anderson, to be published by Crown Business, a division of Random House, Inc., in October.*

#20.10 #3-D PRINTING #3D PRINTER #3D PRINTING #BRE PETTIS #MAKERBOT #SOFTWARE #THINGIVERSE

VIEW COMMENTS

Figure 6: "Smithsonian Magazine" Article

Smithsonian.com

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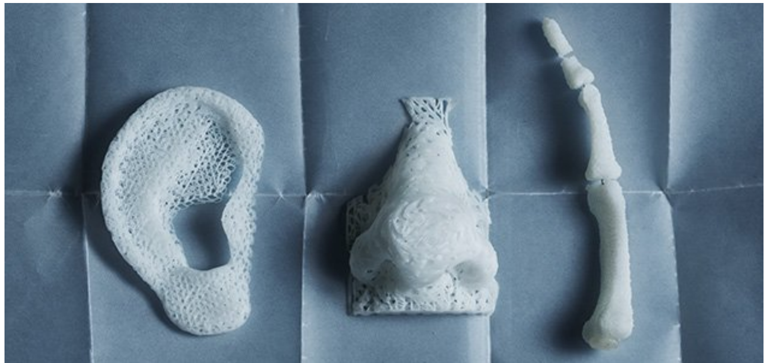
What Lies Ahead for 3-D Printing?

The new technology promises a factory in every home—and a whole lot more



The Wake Forest Institute for Regenerative Medicine prints ear, nose and bone scaffolds that can be coated with cells to grow body parts. (Laurie Rubin)

By **Elizabeth Royte**
SMITHSONIAN MAGAZINE | SUBSCRIBE
MAY 2013

Wandering the brightly lit halls of the 3D Systems' plant in Rock Hill, South Carolina, I gaze upon objects strange and wondrous. A fully functioning guitar made of nylon. A phalanx of mandibles studded with atrocious-looking teeth. The skeleton of a whale. A five-color, full-scale prototype of a high-heeled shoe. Toy robots. And what appears to be the face of a human fetus. "That was made from an ultrasound image," Cathy Lewis, the company's chief marketing officer, tells me, shrugging.

This collection of objects shares one feature: All were "printed" by machines that, following instructions from digital files, join together layer upon layer of material—whether metals, ceramics or plastics—until the object's distinctive shape is realized. The process is called 3-D printing (or additive manufacturing, in industrial parlance) and if you haven't heard of it by now, you haven't been paying enough attention to scores of breathless news stories and technology blogs—or to President Barack Obama, who declared in his most recent State of the Union address that 3-D printing "has the potential to revolutionize the way we make almost anything."

While many people only now are hearing about the technology, engineers and designers have been using large and expensive 3-D printers for nearly three decades, making rapid prototypes of parts for aerospace, defense and automotive companies. Over the years, however, digital design software has matured, scanners have become ubiquitous and affordable desktop printers have come within reach of self-starting entrepreneurs, schools and home tinkerers. Technologists boisterously proclaim that 3-D printing will democratize design and free us from the hegemony of mass manufacturing.

But just because anybody's ideas *can* take shape doesn't necessarily mean they should—a notion that struck me in 3D Systems' lobby, where I saw shelf after shelf of what some people try very hard not to describe as cheap plastic crap: brightly colored miniature vases, phone cases, jewelry, dolls and, inevitably, skulls. (On just one 3-D file-sharing site, I found 101 designs for skull rings and pendants.) The creator of these lobby tchotchkes? The Cube, manufactured by 3D Systems.

"This is our consumer strategy," Lewis explains to me, pointing toward a group of pink, turquoise and lime-green printers. The Cubes are the size of a Mr. Coffee machine, shiny and smooth, and have an on-off switch, a port for a thumb drive and a price tag of $1,299. Cubes create objects through a material extrusion process, in which a print head deposits and stacks thin layers of molten plastic onto a platform. The process begins when users load their digital design into the Cube, whose software helps them scale their model up or down and automatically adds support structures if they're needed. (Supports are made of the same plastic as the machine prints, and they pop off.) Then the Cube "slices" the digital object into microns-thick horizontal layers, creating a blueprint that the print head will follow, moving on x and y axes.

