LEANDROS SAVVIDES

3D PRINTING

POLITICS, MATERIAL HACKING AND GRASSROOTS INNOVATION

Submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

UNIVERSITY OF LEICESTER

SCHOOL OF BUSINESS

MARCH 2018

3D printing: *politics, material hacking and grassroots innovation*

Leandros Savvides

Abstract

This thesis examines the emergence of 3D printing culture outside the professional lab, predominantly in Hackerspaces, Makerspaces and Fab Labs. Such spaces constitute important sites in the development of open-source, desktop 3D printing and provide conducive conditions for the spread of the technology to and often beyond technologically informed publics. Specifically, this research addresses the convergence of activism and the maker culture with prevalent cultural imaginaries such as the visionary creator within decentralized and distributive manufacturing, the vision of autopoietic social systems, or the imaginative leap to space colonization. In addition, it explores the emergence of grassroots innovation and how it is configured through 3D printing. In order to observe the aforementioned social phenomena, I conducted multi-sited ethnography in several experimental spaces in the UK, Germany and Cyprus. The selection of the sites represents different types of Hacker-, Makerspaces and Fab Labs: some of them bring hobbyist maker communities together, while other were explicitly conceived as political interventions and other operate as informal start-up incubators. In my fieldwork I followed users of 3D printing technology as they navigate their activities through grassroots workshops, multiple associated communities and broader hacker networks.

Drawing on the findings of my research, I argue that the emergence of digital DIY and maker cultures was not only powered by 3D printing technologies but also played a vital part in creating, expanding and disseminating knowledge of 3D printing further afield. Within this process, 3D printing users become developers themselves who simultaneously reinvent forms of consumption, processes of learning and re-conceptualizing the relationship between science and craft. Despite the apparent social and collective nature of these practices, there is also a parallel individualistic twist

at the heart of the maker culture. The thesis contributes to a growing debate within Science and Technology Studies which is concerned with the emergence of citizen science and civil society interventions in shaping technology. Moreover, it touches upon challenges and motivations in the field of grassroots innovation by examining how it is organized and conducted in semi-informal contexts such as the Hackerspaces, Makerspaces and Fab Labs

Acknowledgements

I am extremely grateful to Dimitris, Martin and George for their guidance during all these years. You have been extremely helpful and positive forces for the completion of this study and all the things I learned along this process. I would like to thank all the people who shared their thoughts, showed me their projects and opened their spaces for the purposes of this study, its been a pleasure meeting all of you. Finally, I would like to thank all the people who suffered with me and by me, during the last five years, my partner who suffered the most, sister, friends, comrades and non-human companions.

The thesis is dedicated to my parents, who even though had a hard time grasping my life decisions, they nonetheless backed me at every turn.

To all people who encounter technology critically with courage towards the future.

Table of Contents

Table of Figures

List of Abbreviations

AM – Additive Manufacturing

CAD – Computer –Aided Design

CBPP - Commons Based Peer Production

CEO - Chief Executive Officer

CLIP - Continuous Liquid Interface Production

CNC - Computer Numerical Control

DARPA – Defence Advances Research Projects Agency

DIY – *Do it Yourself*

EU – European Union

FDM - Fused Deposition Model

IP – Intellectual Patent

IT – Information Technology

LOM - Laminated Object Manufacturing

MTC – Manufacturing Technology Center

NASA – National Aeronautics and Space Administration

NSF - National Science Foundation

OSAT - Open Source Appropriate Technology

PLA – Polylactic acid

PVA – Polyvinyl alcohol.

R&D – Research and Development

REMAP - Rehabilitation, Engineering & Movement Advisory Panels

SL – Stereolithography

STEM – Science, Technology, Engineering, Mathematics

STS- Science and Technology studies

USB - Universal Serial Bus

UT – University of Texas

WEF – World Economic Forum

Approaching 3D printing

> *Today we are seeing a return to a new sort of cottage industry. Once again, new technology is giving individuals the power over the means of production, allowing for bottom-up entrepreneurship and distributed innovation. Just as the Web's democratization of the means of production in everything from software to music made it possible to create an empire in a dorm room or a hit album in a bedroom, so the new democratized tools of digital manufacturing will be tomorrow's spinning jennies. And the guilds they may break may be the very factory model that grew up in Manchester and dominated the past three centuries.* (Anderson 2012, p. 50 - 51)

3D printing as a technological possibility has been around for more than two decades. Indicatively, the first successful attempt to print objects using the now popular stereolithography method was made by Charles Hull in 1986. The first attempt to commercialize 3D printing technology and methods for manufacturing emerged in 1994, using print materials composed of wax (Jacobs 1992). There are a variety of methods that constitute 3D printing technology, but the underlying general characteristic all methods utilize is to build objects in additive technique. That is in contrast to molding them using a subtractive method (Knill and Slavkovsky 2013). This means that 3D printers can be quite efficient and more flexible than other methods of manufacturing, depending on the state of development of the specific methods in specific industries[1]. Efficient because the additive technique builds objects not by eliminating parts and so as a process, entails much less waste and is a good

[1] Explanation of various methods coming from various companies see the next chapter on the history of 3D printing.

choice for low volume manufacturing. Flexible, because building objects additively offers greater creative freedom with flexible materials as well as more intricate geometric objects.

With the commercialization and thus affordability of 3D printing, it was primarily field professionals and hobbyist practitioners that had access to prototyping, through industrial or semi-industrial professional settings. The technology remained virtually unknown to the vast majority of the population. This would appear to coincide with and even explain why, until very recently, literature that relates directly to 3D printing as technology and process was very scarce, apart from official industry and policy reports. Francis Jacob's (1993) early work on defining the key characteristics and competences of the technology when it was in its infancy is an example of such work published through industry. Indeed, after the turn of the century, research on 3D printing remained technical in the main. For instance, as a field of study, Additive Manufacturing[2] (AM) has been systematically researched in terms of pure engineering and as a scientific advancement of manufacturing (Hague, Campbell and Dickens 2003; Balc and Campbell 2004; Burton 2005; Hopkinson, Hague and Dickens 2006; Sells and Bowyer 2006; Reeves, Tuck and Hague 2011).

From the beginning of the 21st century, 3D printing began to fire the imagination of public media and cultural groups with an interest in DIY and technology, consequently sparking creative narratives. Such narratives helped disseminate knowledge of the existence and practical capabilities of 3D printing among the general public, which gradually became aware of its existence. This was when the Makers movement started to gain momentum, so named because of "*Make* magazine", an American bimonthly publication founded by Dale Dougherty, a leading proponent of open software. The Makers movement had a very simple message: 'Make. Just make. This is the key. Making, is actually fundamental to what it means to be human.' (Hatch 2013, p.11-12)

[2] The name preferred in industry and academy until recently

Creative hobbyists and communities started to use such type of machinery for their own purposes, experimenting and in many ways adding to and advancing the technology itself. The iconic garage where the Apple seed was first planted and similar stories of mega concerns first seeing the light of day in small uncomfortable places where their creators had to hack their initial products and ideas until they took off, became the stuff of legends that provided a motivational boost for those who otherwise might have packed it in after experiencing the inevitable setbacks associated with developing a new technology. Many stuck to it because of the romanticized image of a group of pioneering wunderkinds who achieved success, by defying the sceptics, proving that starting to make is the most difficult step (Turner 2010; Bauwens and Kostakis 2014). So, why approaching 3D printing as a cultural phenomenon apart from a technological development?

As the momentum built and word spread about 3D printing culture, illustrious and established media were quick to get into the act pronouncing 3D printing as a phenomenon potentially 'bigger than the internet' (Morton-Clark and Garrahan 2012) for businesses to exploit the new technology. On the other hand, from a grassroots perspective, as Chris Anderson contends, this is a crucial technology that could bring about a 'third industrial revolution' (Anderson 2012, p. 40) because it will allow people (not just workers) to 'control the means of production' (Ibid, p. 5), a clear suggestion that the technology can bring about cataclysmic social changes.

Whatever the case, 3D printing seems to be exciting news for many fields of study and a technology capable of reconfiguring modes of production and consumption in the future. An obvious reason could be the development and integration of internet and internet-based hardware and software into the everyday life of millions of consumers. For others, it goes beyond a mechanistic understanding of the combination of internet and a desktop machine. The technology and related hardware and software open up a whole new political economic paradigm. Carson has contributed to the field from the perspective of a mutualist political economy (2010) albeit not focusing solely on 3D printer but on desktop manufacturing in general. In policy making circles, the idea of a circular economy meets some of these characteristics half way by proposing new ways of using materials, collaborative consuming and creating new value channels,

> In our business, we have regular discussions with our partners, coming up with new "circular" approaches, such as "second-life markets", where goods are refurbished and marketed to new customers, extending the life of the product and building new revenue streams. The fact is, climate change and resource scarcity won't go away unless we change things. More renewable energy usage and a smarter use of the planet's resources is at the heart of the circular model, in which re-manufacturing, recycling and re-use methods are adopted in greater number. (Stephenson 2015)

The development and conversion of such technology into a brand new manufacturing technique and organization culture has generated an accompanying literature that explores 3D printing as it relates to intellectual property in terms of new exclusions and innovation processes that unravel (Bradshaw et al 2010; Weinberg 2010); how inexperienced users could achieve professional and functional designs (Simpson et al 2006; Campbell et al 2007); and how this could alter the manufacturing industry in terms of mass customization (Baumberger 2005; Chin 2005; Koren and Barhak 2007). Despite the focus on its productive impact, the significance of 3D printing in cultural terms and more importantly in everyday life was perhaps overlooked or under-appreciated until the Makers movement adopted and promoted 3D printers as important desktop technology for making. That this lent itself to science fiction and play proved to be attractive for makers and the wider public alike.