The Cube can create objects in 16 different colors, but it can print only one color at a time (no cartridge switching mid-print). To make a toy robot or a skull ring in more than one color during a single printout, you'll need a CubeX Duo, which costs more than twice as much but has two print cartridges that automatically turn colors off and on—a great leap forward in the eyes of desktop printing aficionados.

Perhaps sensing my ambivalence toward this device, Lewis leads me into a glass-walled manufacturing room to see the company's big guns: a brace of refrigerator-size machines fronted with small windows and surrounded by monitors, keypads and CPUs. Electrical cables snake overhead, Shop-Vacs are ubiquitous and the floor is slippery with powdered nylon. Squinting and shielding my eyes from glare, I stare through the small window of a stereolithography machine, in which a vat filled with a photosensitive polymer is repeatedly blasted by a laser, triggering a chemical reaction that causes a thin layer of the viscous dark blue liquid to harden. Seconds pass, horizontal lightning flashes and a wiper distributes another layer of the resin.

Each layer is 50 microns thick, which is equal to one-twentieth of a millimeter. (The thinner the layers, the finer the resolution and the crisper the details.) The finished object rises while its build bed, or platform, sinks. What was this printer—which costs $170,000—producing? Lewis consults a monitor and surmises it's jewelry, a ring of intricate design. I note that it's a lot of machine to make a bauble, but Lewis assures me that technicians usually build more than one bauble at a time.

She shows me another windowed machine. This time the vat is filled not with dark blue liquid but white powdered nylon. A wiper smoothes the vat's surface, upon which a laser lightly etches the outlines of four rings and a miniature boomerang by fusing together the powdered material (a process known as sintering). The wiper swipes again, erasing the shapes, the laser flashes, and another layer of rings and a boomerang is sintered. The monitor tells us this project is four inches high after 26 hours of sintering, with many hours to go. The "reveal" won't come until the excess powder is excavated and the product exhumed. It might be a drone, it might be a cast for an engine block. Lewis can't say (it's definitely not a boomerang). But she knows this part will be as durable as whatever traditionally manufactured part it's replacing.

My tour ends where it began, among the plastic robots and phone cases. In two hours, the history of additive manufacturing has passed before my eyes, starting with technical applications and ending in homes and offices—not unlike the trajectory of computers and laser printers. With the ability to replicate or create such objects on demand, says Dale Dougherty, publisher of *Make* magazine—part of the burgeoning DIY "Maker Movement" that privileges customization over commodities—the 3-D printer is "Wal-Mart in the palm of your hand."

***

That notion may thrill or horrify you, but the business model—on-demand printing of customized products—has significant advantages over traditional retailing models. If you can quickly and cheaply replace a broken cabinet handle by printing it at home (or scanning what you want and e-mailing those specs to a print shop), you needn't travel to a store and stores needn't keep millions of everything on hand. Shoe designs could be encoded as digital templates that could be manipulated and printed to perfectly fit any customer's feet. Inventories would shrink, along with transportation, handling and storage costs. (Retail shops might even disappear if orders can be fulfilled directly by manufacturers who deliver to their customers' homes.) And if supply lines are less dependent upon manufacturing centers abroad, they're also less vulnerable to interruption.

In conventional manufacturing, every increase in design complexity costs money and time. With additive manufacturing, it's as easy to print a simple tube as it is to print, say, a double helix wrapped in a spiral staircase draped by a spider web. High-resolution printers can even make products with gears and hinges.

Shapeways, a 3-D printing service, has built its business upon the assumption that a sizable demographic is willing to pay more for customized products than for mass-manufactured goods. The company fulfills design orders from tens of thousands of customers, or "community members," at plants in the Netherlands and in Long Island City, New York, using printers that handle a variety of materials, including ceramics, sandstone, plastics and metals.

"We're giving people access to million-dollar machines," Elisa Richardson, Shapeways' PR and social media manager, says. "We're enabling them to run businesses through our company." And what do those businesses sell? "Mostly cultish things, like Minecraft models and Dungeons & Dragons dies." Ah, I think: We're back to the skull rings. "Are customers requesting prints of anything truly surprising?" I ask. Richardson pauses, then says, "It's amazing how *unsurprising* the stuff we make is. It's a doorknob or a crib part from a mom in suburbia."

Clearly, 3-D printing is a boon to personal consumption, but the machines can potentially provide great social value as well. Imagine villages in the developing world printing parts for farm equipment or water pumps, and the solar panels that drive them. Imagine mobile production plants quickly deployed in disaster zones, printing out anything from arm splints to tent stakes.

In the future, suggests Peter Friedman, publisher of the *Innovation Investment Journal*, car dealers might include free printers with vehicles, so that owners can make their own parts, replacing and redesigning forever. "3-D printing is not just the future of making things you don't have," he wrote in a column. "It's the future of making things that you do have immortal."

One of those things might even be the human body—or at least some of its parts.

***

Carlos Kengla, a slim young man wearing statement eyeglasses and a four-inch-long soul patch, could easily pass for a hipster Maker of small-batch bourbon or bespoke bicycles. But Kengla has spent the last few years focusing on the production of ears, which he prints using cells that are taken from human ear cartilage and then propagated in the lab. Kengla's fellow scientists at the Wake Forest Baptist Medical Center's Institute for Regenerative Medicine are developing, in collaboration with other labs, processes to systematically print muscle tissue, skin, kidneys, cartilage and bones. For years, researchers have been building organs by hand, pipetting progenitor cells—which have the capacity to differentiate into specific types of cells—onto degradable scaffolds. They've had varying levels of success: Handmade bladders have been functioning in a handful of patients for many years; a miniature kidney implanted in a cow successfully excreted urine. But constructing organs by hand is laborious and plagued by human error. Rapid prototyping, with cartridges of cells squirting from a print head and guided by a computer, Kengla says, "is faster and more precise, to the micron. It allows us to place different types of cells in specific shapes and in intricate patterns."

Kengla stares into a computer monitor, clicks through what seems like a hundred menus and initiates three cartridges loaded into a print head that hovers over a petri dish atop a small platform. One cartridge contains cartilage cells, another contains biodegradable scaffold material and the third contains a water soluble gel, which temporarily provides support until it's later washed away. Back and forth the print head shuttles with a pneumatic whoosh, switching between the cartridges, constructing the organ in stacked, successive layers, each 150 microns thick. A high-intensity light and microscope allow Kengla to follow the machine's progress on a monitor. After 45 minutes, the shape of an ear begins to emerge.

Perfection remains a few years in the future. Still, the printing of organs—and cartilage and skin and tissue—holds great promise for transforming health care and extending longevity. Transplanted organs created from a patient's own tissues won't be rejected. Waiting times for kidneys and other donor organs will decrease, and organ traffickers could be put out of business (the World Health Organization estimates there were almost 11,000 organs sold on the black market in 2010). Prescription drug companies are eager to test drugs and other therapies on rapidly prototyped organs or tissue, instead of on animals or human beings.

Anthony Atala, who leads the Institute for Regenerative Medicine, predicts that it's only a matter of years before hospitals have machines that can print skin—from subcutaneous fat up through keratinocytes to hair follicles, oil glands and melanocytes—directly onto a patient's body. "Skin is the least complex organ," Atala says. "Then we'll see tubular structures, then hollow and then non-hollow organs." Including, eventually, a heart? "I hope in my lifetime," he says, laughing. "And I'm still very young." (Atala is 54.)

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Dealing with complexity is what additive manufacturing is best at. Engineers for Lotus Renault GP, in pursuit of lighter, faster and more fuel-efficient Formula 1 race cars, use stereolithography and laser sintering to experiment with cooling ducts and fins, eliminating material that's inessential to function. And the process is quick. Pat Warner, Lotus Renault GP's advanced digital manufacturing manager, says he can turn around parts in two days instead of ten weeks.