After the 1960s, when the space race brought new audiences to science fiction and then the 1990s, where the mass adoption of personal computers and the internet created the cyberpunk genre (Pierson 1999; Bacon-Smith 2000), futurism came back into fashion[3]. This alluring futuristic imaginary is what also attracted me to the study of 3D printing not simply as a technological development but more broadly as a social and culturally induced phenomenon. Ubiquitous manufacturing and the ability to deliver finished products through 3D printing machines in networked and decentralized centers motivated communities and artists alike to start dreaming of a 3D printed future (Birtchnell and Urry 2013). Following suggestions by cultural icons such as Anderson, for many years' editor-in-chief of Wired magazine and later founder and CEO of 3D Robotics, I approached this project in a manner allowing me to discern such cultural imaginaries whilst attempting to document its real time development. I decided to look for 3D printers in these bottom-up spaces and juxtapose my observations, experiences and interviews with official documents, newspaper articles and policy documents.

In this manner, my hope is that the outcome of this thesis explores and describe to some degree a broad social movement that encompasses work, hobbyism and political activism through the lens of 3D printing. 3D printing is closely related to the hacker ethic (Levy 1984; Soderberg, 2008) as much as it is associated with networked modes of alternative production and sharing of information (Castells 2000; Bauwens 2005; Benkler 2006; Bowyer 2007; Carson 2010; Powell 2012; Kostakis 2013). The hacker ethic has proven to be a key component in innovation strategies, which suggests that just being a hacker or a maker does not necessarily mean alternative ways of doing and living. Other factors have to be taken into account to explain the alternative modes of production and distribution – e.g. motivations, infrastructure and cultural imaginary. This thesis is the product of my initial attempt to engage with STS. The choice of STS seemed to be the most appropriate, as it is an

[3] Not only through the lens of 3D printing, it is evident that new technological and scientific developments have been reflected in social and political thought. One example is the advocacy of Accelerationism, which has left and right wing variants. However, the differences of the different variants, the main tenet of Accelerationism is that technological and scientific developments are exceeding the limitations of capitalism and lead towards post-capitalist futures. See for example, Williams and Srnicek (2014).

academic field which allows an interdisciplinary approach to technological phenomena, looking at 3D printing through society, politics and culture.

My interlocutors in this endeavor to find links between grassroots communities and the technology itself, range from experts, university students and researchers, to hobbyists, artists and political activists. Each had something to talk about when asked about 3D printing and each helped position a piece in the puzzle of the phenomenon for this study. Indeed, some of the arguments I make throughout the dissertation are triangulated in order to show how individual perspectives connect to a broader cultural phenomenon. Some people have identified themselves as part of the Makers movement whilst others although not identified as such, revolved around for completing their projects. Although not all of those involved in this study necessarily identify themselves as being part of this movement, the movement's swift rise to prominence had significant impact on the technology, the people who are involved and the spaces they conduct their practice.

The Makers movement that started to increasingly expand over the past five years, found something that was already there. This something has to do with three factors. Firstly, the collective experience and cultural legacy of the urban working class of previous generations, whose radical science movements for democratic decision making challenged the direction of scientific explorations taken by government administration (Rose and Rose, 1979). Another factor was industrial production upgrades like digitizing manufacturing (Wu et. Al, 2015), the question being did they constitute a new paradigm or are they simply an addition to old structures. Last but not least, shifts in educational trends which expanded traditional learning practices to include informal playful practices while retaining basic educational values. These innovative educational practices use collaboration to unsettle the balance of power between those being educated and the educator, resulting in a more democratic learning experience (see Tanenbaum et al. 2013). In addition to these informal practices, new methods of learning place greater importance on the methodology of searching for answers than on the answer itself. There is also the growing, necessity-based collaboration between industrial workers whose skills are outmoded(due to redundancy and/or industry changes[4] or the availability of cheaper production and bigger profits elsewhere) and skilled university graduates who find it increasingly difficult to find secure jobs[5]. As such, the field covers a wide range of often overlapping practices, technologies, lifestyle and ways of thinking, including art and small start-up enterprises, all of which find it increasingly beneficial to collaborate in some way or another. For this matter alone, grassroots community workshops add a physical dimension to the previous online collaborations of the open software movement, which now seem to be the favorite physical platforms where they can engage.

With this emergence of new forms of collective community workshops in the heart of cities, 3D printers have become a common tool for makers and hackers. Despite the efforts of Johan Soderberg (2013), Vasilis Kostakis and Michel Bauwens (2014), the available literature exploring the technology of these emerging movements and the field for integrating user perspectives with broader social developments is very limited. This is understandable since the hype surrounding the particular technology and the Makers movement has only been addressed recently. Another research example from this perspective is the study conducted by Jones et al (2011) which specifically brings up matters that could only have been learned by insiders and people spending a considerable amount of time delving into forums and blogs that explained the birth and development of RepRap. RepRap sought to create a general-purpose machine with self-replicating and mass customization capabilities through open design, under the license of free software (see Sells et. Al, 2010). In their book “Fabricated: the new world of 3D printing”, Kurman and Lipson (2013) provided some insight from the perspective of the mainstream economy and industry urging that they utilize the technology by resorting to futurology.

---

[4] See for example a “SPERI British Political Economy brief” commenting on the decline of manufacturing industry in the UK during the past two decades.

[5] The inability of youngsters to find jobs coupled with the increasing capabilities of desktop technologies have had some effect, turning many towards DIY projects on their own.

The Hackerspaces, Makerspaces and Fab Labs that were springing up near the UK's Midlands industrial area, offered extra easy access to look into what makes this spreading culture so attractive to hackers and makers alike. But it wasn't confined to the traditional core of Midlands manufacturing around cities like Birmingham, Derby, Coventry and Leicester. The opening of these spaces inspired others, not necessarily from industrial towns or backgrounds, to create their own workshops. These workshops had to find legal ways of establishing themselves just as they had to find more interested people in order to increase prospects for collaboration and expansion of their networks. In a few brief years, they grew from isolated pirate-like organizations within cities, to large communities integrated within the fabric of their respective local societies, some even with national appeal. Some collaborated with companies, others less so. Some actively encouraged start-ups, others preferred to create inclusive communities, a way of showing they were concerned with more than just creating projects. Susana Nascimento (2014, p. 1) writes on their importance,

> These new settings are promisingly opening up concrete opportunities for decentralized and collaborative engagements with technology, not only related with material and technical experimentations, but also with economic, cultural, social and political consequences, and ultimately with conceptual and epistemological changes. With due attention to their differences, there is a common and shared rationale attached to these emerging spaces that supports an openness when approaching and thinking about technology. This powerful and captivating rationale expresses that any user, consumer, or citizen should be ultimately able to produce, use, share, copy and improve technologies, with little to no help or backup from traditional technological experts, organizations or

> institutions. And from this standpoint, derives a multiplicity of potential pathways for empowerment through technology and democratization of technology for broader social groups.

Decisions, such as how to organize or the name the community should adopt are usually a matter for those who set up each community. Some adopt a democratic framework, presuming the community to be as important as the sharing of tools and machines. Others focus more on sharing resources and apply a managerial style to daily care. The decision on what organizational style each community prefers, is usually affected by operational costs and the direction it wants to follow. For example, a shared machine shop for commercial purposes is not likely to follow democratic style management. At the same time, a community which seeks to operate as a hobbyist group usually promotes cultural values such as participation through collective decision making. Although rather different in some aspects, in this dissertation I group these non-commercial spaces on many occasions as community workshops, since I think they share similar core attributes. People within the Makers movement often act in the same way despite the label chosen.

The thesis explores the dynamic interplay between these spaces, the Maker community and 3D printing technology, not as isolated issues but in context. In other words, by challenging popular notions of hype-driven technological narratives, Technoscience and grassroots communities, this study aims (after a historical outline of 3D printing development) to explore a 3D printing ecology -- 3D printers' habitat, uses, the actors involved while at the same time capturing its latest developments. A vital part of my analysis of the development of 3D printing is the wider context, i.e. the social and economic environment as reflected in this phenomenon after the global financial meltdown (Albo, Gindin and Panittch 2010) as well as the debates on innovation, science and technology (Kline and Rosenberg 2010). The post-financial meltdown landscape is characterized by increasingly precarious and self-employment work (especially in the creative industries), the prevalence of social media (see O'Keeffe and Clarke-Pearson 2011), and the increasing importance of STEM education (Bybee 2010). Such an environment hosted favorable conditions for the re-emergence of a DIY attitude, as advocated by the Makers movement.

During preliminary reading in 2012, although the academic landscape on 3D printing was much different than today[6], I was aware of some studies already being done on its development. During the years of study, there has been an increased availability of much faster and more reliable 3D printers as well as the development of a distinct culture along with the expansion of grassroots community workshops. Literature that relates directly to this specific technology and process is essentially very scarce other than official industry and policy reports. Francis Jacob's (1992) early work attempted to define the key characteristics and competences of the technology at the time of its infancy. Considered as a natural continuation of Jacobs' work, Hopkinson, Hague & Dickens' (2006) record the developments in the field for over the past two decades. Neil Gershenfeld's (2006) work on the emerging desktop manufacturing, situates 3D printing within a background of the MIT Media lab as well as providing extensive descriptions on the existing situation endeavoring to reflect on social and technical paradigms that might emerge. As with any technology, the degree of its popularization and by extension demand for development, can be measured by its presence in popular culture literature. In terms of science fiction "Makers" (Doctorow 2009) and non-fiction such as "Shaping Things" (Sterling, 2005), have gathered some popularity in academic and non academic public. The development of 3D printing has compelled Ratto and Ree (2012) to attempt to restate the question of the material versus the digital in the light of social change.

The re-emergence of the concept of ideas materializing through altering production paradigms and shifting the way of thinking, prove it is no coincidence that old questions about the primacy of the material are returning (Latour, 2007). 3D printer is a technology that sparks such imaginations

[6] The proliferation of studies conducted 2012 – 2017, expanded the literature on the subject.

about potentialities. What is real in terms of 3D printing production (Van Den Berg, 2015), are ideas preceding thoughts or are material conditions preceding ideas? A radical change in production practices culminated in the development of this technology will force researchers and practitioners to answer again and again the question of materiality and its fusion with the digital, the blurring of clear distinct lines (Loy 2014). However insightful, many previous studies have tried to focus on certain aspects of the technology yet failed to include the political disputes as well as the ideological dimension that take place within social, economic and political landscapes. Hence, this dissertation is a product of that missing link, an attempt to understand this dynamic interplay firsthand but having in mind its social, (geo)-political, economic, technological and environmental implications in an integrated rather than isolated and fractured way.

Innovation: economic, non-profit and informal

What is technology? What drives technological change? These are the fundamental questions concerning the issue of technology and innovation. There is no general agreement as to what constitutes an objective reality or factor that drives technological change. Increasing productivity, creating new objects and altering social relations through new ways of integrating society with technology are integral characteristics of what it means to innovate. However, in themselves, such characteristics do not seem to constitute enough reasons to be called innovations. This is because innovation seems to be an elusive term. What constitutes an innovative practice or technique? Perhaps the most certain feature of innovation is that since the first industrial revolution, it seems to be closely linked with economic growth. Moreover, the innovation process owes some credit to instincts that the entrepreneurial attitude entails, a feature that recently has gained attention (Boltanski and Chiapello 2005; Oost, Verhaegh and Oudshoorn 2009; West and Lakhani 2008). Hence, this seems to be a barrier in attempts to count in a formulaic fashion the factors affecting innovation (Rogers 1962, 2003). With the rise of the capitalist mode of production, one thing is certain; under this mode, the world has seen an unparalleled technological advancement and increase in productivity. For example, social thinker and economist Karl Marx (1990) specified the need of the entrepreneurial bourgeois class within capitalism to constantly innovate in order to ensure profitability and thus their existence as a class. However, despite his thorough analysis and critique of capitalism, he did not point out a definite theory or a path on how innovation is achieved; only some aspects scattered between his texts.

Economist Joseph Schumpeter, building on the work of Marx, was perhaps the first economist to give great importance to innovation as a powerful force of economic as well as social and political transformations. As a fundamental contribution, he suggested that we should comprehend innovation beyond a narrow spectrum of technical change, but rather as a shift that can happen in production after a variety of causes that may include new markets, new raw materials or new structural changes in industries (Schumpeter 1934, p. 66).Thus, for Schumpeter (1935, p.7) it is impossible to methodologically reduce innovation of component factors, but rather see innovation as a holistic approach[7]. Perhaps the biggest difference between Schumpeter and Marx was that while Marx thought that the destruction of surplus production would weaken capitalism and its structures, Schumpeter contended that creative destruction is the reason capitalism survives.

Besides Schumpeter and Marx, most economists and technology theorists in the late 20th and early 21st centuries agree that capitalism is the system of production which made feasible this great advance in technological change (Antonelli 2009). Some attribute it to ahistorical factors, as Carson (2010) does by arguing that technological preference was based on the choice of agents rather than historical conditions. Others attribute it to economic growth (Nelson 1990; Rosegger 1996; Ruttan 2001; Tassey 2008), while there are parts of each work which seem to supplement or overlap others. Nathan Rosenberg (1980, p. 234) suggested that because the

[7] Schumpeter (1935, p. 7) states that "the historic and irreversible change in the way of doing things we call innovation and we define: innovations are changes in production function which cannot be decomposed into infinitesimal steps. Add as many mail-coaches as you please, you will never get a railroad by so doing."

innovation process is an economic behavioral activity 'in which uncertainty and complexity are absolutely central characteristics', it is therefore important that studies involving innovation should entail empirical cases. In fact, empirical studies alone would not suffice, if the research is not 'cognizant of the processes that underlie the output of innovations' (Ibid). A deeper analysis in each case would provide far more understanding of 'information flows and processes that are responsible' (Ibid) for a new adaptation or failure of innovation.

More recently Marianna Mazzucato (2011; Lazonick and Mazzucato 2013), attributed technological change and innovation of the post-war era to the welfare state, through direct subsidization or sometimes innovating at government-managed laboratories. Neo-Schumpeterian approaches (Perez 2002) approach innovation stressing the importance of adaptation and creation of new environments through the process of "creative destruction" (Schumpeter 1942), taking Kondratiev cycles and arguing the correlation between crises of capitalism towards its reorganization along other socio-technical paradigms (Korotayev and Tsirel 2010). For pro-capitalist economists, technology and innovation, whether disruptive (Christensen and Overdorf 2000), targeted[8] (Carayiannis, Meissner and Edelkina 2017), assymetric[9] or evolutionary (Antonelli 2008), deals with creating markets and thus is represented by an increase in economic activity be it in terms of economic growth or otherwise. According to this understanding the more economic activity captured and channeled through legal exchanges, the more people participate in, the more needs will be accommodated.

The various technological theories however seem to stress or undermine factors according to their stance on the issue of capitalism. Socialist and progressive economists are more prone to discuss society's involvement and decision on the direction of science and technology and the

[8] Targeted innovation refers to the type which governmental and commercial institutions are producing innovation systems to achieve a specific end.

[9] Asymmetric innovation refers to the type of innovation which acknowledges that not all organisations and institutions have the same information and resource flows, and as such produce innovation systems which take into this into account.

complex dynamics behind it. On the other hand, pro-capitalism economists stress the importance of economic growth and investments. Innovation as empirical studies have shown, do not follow a ''formulaic'' path and are not always profit-motivated (Morton and Podolny 2002; Shah and Tripsas 2007), where communities and their relation to the corporate world are not merely exchanging information and resources with each other, but something more complex (Oost, Verhaegh and Oudshoorn 2009; West and Lakhani 2008). User-related innovation on the premise of unfulfilled experiences and demands are for example something which can generate innovation (O'Mahony and Bechky 2008; Tuomi 2003). Everet Rose (1962, 2003), a communication scholar, popularized the term 'diffusion of innovations' in order to provide a broad qualitative theoretical framework on how innovation happens and spreads between cultures and social systems, giving a primary importance for it on the human capital.

Entrepreneurial approaches that instill political motives to economic and informal activities, look at the growth of the economy and the agents of innovation. the new grassroots movements are expected to take over innovation, a development which will give an eventual natural death to capitalism(s), or at least perform an extreme make-over of the kind that exists today. Such approaches can be seen in the work of Anderson (2012) as argued in "Makers: The new Industrial Revolution", and, on the other hand, Paul Mason (2015) in his book "Post-Capitalism; A guide to our future". Both works base their arguments on one similar to that made by Dickel, Ferdinand and Petschow (2014, p. 1), that the proliferation of shared machine shops within cities has made innovation a widely distributed practice,

> Innovation has become heterogeneously distributed, ubiquitous, and reflexive: Innovation is increasingly produced by decentralized networks which involve actors from divergent social fields. Innovation therefore leaves the traditional sphere of the restricted laboratory and is transformed into a ubiquitous practice which is

> also adopted by non-professional as well as non-commercial actors

As such, technological advancements are seen as central to the growing power of the non-professional landscape. This is because users outside the realm of the professional laboratory and the wage relation, find it increasingly more accessible to create their own products and objects. in such a context, building infrastructure and networks of distribution for these changes is seen as of equal importance in order to utilize these technological changes to their full extent. However, arguing a few years earlier on the similar expansion of communication media, Jodi Dean (2005) has warned about an idealization and technology fetishism particularly as it relates to participation in media technologies which were popularized a few years earlier than my subject matter in similar fashion. The imagined active participation is delivered within the act of participating and circulating content, creating the sense that participation is empowerment. Jodi Dean argues, that participation can deliver the exact opposite if taken on its own, by depoliticizing the subject matter as it replaces a political problem with a technological one.