It's high-end applications like this that have raised 3-D printing's public profile. "The aviation industry has more than 22,000 printed parts flying right now, and people are walking on 3-D printed orthopedic implants," says Terry Wohlers, the president of the independent consulting firm Wohlers Associates. "These are very regulated, very demanding industries and these parts are performing well."

Canadian designer Jim Kor is building a three-wheeled, teardrop-shaped car that weighs just 1,200 pounds. Kor shaves weight by combining multiple parts. The dashboard, for example, is printed with ducts attached, eliminating the need for multiple joints and their connecting plastic and metal parts. Somewhat less dramatically, bakers are extruding icing from print heads to decorate cakes; stop-motion animators are using rapid-prototyping 3-D printers to create thousands of nuanced facial expressions for film characters; mathematicians use the technology to model complex geometric shapes; and 3-D photo booths are scanning people and printing miniature replicas of their heads or entire bodies.

Additive manufacturing would not have flowered without major advances in computer-directed modeling. A decade ago, it took weeks to generate a digital 3-D model; now it takes only hours. Design software has become more accessible, and scanners, too, have become more powerful and easier to use—even at home. This past March, Microsoft announced a forthcoming software release that will endow its Kinect for Windows computer sensor with the ability to quickly create detailed 3-D models of people and objects.

Engineers and product designers scan an existing object or contour by shooting thousands of points of light at it and loading the "point cloud"—a 3-D ghost image of the original—into a computer. Multiple scans are aligned and filtered, points are connected to their near neighbors to form polygons, holes are filled and blemishes removed. Finally, with a click of the mouse, the surface of the image is smoothed to form a shrink-wrapped version of the original. Off to the printer the digital file goes.

And if the client doesn't like the finished print? Not a big deal: The supply chain is a computer file, not parts from around the world, and there's no need to retool machines to make design changes. The trajectory from idea to approval to manufacturing to marketing to sale is, again, vastly accelerated.

“Once a shape is in a usable 3-D format, the sky’s the limit,” says Rachael Dalton-Taggart, director of marketing communications for Geomagic, a pioneer in sculpting, modeling and scanning software. The company’s products include software that gives digital designers tactile feedback. Wielding a penlike, haptic device—which has motors that push back against the user’s hand—designers can trace the contours of a digital model, feel its surface textures and carve shapes. “It’s like working in digital clay,” says Dalton-Taggart. “The program lets designers create particularly complex and highly detailed organic shapes,” whether for sculptural jewelry or patient-specific medical implants, such as a perfectly modeled prosthetic nose.

The opportunities for customization have long made additive manufacturing appealing to the medical community. Biomedical companies commonly use 3-D modeling and printing to produce personalized hearing aids as well as dental restorations, orthodontic braces—and most recently, skulls. This past March, after FDA review, an unnamed patient had 75 percent of his skull replaced by a plastic implant printed by the Connecticut-based Oxford Performance Materials.

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From organs to O-rings, 3-D printing has prognosticators buzzing over its transformative, and even disruptive, potential. If the technology fulfills the predictions of its most ardent cheerleaders, supply lines that connect mass manufacturers in cheap labor markets with consumers in the developed world will be shortened. Mass manufacturing in low-wage countries will decline and markets will be re-localized. With a lower bar between innovating and producing, thousands of new businesses are expected to blossom.

But the growth of this technology raises a thicket of legal questions. Who is liable if a home-printed design fails to perform? Who owns the intellectual property of codes and the objects they produce? (Physical objects can be trademarked and patented, and digital 3-D files can be copyrighted, but in the Maker universe this is considered uncool and counterproductive to innovation.) Three-D printing is bound to encourage counterfeiting, with serious consequences for brand owners. Disney, whose characters are widely copied by Makers, is so far ignoring infringements, but that may change.

Then there are security concerns. Using blueprints downloaded from the Internet, people already have begun printing gun parts. Hackers have stolen personal banking information after creating a widget that fits inside an ATM. As ever, tools can be used for good as easily as for ill. It will be up to myriad government agencies to address the wide spectrum of legal and criminal concerns.