> it is depoliticizing because the form of our involvement ultimately empowers those it is supposed to resist. Struggles on the Net reiterate struggles in real life, but insofar as they reiterate these struggles, they displace them. And this displacement, in turn, secures and protects the space of “official” politics. This suggests another reason communication functions fetishistically today: as a disavowal of a more fundamental political disempowerment or castration. (Dean, 2005, p. 61)

Adjusting this critique and being aware of the direction politics within new media had turned for radical politics, it seems that similar arguments surround 3D printing in terms of participation. Although the 3D printing culture that remains close to the Makers movement does not have such explicit political aims, there is a general slogan circulating that by participating in projects within grassroots organizations one can change one's community and ultimately the world. , Ultimately, change for the betterment of all can arise from the passion of each individual or group to pursue their own interests, to create their own projects and technologies and test their ideas in the real world.

On a different plane, Actor-Network theorists advocate that the distinction between technical and social may be outdated (Latour 1988). Under such an approach, the binary between an economic or non-economic activity are seem to be problematic as well, because it does not recognize informal or out of production activities as part of the innovation process. Instead of giving primacy to either social changes or technical ones, Latour (1991, p. 117) suggests that,

> Contrary to the claims of those who want to hold either the state of technology or that of society constant, it is possible to consider a path of an innovation in which all the actors co-evolve.

Instead of focusing on a special variant factor, such an approach emphasizes the asymmetry and heterogeneity of networks. Because their structural formation instills an inherent instability, actors and by extension networks of actors, are constantly reconfigured materially. In other words, it suggests to look at such heterogeneous networks as

> made up of people, organizations, agents, machines and many other objects. It explores the ways that the networks of relations are composed, how they emerge and come into being, how they are constructed and maintained, how they compete with other networks, and

> how they are made more durable over time. (Tatnall and Gilding 2005, p. 959)

As the thesis unfolds, it will become evident that at least some aspects of such understanding is taking place within hacker and maker communities, as they try to build their own organizations, machines and infrastructures within cities. Similar studies focus on ethnography as a method to explore their subject matter, such as Grint and Woolgar (1997) who used ANT to describe the Luddite movement. This is not to say that the thesis is a product of an ANT approach to 3D printing, but rather a grounded approach that recognizes some of its features. For example, how cultural imaginaries translated the message of the Makers movement should not be considered a factor for the spread of 3D printers but rather in relation to how 3D printers co-evolved with grassroots community workshops such as Hackerspaces, Makerspaces and Fab Labs.

Hacking and user-producer relation

The modern history of technology and a crucial part of desktop manufacturing being available through 3D printing is intertwined with hacking. Desktop manufacturing would be inconceivable without the rise of the personal computer. Levy (1984) in his seminal work ''Hackers: heroes of the Computer Revolution'' tried to identify the people, machines and events that lead to the rise of the hacker ethos. He claimed that the personal computer was in fact the brain child of the hacker way of collaborating. Fast forward two decades and Fred Turner (2006) attempted to trace the origins of hacking in the military-industrial-academic complex research facilities of the cold war. He provides a detailed account of how the 'non- political' side of the hippie movement of the 1960s moved on from idealism and open-source collaboration to building mega corporations in the space of just twenty years.

The hacker ethos, collaboration and the primacy of the technology over politics favored by such groups were translated into businesses once the projects they envisioned took the form of successful products. Mega corporations such as Apple got their start on open source projects, then closed their ‘systems’ once they became successful. The initial purpose of Hackerspaces was to tackle practical problems such as openness vs closed software environments. Another concern was to provide safe spaces for collaboration and entertainment of the members. Taking geography as an important parameter, these spaces aimed to liberate those who were fed up with the increasing pervasiveness of the work/home paradigm that the capitalist society had to offer. But this has changed over the years. Grenzfurthner and Schneider (2012, p. 97) assert that ‘Hackerspace politics are for now in the interest of white middle-class males’, denoting that they do not seem to be as open as they could. This can be evident from the direction the communities take in terms of organizational culture and its relation to commercial enterprises. This is half the story. Hackerspaces are themselves contentious spaces, sites of constant negotiations and re-identifications, reflection and at times harsh critiques. Similarly, Hackerspaces/Makerspaces and Fab Labs that have opened across the world as part of or under the influence of the Makers movement, have their own peculiar relationship with one another and with larger corporations. While some take their lead from the initial stance of the Hackerspaces against capitalist development, others are playing their part in developing what is now generally called the digital economy. I say peculiar, because as the thesis progress, it will become evident that such spaces have yet to develop a clear relationship to work, blurring the lines between producing and consuming, labor and play.

The political economy terrain of today seems to be in desperate need of new terms to characterize modes of production that involve the user as an active component in the production process. Usually these terms involve a variety of theories that endeavor to establish a compound word for an ostensibly new way of production. Terms such as ‘user-generated content’, ‘consumer-generated con-tent’ and ‘crowdsourcing’ or ‘audience labor’ are among the newly coined descriptors favored in the field of media studies for example (Hamilton, 2014). Other terms include ‘produsage’ (Bruns 2008), ‘prosumers’ (Denison 2011) and ‘produmption’ (Ruckenstein, 2011). Despite these seemingly new articulations of the user-producer relations, the concept itself is not novel. Capitalist and even pre-capitalist societies contained forms of ‘prosumption’ (Ritzer and Jurgenson 2010). Against the position of Marx (1990 [1867]), leading proponents of the concept of prosumption usually proclaim that post-war capitalism is driven by consumption rather than the opposite (Cohen 2003; Braudillard 1998 [1970]; Ritzer, Zhao and Murphy 2001). Therefore, they stress the importance of consumption practices and suggest that they play a vital part on production. 3D printer Utopian visions have been constructed in line with this type of narrative – i.e. that, ultimately, the consumption desires of the users will shape the production paradigm, hence the 3D printing technology that will enable this paradigm transition.

A prominent political vision on the form of organizing production and consumption of 3D printing is the idea of “commons”. How the free or open software movement interacts with 3D printing for example is interesting because its actions and practices contain ‘characteristics [that] seem to violate economic logic and the principles of private ownership and individual autonomy’ (Kelty 2008, p. 1). This culture of non-institutionalized tasks, collaborations, constant modulations of the technology and experimentation not only inspires individuals who enter into this subculture, but contain seeds of alternative organization paradigms as well as methods for making and sharing knowledge and objects (Delfanti 2013). User innovation (Flowers 2010) impacts on the industry but also has implications in the intellectual patent race; windows of opportunity for developing the technology, politics and conflict as well as collaboration with the industry are themes that are of particular interest in this study.

Rugged consumerism in the digital age

Almost all the spaces I have visited took a positive attitude towards recyclable material. In every space there is a box for collecting the various waste materials from prints, support structures, unwanted clots, with the clear intention of finding, short-term or long-term, ways for re-using and thus putting such materials back in the cycle. Why would most of the users across countries that I visited have boxes of waste material from prints, trying to find ways to recycle in the midst of seeming abundance? Such practice does not make sense from a consumer standpoint. After all, users of 3D printers can find material very easily rather than trying to tinker with waste plastic. A closer look however, revealed that not only 3D printing is often an inexpensive and practical way of learning about waste management, but the practice is also imbued with an ethical and political stance. Such actions are perhaps better described as a way of thinking, since waste takes the form of concept in grassroots innovation. It is a form of rugged consumerism

I take this term from Malewitz (2014) book "The practice of misuse" in which he attempts to further 'thing theory' through literature vignettes from American culture. In this study, rugged consumerism, by making learning and objects experiential activities, other forms of consumption emerge that alter the relationship of users to objects. For instance, consuming through making, entails the concept of material as active ingredients in making rather than passive consumer objects. This process entails a ritualistic and playful experience. For example, playing with 3Dprinting generates an alternative attitude and definition of waste. Using 3D printing, users imagine circular systems where nothing goes to waste. The insistence on innovation, waste management and the re-introduction of the concept of scarcity amidst the seeming abundance of information are issues that in many instances 3D printing users cite to justify their actions. So, what exactly is rugged consumerism and what is its relationship to innovation and 3D printing? For Malewitz, a general description would be that 'the rugged consumer views the world outside the prescribed limits of sanctioned use-values' (2014, p.6). But describing practices of rugged consumerism makes more sense of what it is,

> through their fluid encounters with the material world, rugged consumers behave in constructivist ways toward objects, turning the aforementioned theories of

> object life spans into practices of misuse. Rugged consumerism has the potential to temporarily suspend the various networks of power that dictate the proper use of a given artifact and to allow those networks of power to be understood as contingent strategies that must be perpetually renewed and reinforced rather than naturalized processes that persist untroubled through time and space. (Malewitz, 2014, p. 6-7)

As the predominantly consumerist culture of the 20th century propagated a throw-away mindset, rugged consumerism offers an alternative route, in fact an opposite proposition to its predecessor. Individual agency and autonomy is still at the core of this emerging ideological narrative. However, new experiential activities politicized practical issues of waste. In addition, the experience to create ones' own gadget, infused impulse and instinct, producing a level of familiarity overcoming alienation with objects. In the 20th century, forced co-operation was compulsory in the factory for production purposes, resulted in feelings of alienation to objects being created. The digital rugged consumers are suggesting this process should be reversed by co-operating on the basis of their own autonomy to choose between people and what to create. Malewitz suggests that despite its noble cause, such

> Utopian ideal is rarely met: most examples of rugged consumerism conceal rather than foreground the class-, race-, and gender-based problems to which they respond and thus support or ignore rather than challenge the cultural dominance of late capitalism (Ibid, p. 7)

The non-expert character of what kind of electronic components, human skills and where to complete the task, leaves the maker with a degree of autonomy. These are dilemmas of course on how to proceed to choose how best to accommodate their tasks, for example. A user may choose to print one part of their project on their own 3D printer or go through printing services in order to utilize another printing method. The choice predicates on durability of material, size and shape of the object needed. Similarly, a user's choice to build their own machinery, Malewitz contends, lies in a masculine identity of individual agency, the very essence of rugged consumerism. This means adjusting to the current situation but building on older notions of assuming agency through ruggedness (Crawford 2009).