And all new technology produces winners and losers. Additive manufacturing will create new industries and new jobs. But it may also displace skilled craftspeople, artisans and designers who work with raw materials, just as Amazon displaced bookstores, and desktop printers eviscerated mom and pop copy shops. Thanks to the Internet, we are all writers, photographers, filmmakers, publishers and publicists. Soon, we may all be Makers, too. Those who rue that day can take some comfort, for now, in 3-D printing’s weaknesses: The printers can produce objects only as big as their build platforms; and most desktop machines print only in one or two materials, which are fragile compared with those produced by the high-end industrial machines. And, unlike industrial printers, desktop models lack standardization, so different machines using the same design files won’t necessarily produce identical objects. (The National Institute of Standards and Technology is currently helping to develop standards for the industry.)

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Throughout my travels in 3-D, cognitive dissonance stalked me. One can intuitively grasp that additive manufacturing has a smaller resource footprint than subtractive manufacturing, in which designs are chipped or cut away from larger blocks of material. Shorter supply chains have smaller carbon footprints, and printing on demand could reduce the waste of closeouts, overstocks and other products that never get bought. But the feedstock of 3-D printers—whether plastics or gypsum powders or metals—still needs to travel the world. Moreover, ABS plastic, the principle feedstock of desktop printers, is derived from oil or gas, which are both finite, polluting resources. (PLA, another common feedstock, is made from corn, which also has a sizable environmental footprint since it requires fertilizer, pesticides and irrigation.) 3D Systems’ Cathy Lewis stresses the recyclability of ABS and PLA, but most communities don’t accept or collect these materials for processing, and I doubt that many customers are likely to mail their unwanted Cube creations to South Carolina for re-milling.

More important, I worry that the ease and relative affordability of making niche or customized products—with the exception of medical and some industrial applications—is just as likely to speed their disposal: Easy come, easy go. When new sneaker designs move from idea to retail shelves in weeks instead of months, design fatigue may set in sooner as well. The result? Ever more sneakers on the trash heap of fashion obsolescence, and a devaluing of the creativity that went into producing them.

While 3-D printing offers the promise of democratizing design, it does so by letting Makers off the intellectual hook as they bypass deep knowledge of materials and process. As Chris Anderson, the former editor of *Wired Magazine*, writes in his book *Makers: The New Industrial Revolution*, “You don’t need to know how the machines do their work, or how to optimize their toolpaths. Software figures all that out.” That might not bode well for the future. Designing and producing only on computers, says Scott

Francisco, an architectural theorist and designer who teaches at Parsons The New School for Design in New York, has the potential "to drown human learning, creative skills and even basic productivity with its information and numerical-technical approach to problem solving." Sure, the machines themselves are innovative, but they reduce the need for designers to work face to face with collaborators—crafting and refining, one slow iteration after another. The next generation of designers, Francisco fears, will know little about how real materials look, feel and interact with each other, leaving people ill-prepared to be innovators in their own right.

Such worries may be premature, for 3-D printing has yet to reach either its "killer app" moment—which makes it as ubiquitous as home computers—or its "rubber ducky" moment, when it supplants mass manufacturing. Traditional methods of production in low-wage countries are still far faster and cheaper than additive manufacturing when large numbers of parts are needed, says *Innovation Investment Journal*'s Peter Friedman. And while Geomagic co-founder and CEO Ping Fu has predicted that "mass customization" will replace mass production, even matching it in costs, one can't help feeling, gazing at a set of metal mixing bowls (to name just one household item), that customization isn't always called for.

Yes, additive manufacturing is being used to create prosthetics and aircraft components —products that epitomize the technology's sweet spot of low volume and high complexity. But for the vast majority of people, 3-D printing may remain an upstream, out-of-sight industrial process. Only the technorati, with cash to burn and a burning desire to Make, are likely to pursue desktop printers. Anyone else compelled to own a 3-D-printed skull ring will find easy satisfaction perusing the many on offer through print bureaus. Some of them are even anatomically correct.

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