For the rugged consumer, the desired outcome of creative misuse is a re-naturalised world in which artificial objects become raw materials for the postproduction reproduction. Such a startling transformation is the hallmark of rugged consumerism and promises an alternative to the passive, collective consumer behaviours (Malewitz 2014, p.23)

The matter of repairing, fixing and creating one's everyday objects and spaces is not only a powerful means of usability but also of identity making. 'Productive leisure' as Gelber put it (Gelber 1999, p.2; Gelber 2013) emerged as a result of historical transformations during the postwar period "When industrialization separated living and working spaces it also separated men and women into non-overlapping spheres of competence." Men and women were separated into different spaces, the former being the ones who entered the labor market as the wage earners and the latter staying informally in the household performing reproductive tasks. "Mr. Fixit" arose as a response of the male's need to create a new space and place within the house. Although there were precursors to this form during the 19^{th} century, it was not until the 'end of the 1950s the very term 'do-it-yourself' would become part of the definition of suburban husbanding'. Although still in a masculine form, this identity in the making was, according to Gelber, heralding a progressive era of equalitarian living between husbands and wives, who could share and use the same tools as bonding practice while many would remain as a helping hand to the masculine fixer identity of the male partner. But such masculine practice entailed contradictory terms.

Despite being used as a way for the male to regain pride in using his hands and finishing objects of everyday use, skills lost due to the rise of white collar jobs, were nevertheless housed in spaces such as the garage or the household. Protected from outside gaze through privacy, gender roles were more flexible in those spaces. Certainly, such rhetoric and identity can be seen in places that once were or still are industrial sites. My visits to community workshops at the heart of the industrial belt of the UK, exhibited much of the older sense of pride that stems from handcrafts. Former workers in the industry either as factory workers or in craft workshops recall with pride a time before thorough automation where people had significantly more control over their objects and machines. Some of the people I encountered in Hackerspaces, Makerspaces and Fab Labs were nostalgic about older times when factory workers felt a sense of purpose that today's industrial landscape lacks. This aspect of nostalgia, coupled with the legacy of social movements, sci-fi futurism and enthusiasm about new digital technologies, constitute a unique blend within the 3D printing culture.

Research Questions

Aside from this chapter on how 3D printing is approached in this research, the historical aspect of 3D printing gives important context to the chapters enriched with ethnographic material. As a technology at the center of discussions on decentralized production and authority, 3D printing was born and developed, at least until reaching turning point, by the military industrial complex. The chapter on the evolution of this technology serves to bridge the gap between literature that either minimizes the importance of its history or is unable to provide a coherent narrative linking its past and present. Following the historical context, the thesis tracks several cultural imaginaries and political narratives that emerged as public attention grew. Furthermore, it provides an account of a revolution that seemed to be in keeping with the spirit of the times for decentralized production paradigms, alternative conceptions of the productive forces and economic social systems as well as imaginaries stemming from science fiction culture. In the following chapters the thesis explores the infrastructure of communities, user politics and an alternative learning paradigm that constitute important factors for the wide distribution of 3D printing to Makers communities and beyond. Moreover, the thesis explores personal stories and motivations of those working within these infrastructures to complete their own projects utilizing 3D printing and the technological ecology available. The thesis is divided into three main questions,

1. What are the main political narratives and cultural imaginaries in representations of 3D printing and what are their main characteristics?

2. What is the effect of 3D printing on building hacker and maker communities and how these communities allow for its widespread adoption?

3. What types of grassroots innovations and practices are enabled by 3D printing?

Methodology

In order to examine the political and cultural context whilst uncovering everyday practices of 3D printing culture, I utilize a multi-sited fieldwork study in spaces and events where the technology is used outside the professional realm. This study is in line with other multi-sited ethnographic works that aimed at understanding and uncovering complex processes and everyday relations (Delfanti 2013; Soderberg 2007, 2011; Kelty 2008; Han 2012; Petryna 2009; Cerwonka and Malkki 2007). The ethnographic methodology includes formal and informal interviewing, and participant observation. This was the preferred method in order to 'illuminate the unknown' as well as 'interrogate the obvious' (Fassin 2013). Using this approach, I intended to uncover facets of 3D printing culture through ethnographic inquiry and unique stories while at the same time juxtaposing them with already described narratives and theoretical works.

I should note at this point to the reader, that the structure of the thesis does not follow a path that is often familiar in thesis, in which ethnographic data is used to validate or illuminate aspects of a pre chosen theoretical foundation. Rather, theoretical implications that emerge from the empirical data and the experiences acquired during fieldwork are presented within the context of the latter. In other words, the ethnographic narratives presented are not to be used as samples of a larger group of people and organizations. Under such an approach, theoretical vignettes and mentions in the narrative should be understood neither as inductive or deductive but as something in between. This is certainly not unique to this study, as Wilson and Chaddha (2010, p. 4) observed,

> there are some ethnographic studies that incorporate theory into research that can be described as neither purely deductive nor inductive, but reflect elements of both. In other words, there are studies that start out with a deductive theory and end up generating theoretical arguments in an inductive process that integrates old theoretically derived ideas with new and unanticipated theoretical arguments based on data uncovered in the field research.

As far as this thesis is concerned, I did not follow a strict and narrowed understanding on the theory presented along with the empirical results. Theory in this work should rather be read as an unfolding explorative narrative on the phenomenon of 3D printing as something more than a machine. Each chapter is used to shed light on aspects surrounding the development of 3D printing from commercial laboratories into the city. Ultimately, to give context on why 3D printing should be viewed not as just another innovation but as a machine that encapsulates and reflects the spirit of the times. This proved to be a helpful strategy in analyzing the experiences of individuals and communities I traveled to, as I used the interpretation given in context during fieldwork.

In this respect, the approach is more dynamic, and describes the process of 3D printing phenomenon as it happened, revealing details of everyday life, without the need to conjure the people involved under a narrow theoretical box. This was chosen in order to ensure fairness towards individuals and communities whose work and activities helped the thesis, without necessarily espousing or even developing a theoretical framework with discipline. To achieve such result, I consciously excluded the possibility of subordinating the complexity of the field to a specific theory. Despite raising some theoretical points within the thesis, in some instances as was the case of St Pauli, the people involved were interested to raise but not through academic form or rigor but rather through a political and activist perspective. It could be argued, that theory in this work is ethnography as well, part of understanding heterogeneous phenomena such as the 'Makers movement' and Hackerspaces/ Makerspaces / Fab Labs. For the aforementioned reasons, the thesis does not contain a chapter to assert theoretical commitments; rather, theory will be part of each empirical chapter throughout this work.

The thesis includes a blend of my attempts to find routes within city networks of makers, finding policy papers, cultural reference points and other types of information including but not limited to media leaflets. In other words, my presence at the site enabled me to capture the cultural norms and patterns that arise within the hacker and maker community and among 3D printing enthusiasts. As the ethnographic work progressed, analysis, using additional empirical material such as professional and vernacular images, information leaflets, technological manuals, legal documents and policy papers was proceeding apace. Since information can at times overwhelm and seem to have no beginning or end, I decided to integrate all these different types of data within the historical context in order to ground my observations in the broader frame wherein I conducted the study. This procedure can be quite complex and initially challenging, given the vast universe of information that sent me to all sorts of different locations and concepts. However, it seemed inevitable, the only route to uncover the extent to which 3D printing culture issues have been reflected in the larger context of cultural and social reproduction. Essentially, the thesis aims to show 'the relations of indeterminacy as the autonomy of culture within larger processes of social reproduction' (Beach 2008, p. 171). For example, some encounters in community workshops would later lead me to a startup meeting, an industry sponsored technology exhibition. In one case, I attended a book launch referring to 3D printing and new technological developments using an anti-capitalist outlook and philosophy. In general, reading policy papers, cultural references in magazines and economic analyses proved vital to providing essential parts of the jigsaw.

I designed the methodology of this research in such a way as to map the relationships of actors and agents of innovation both within their natural and externally collaborative environments, and the development of the technology as part of a movement and business practices, all placed carefully within a 'broader historical, political and sociological context' (Fassin 2013). The insider context - common language, visions, culture - provides an understanding of the shortcomings and virtues behind what was covered by the media, the marketing strategies and sometimes, personal preferences. Thus, this study already alludes to the critical approach I adopted to describe essentially an ecology of phenomena that intersect, but also to engage with it in a deeper sense; to try and analyze its movement within the very real terrain of everyday life and existing utopian projects (Burawoy 2005).

The intedisciplinarity that ethnographic fieldwork proved essential as my impression and understanding of both technology and communities that are based around such cultures transformed and aided my intellectual capacity to come to grips with my research topic (Cerwonka and Malkki 2007). Observation and snowballing in the field showed that my participation in the field was overt and that my decisions to go this route were an important part of the process rather than to be guided through other literature (Das 2007; Gadamer 1999). For example, accessing places and communities as a researcher and sometimes as a member, are qualitative processes that can only be understood through the fieldwork, whilst at the same time guiding the research (Becker et al. 2004). As I have already argued, I understand technology not only as an object of inquiry but ultimately as social relations expressed in practices and objects created, shaped by and shaping the local ecosystem as well the larger context. This has been an important reflective point upon which studies that include everyday culture, politics and technology, are conducted.

The hermeneutical process of ethnography 'involves a reading of social practices through theoretical concepts without simply reducing the practices to a mere 'illustration' of the theory' (Cerwonka and Malkki 2007). Ultimately, as I tried to untangle dilemmas about the directions information was taking the research during fieldwork, it became clear that unless the researcher was prepared to make those decisions the study would inevitably find it hard to make sense. Typical of these dilemmas were such issues as what type of events to follow or how much time should be spent at a site. The empirical nature of ethnography helped this study to revise the theories (Tsing 2005) built upon this social shaping of technology, the cultural negotiations and antagonisms, social transformations and structures that govern its practice and development (Wajcman and McKenzie 1999).

Examples of recent studies in STS show that this type of methodology and the subject matter have better chances of showing the complexity of their respective fields. Such studies led researchers to visit a variety of places and spaces from animal health clinics and pharmaceutical corporations to Hackerspaces and pubs in Silicon Valley (Delfanti 2013; Soderberg 2007, 20011; Kelty 2008; Petryna 2009). Similarly, Petryna's (2009) research on the global search for clinical trials data explored aspects when other methods could not enable her to do so. Whilst literature equipped her to understand the important focal points for her fieldwork, ethnographic fieldwork allowed her to uncover how culture and economic differences influenced the decisions of clinical trials participants in the pharmaceutical industry. The investigative character of the ethnographic research can entail surprises. This research also aims to uncover possible surprises that may lie beneath the surface. Much of the research that is being carried out using this type of methodology to explain complex relations of everyday life, employ narrative methods to bring their data to their audience (Kelty 2008; Han 2012; Petryna 2009). This study employed the same narrative strategy to ensure that interpretation and reflection of the empirical part were important aspects of this study.

Research Design

Preparatory work to fieldwork included regularly following of leading business newspapers (Financial Times, Wall Street Journal, Economist, Harvard Business Review, Investopedia, Bloomberg), Government and EU Reports on 3D printing or reports that may refer to the technology, official sources of industry statistics such as the Wohlers Associates reports[10] on the state of the industry, documents and the structure of 3D printing industry, video presentations and lectures, infrastructure and virtual communities. Although my fieldwork focus is on non-commercial aspects of 3D printing usage, I visited the industry exhibition Develop3DLive at Warwick University in order to acquire an insight to the context from an industry perspective. Such events provide a good opportunity to engage with all aspects of 3D printing, including proponents of mass additive manufacturing. They tend to cater more to industry partners than everyday consumers.

Moreover, the use of online media allowed me to access information that provided a better understanding of the development of 3D printing as technology and practice. This preliminary work has prepared me in terms of understanding the nature of 3D printing, the debates around the technology and its use, the futurology associated with it and its context within various settings. The questions arising in this research were an outcome of such preparation and thus a vital component of the study. My ethnographic

[10] Wohlers Associates, perhaps the most respected consultancy agency following 3D printing technologies over the years. Their reports provide a must have authoritative insight into the industry and commercial enterprises pay close attention to their opinion and predictions.

fieldwork includes spaces of collaboration and hobbyism such as Hackerspaces, plus events surrounding this culture as well as following up on my interlocutors' perspective.

Hackerspaces, Makerspaces and Fab Labs

Such spaces seem to be vital components in the development of 3D printing culture in terms of allowing users to create or upgrade their own machines, but also through distributing knowledge. They provide a breeding ground for the spread of the technology into its natural audience, tech publics. As centers for distributing and disseminating 3D printing culture, these spaces are more than places of consumption, given their unique ability to appeal to several different audiences. This heterogeneity of audiences becomes part of the development of 3D printing and helps shape its direction. This seems to build upon previous cultures, for example the one surrounding the development of the personal computer. John Markoff (2005) noted that 'the hacker ethos of sharing information lies at the very heart of the explosive growth of the personal computer'. Indeed, as he argues, the very existence of the Silicon Valley as the USA's 'most dramatic technological and entrepreneurial boom' is indebted to the 'information libertarians' who successfully forced AT&T to license the transistor (a key feature in the development of the personal computer) 'under the terms of an antitrust settlement with the Justice Department', and thus made it freely available for further innovations. He asserted too, that the personal computer 'emerged from a handful of government and corporate-funded laboratories, as well as from the work of a small group of hobbyists'. Steve Wozniak (1984), founder of the enthusiast's "*Homebrew Computer Club*" and later co-founder of Apple Corporation, admitted that 'without computer clubs there would probably be no Apple computers', essentially giving credit for the birth of the giant company to a small circle of computer engineers and enthusiasts back in 1975.

Is 3D printing's 1975 now? Coming from such grassroots workshop communities, Makerbot[11], certainly aspires to emulate Apple. The personal computer is a fundamental component of desktop manufacturing. In fact, earlier forms of Hackerspaces played a crucial part in the popularization and the distribution of the technology that is now deemed essential in every household. It is worth keeping in mind that before the emergence of such spaces, there were voices that were highly skeptical that people would want to process data in their homes. Just as these spaces proved to be successful distributors of personal computing, showing the world what could be done with data, they can do the same for hardware technologies like 3D printers, with the added bonus that people are already familiar with personal technologies and the internet. Hackerspaces such as NY Resistor have provided fertile ground for many start-up companies, including, for example, Makerbot, the most successful personal 3D printing company to date. The history of Bre Pettis, the CEO of Makerbot Industries, an organic member of the hacker community in New York (NY resistor)[12], illustrates the hospitable 'start-up environment' in which the hacker of today is integrated in the industry. It is no secret that the Makerbot replicator was built upon the open-source project RepRap, itself influenced by ideas of democratization of manufacturing (Pettis 2014). The relationship of Makerbot with the open-source and hack communities, although in tension[13], is promoted to this day by the company as a shining example of the wonders that collaboration can create. Makerbot hosts the online community Thingingverse, which enables users to download 3D object ideas and to co-create physical objects in networks previously unavailable.

Consequently, given the vital role played by Hackerspaces in the development of 3D printing, I consider them as one of the main empirical

[11] The most popular 3D printers maker rising through such spaces and communities.

[12] Bre Pettis presented himself as a rock star or a poster boy of the Makers' community and was generally accepted by both media and the Makers' scene as a leading figure of the new DIY and Makers movement.

[13] Since Makerbot moved towards a business model cautious to open source, the community which initially supported the start-up, became increasingly critical of the new developments.

sites of the study. My fieldwork began at the Nottingham, Leicester and Derby Hackerspaces. The reason I chose them, was because of their proximity to an industrial region in decline for decades, in which factories were closing and workers lost their jobs. Government/private sector initiatives have pushed these regions in another direction, towards creative industries, as they experience transformation through gentrification in reconfigured cities. The fact that my university and my personal base were located in the region also facilitated my fieldwork preparations. I was fortunate enough to make invaluable contacts both with sympathetic individuals and with the hacker and makers' community in the Midlands region all of whom proved happy to share their experiences, including some who at a time were just starting (Leicester Hackerspace). Others shared perspectives on the changes they were undergoing that affected the viability of their communities in the spaces they chose (Derby Hackerspace, "NottingHack"). During fieldwork, I visited all the spaces regularly during the same stretch of time, rather than focusing on one space at a time. This gave me a real time understanding of the development of each community. In the case of the Derby Hackerspace, my attempts to visit were sidetracked by the limits of the community and my inability to become a member due to a congested calendar. Derby Hackerspace was only visitable on Wednesdays, which, inconveniently, coincided with open hack nights at "Leicester Hackerspace" and "NottingHack". Faced with this, I had to make decisions on where and when to visit and should note that while I became a member of the "Leicester Hackerspace"[14] on the day of its official opening, I failed to become a member of "Derby Hackerspace".

Although not calling myself a hacker or maker of any sort, I did try to perform activities associated with both in order to better understand their respective approaches. These activities included trying to print my own objects, often ending in frustrating failures. The strategy proved to be particularly fruitful as hacker and makers' networks within the region had already provided me with a fair amount of context. Communities are more

[14] In order to have access on days other than "open hack nights".

likely to trust a researcher from a local university, one who can give something back to the community, than they would a complete stranger. Trust is important for these communities. If it doesn't exist, the community may ask itself why waste time participating in the study in the first place.

The initial spaces I visited reflected the DIY attitude, but lacked aspects of 3D printing narratives which included an entrepreneurial spirit. For this reason, I chose "Cambridge Makerspace" as a site where I might experience a broader range of practices and narratives within the spectrum of 3D printing culture. This space attracts a great number of people with access to the universities and is utilized more as a start-up incubator (university projects) more so than a community as is the case with the other three sites. Access to the Makerspace was achieved using personal contacts, the only option available to me, given that I was neither living or working in the area and nor was I attending a local university.

Following discussions about my thesis subject with makers and colleagues, I was referred to Fab Lab in St. Pauli, an area in Hamburg, Germany. The reason for the referral was the perceived political stance of the community there. However, it was not solely about how it relates to politics. Fabulous St. Pauli presented an emerging point of reference in European Fab Labs because of its activities as they relate to the city's urban gentrification transformations. This Fab Lab provided examples and answers, key pieces in the puzzle that other places did not. Whereas, as mentioned, I was shuttling between the Hackerspaces and Makerspace on a more or less daily basis between February 2014 and June 2016, practical reasons dictated that I visited St. Pauli on two occasions, each time for a two-week period, in October 2015 and again in March 2016.

Compared to all the other spaces I visited, my experience at Grammar School in Nicosia, Cyprus, was markedly different. As the thesis suggests in the following chapters, alternative learning experiences are a key aspect of this culture. And it was at the Grammar School that I managed to explore this aspect in greater detail, close up in an educational space and environment. The set up here was different than in other spaces. I was invited to attend as a guest by the head of the school's robotics team. I had been in contact with the teachers but not as part of any class sessions since my visit was during the summer break. However, interviews and a tour of how the school utilizes 3D printing as part of its curriculum offered a new perspective on learning. Despite the similar general attitude to grassroots workshops, the school also exhibited professional learning structures (i.e. classes and the role of educators) that were rather different to a community space. Thus, this site enriched the educational aspect of 3D printing in this research.

In terms of events, Maker faires such as the one carried out in Derby every year are a good indicator of local activity designed to enlarge networks and promote meetings between companies, users and universities. Such events reveal Makers infrastructure as well as shape and are shaped by cultural trends within the community. Following them as part of my fieldwork proved to be a good guide on how to see technical information cross-spaces and communities as well as adding to the development of context. During my time in the field, I favored taking notes (Emerson, Fretz and Shaw 1995), audio recording and taking photos. This approach allowed me to capture various environments and events as they happened (Carspecken 1996). Photography (some photos are presented with captions) helped me remember aspects that otherwise would need more time to describe. As the thesis progressed, it will become evident that photos help to better describe other types of data (such as notes, memos and audio recordings) and to justify arguments.

The ability to handle data on small portable devices[15] was also a critical factor in determining to adopt this approach. This process helped me to gather data in the field without being unduly intrusive. Participants were more comfortable and relaxed; and it meant that I didn't have to wait and leave the site before starting to write up what I could remember. Notes, audio recordings and photos as primary data enabled me to develop scenarios and arguments that otherwise might not have initially made sense. At times consulting them even suggested a change of focus as they allowed for a

[15] I usually carried an audio recorder, a smartphone for taking photos and a small notebook.

more thorough analysis of the data collected during field time. In this way, data directed theoretically informed discussions in each chapter (Glaser 1978; Denzin 2009). For example, much of my talk about frugal innovation at the latter empirical part was extracted from a story I followed in the field.

Collection and Analysis of Data

I followed an open plan, allowing the fieldwork to guide me. How participants understand the technology and the inner workings of the sub-culture, to cite a few examples, were important vectors that I did try to present as much as possible (Carspecken 1996). As meanings within sub-cultures are not fixed, they are subject to constant re-negotiation in terms of meaning and initial concepts. At the outset, this type of ethnographic fieldwork may have appeared to be chaotic and perhaps followed too many leads, in the long run, it facilitated not just the gathering of data but how to connect the pieces.

As indicated, much of the empirical research was collected through fieldwork. However, a few aspects of the empirical information came from participation in online forums. I followed advice such as Barny Glazer's (1978) "all is data". My interlocutors advised on what they were comfortable to reveal about their practices and communities. The research involved recording actions through observations, open-ended and semi-structured interviews and document analysis (Goulding 2002). The places they were involved and moving around enabled the development of key analytic ideas as the study progressed (Charmaz 2006). Recording open coded[16], proved to be very helpful especially in the beginning of the fieldwork data analysis. I was able to use material to facilitate introspection, a process which yielded subsequent themes. As part of my ethno study, I conducted dozens of informal interviews and 22 recorded interviews with participants of the Hackerspaces, Makerspaces, Fab Labs and other organizations I was involved with. The interviews were conducted in a natural environment, courtesy of the participant (Cresswell and Clark 2010).

[16] Open coding means having the data as open inquiries rather than placing data in categories that were formed prior to fieldwork.

After a first phase of open coded gathering and analysis of data as part of my fieldwork, I considered my filtering strategies from the emerging themes (Ibid). There was already a sizeable amount of written material to begin with, since the writing process began at the start of my fieldwork. Material was constantly molded and reassessed in the light of new data. Coding was used as a way of organizing and making sense of the data, which then informed the write-up. Such methods allowed for creative use of data to entangle relationships of ideas that came up and interpret them. On the other hand, some of the data gathered suggested that my initial thoughts and research questions needed some changes either in perspective or otherwise. The aim was for an ethnographic narrative, a (mostly) textual (with some visuals) representation of real life in which 'thinking, research, and writing occur in complex webs of interrelationship' (Cerwonka and Malkki 2007). Writing unfolded both as a thinking pattern and, as the fieldwork progressed, in real time as far as my partial and limited perspective could develop in a constantly changing environment. Data gathered in specific locations can illuminate aspects of 3D printing culture but cannot be considered as a general statement on the phenomenon. For example, data from Hackerspaces, Makerspaces, Fab Labs and other events that where used in this research cannot be generalized to include all others which participate in such spaces or culture. Theory and empirical evidence were not treated as two distinct methods but were interwoven and in dialogue (for example, see Soderberg 2008). In this respect, the intended audience, is the audience which understands or wants to discover the dynamism of culture within webs of social - political - economic structures.

Reflections

One of the issues that I had to take into account was the ethical commitment to produce a research study in a framework that would not endanger or compromise participants or sites. Although this is not a study which engages with vulnerable social groups, I used anonymity for all participants except on two occasions. This was deliberate and an extra measure to protect study participants who might, inadvertently or otherwise, reveal information that could put them in direct confrontation with others or with their communities. The case of Niels at Fabulous St. Pauli was used under a signed agreement, because anonymity would have hindered many aspects of the fieldwork and have had to remain unused. The case of Daniel whom I interviewed was impossible to anonymize as after given permission, I discuss his project (3D Additivist Manifesto) which is presented in public.

That said, let me make clear that I did not utilize information that communities wished to remain classified to outsiders. I realized before engaging in fieldwork, that there might be some encounters that presented problems with ethical issues. In fact, I did not experience serious problems during fieldwork. One reason, was because the issue of access was addressed on personal terms in most cases. Personal contacts and networks within the area and the spaces involved helped create a friendly environment at the outset and for the fieldwork that followed. Another reason was that I openly approached prospective participants and communities, informing the participants about my intentions and assuring them of my bono fides and what I was setting out to do. In essence, I recorded anything the participants and communities allowed me to and accessed only spaces where I and when I was given access. The subject of inquiry helped to avoid other types of situations.

More broadly, being at the site when taking notes, audio recording and taking photos, made me more comfortable and aware of what I was researching. Writing while physically present in the context of the research theme helped avoid the mistake of analyzing participants and interactions outside their context: i.e. falling into the trap of mistakenly ‘othering’ the participants (Torres and Reyes 2011).

Structure of the thesis

The thesis started with an introductory chapter on how 3D printing was approached for the purposes of this study. Building on literature that explores innovation, hacking, the proliferation of different forms of ‘prosumption’ and rugged consumerism, this chapter's purpose was to give context on how the thesis approached the research questions. The context gave a basis on which the narrative is built, justifying the multi-sited ethnographic methodology utilized. Moreover, this chapter clarified how the field was approached, which sites were used and for what reason. The second chapter gives a historical perspective on the development of 3D printing up to the point it became a focus of broad public attention in 2012. The thesis traces the historical development of 3D printing in three distinct waves. Understanding its history, context is provided on why the technology, after remaining outside the public realm and relatively obscure for almost three decades, came under the spotlight and is celebrated as few are today.

The third chapter aims to expose and analyze political narratives and cultural imaginaries of 3D printing. The themes are explored with the aid of theoretical, policy and cultural publications combined with fieldwork material. The lone maker entrepreneur, the new relationship of user-producer which makes commons-based economy possible, the revival of state manufacturing through 3D printing are among some of the utopian political narratives. At the same time, a cultural narrative suggesting 3D printing cities on Mars has a dystopian element at its core. Namely, this narrative suggests that only colonization of other planets can aid humanity to survive and save the human species from total destruction. Such narratives build upon qualitative changes in science and technology (ideas and matter) and shifts in technological structuring both at work and in the everyday context. The characteristics of these narratives that are highly visible to a broad public challenge the seemingly inordinate fusion between art and science. Art and Science become important values for one another as the dichotomy between material and ideas is challenged. The chapter ends with a discussion on neotechnic technology and the 3D printing instilled possibility of an alternative social system. I argue that Autopoiesis or commons- based peer production (also presented with some differences as circular economy) is possible and is in fact emerging through the various Hackerspaces, Makerspaces and Fab Labs that have sprung up across the world.

The following chapter explores how individuals and communities using 3D printing are organized and their effect on 3D printing. These communities offer a different kind of political engagement through practice. Hackerspaces and other forms of community-based workshops and their infrastructures became the dominant form of organizations that promote the 3D printing usage. The chapter starts by exploring the correlation between the spread of such spaces overlapping the spread of 3D printing. The relationship between the two can be seen both in terms of sheer numbers as well as through the story of how I found my way around 3D printers in the first place. Moreover, in this chapter I locate the political aspect in this culture as well as what these grassroots community workshops represent. Used in the context of Hackerspaces, Makerspaces and Fab Labs, 3D printers challenge the notion of the city center as a space of consumer activities. Rather, the Maker infrastructure that is building up fosters new networks of people, software and machines that produce other forms of cityscapes. In the latter parts of this chapter, I ask how practical is a 3D printer and relate the story of the St. Pauli Fab Lab which gave a different perspective on the relation of 3D printing with a grassroots community, between entrepreneurship and social movement politics. An important aspect that arises from these spaces is the issue of collaboration and learning in mixed expert and non-expert environments, such as these communities provide.

The succeeding chapter uses ethnographic vignettes to explore types of innovations and uses of 3D printing in collaborative environments that may extend beyond Hackerspaces, Makerspaces and Fab Labs. The chapter includes a theoretically informed discussion on user innovation and characteristics of what is termed ‘democratization of technology’. Added to this, the visit to the Grammar School in Nicosia, Cyprus, provides a core element of an alternative educational paradigm using technologies such as 3D printing. Educational and learning practices have changed the method for creating both collaboratively and simultaneously as individuals. Following the story of how my former school uses 3D printing to change its educational practices, I return to grassroots community spaces. I look at the story of

Benjamin, a radiographer who utilized both the community's learning practices and 3D printers to craft his own device. His story is an example of how crafting and alternative learning practices can aid in creating tools for scientific ends. Craft in this case blends with science instead of opposing it. This story underlines the importance of frugality and craft thinking in this method of making. The last ethnographic vignette of the chapter explores the case of a 3D printer maker, the personal motivations in making 3D printers and the ability to do so in an open software and hardware ecosystem. In addition, the thesis looks at how such an open ecosystem is affected by online communities and what it means for machines to be open for tinkering.

Concluding, the thesis considers the implications of 3D printing as a politically charged cultural icon. By analyzing what types of narratives and imaginaries 3D printing instills, this study unravels motivations and reasons for the public's growing interest and fascination with it. Navigating through grassroots community workshops and city-built infrastructures, shows an emergent new culture as well as new ways social movements conduct politics. The mixture of these organizations, individuals and new technological ecosystems within cities alter ways of living and learning. As such, it is not unreasonable to argue that 3D printing can be looked at through the lens of what Marshall McLuhan (1964) called 'the medium is the message'.

A history of 3D printing: 3 waves of development

> *The bourgeoisie cannot exist without constantly revolutionizing the instruments of production, and thereby the relations of production, and with them the whole relations of society* - Karl Marx, The Communist Manifesto.

In an article celebrating the arrival of 3D printing technology as a mature production technology, the Economist[17] (2016) argued that 'when a manufacturing technology arrives in the workshop of the world, it really is coming of age'. The article was referring to the use of additive manufacturing[18] by the technology company LITE-ON, in its factory in Guangzhou, China, to 'print electronic circuits, such as antennae and sensors, directly into products instead of making those components separately and assembling them into the devices either by robot or by hand' (Ibid). The company is one of the main global manufacturer contractors, creating millions of smartphones and other consumer electronics. 3D printing is no longer a singular process, nor is it simply a machine that melts plastic into shapes. It is a combination of processes, some sufficiently developed where high technology can be integrated with traditional manufacturing methods.

3D printing, like any other new or evolving technology, cannot be read in a monolithic way. The history of 3D printing is also the history of social interactions by a diverse range of agents that shape and are shaped by the technology. Its history is also the history of the politics around the technology, to paraphrase David Noble (1984). Since this study is an ethnographic account of the seldom told everyday life that rarely registers in economic data, it is crucial from the onset to spell out the framework within which 3D

[17]The Economist, remains one of the most prominent media publications to promote 3D printing as a technology for all (young start-up entrepreneurs, hackers and industry). In some instances, it deliberately promoted the blending and collaboration of all three.

[18]a broader term used for the many different 3D printing processes

printing was conceived and then matured over the years. How and why did 3D printing come to be one of the most widespread technologies today and why did it not happen earlier? What impelled its growth? Is it a technology in search of a purpose? An amalgam of a variety of different evolutionary developments and breakthroughs in a variety of technical fields, 3D printing is a technology whose time within the industrial production paradigm seems to coincide with the political economy of manufacturing and the different structural transformations that have taken place in the global economic environment. It is a prime example of the kind of technology that best represents such structural transformations[19].

Unlike the narrative story of Makerbot (friends tinkering around with tools to create a machine through an arts and crafts process), the birth of 3D printing was a capital-intensive, research-oriented undertaking. I will revert to Makerbot, the first explicitly desktop manufacturing 3D printing model created in a New York-based Hackerspace, that incorporates many elements of the collaborative or gig-sharing economy. The idea that it might be possible to even conceptualize 3D printing or additive manufacturing is the outcome of advances and infrastructure emerging from precursor technologies. In order to understand the shape of 3D printing today, it is vital to see its origins and how additive manufacturing escaped the closed confines of industry to become 3D printing as a cultural phenomenon. Rather than indulge in a scholastic historical endeavor, this thesis seeks to show that the foundations of 3D printing were rooted in research and a capital-intensive process. Subsequent utilization and development of the technology by small grassroots organizations and groups experimenting in garages or in Hackerspaces was spurred on once the technology moved away from the professional laboratories and became more readily accessible to a less technologically informed public. Arguably, 3D printing may have been more subject to hype than other technologies precisely because the technology reflected the spirit of the times.

---

[19] More on this in chapter 5 '3D printing in Hackerspaces'

The technological development of 3D printing occurred in three distinct waves: the initial period of experimentation and articulation of the concept from prior technologies associated with the early 1960s; first commercial applications and emergence of multiple 3D printing methods between 1984 and 2009; and, thereafter, adoption of the technologies by the Makers movement giving rise to the consumer boom for 3D printers. Additive manufacturing, 3D printing and solid freeform fabrication are all terms used to describe the technology. 3D printing is the preferred term within the Makers community, whereas additive manufacturing is the choice within the industry.

Precursor Technologies: origins of 3D printing

The idea of 3D printing was born in the Cold War laboratories of the Battelle Memorial Institute[20], which was closely collaborating with academia as well as industry at the time. In the 1960s, the initial focus was on developing a technology to use photopolymers and create solid objects from a photopolymer resin that had been invented by DuPont in the 1950s. The experiment involved the use of two laser beams of different wavelengths in an attempt to solidify the material resin at the point of intersection (Wohlers 2012). DuPont research scientists had been experimenting since 1949 with a technology involving the use of light sensitive material, when they discovered 'the possibility of making printing plates by using a plastic material which hardens when exposed to light' (Ibid). Before these attempts, on 25 December 1956 the U.S. patent office granted patent number US 2775758A on the claim submitted by John Otto Munz on 25 May 1951. In January of that year, Munz had filed for a patent claim for a 'method for three-dimensional imprinting a thermoplastic object' (Munz 1968) expanding on the same work. Munz, named the method photo-glyph, the idea in essence being

[20]Battelle Institute was set up in 1929 by industrialist Gordon Battelle to promote his vision that business and science interests are intertwined. The Institute was involved in the Manhattan project Today, it is the largest global nonprofit research and development organization, employing over 22,000 people in more than 60 locations around the world. As stated by *Science Journal* in 1928, the institute's mission_combines 'industrial research under the fellowship system 'while devoting substantial income institute funds 'to long-distance industrial research for the broad benefit of American industry and for scientific research.'

that of light carving material into three dimensional objects through a process of photosynthesis.

> An object of this invention is to provide a novel method and apparatus for the creation of a permanent three-dimensional record in space of three-dimensional phenomena, such as the shape of physical bodies. This record, since it is not a graph and does approach the idea of a carving, hereinafter will be called a glyph, from the Greek glypho which means to carve. It is produced with the aid of photographic means and therefore is called a photo-glyph. (Munz 1956)

The process was similar to ideas developed later in the 1980s through stereolithography and like processes as well as the 2D printing process that was to emerge in subsequent stages of technical development. The basic idea was a machine that would give the capability of controlling photo generative rays 'mechanically, optically or electronically in response to the phenomena to be recorded' (Ibid). The patent illustrated the history and evolution of technical upgrades which provided the conceptual platform for the emergent methodologies known as 3D printing technology. Patents such as the 'photographic-printing process' (Edward 1919), 'radio echo system for mapping contours' (Holser 1952) or 'making models in relief in gelatin by photographic processes' (Frank 1954) were cited as technologies which significantly contributed to the eventual technical upgrade. The invention was critical in conceptualizing and developing what later came to be known as rapid prototyping/additive manufacturing or 3D printing. This is reflected in a range of subsequent patents which refer to Munz's (1956) 'photo-glyph process' as a turning point. The historical timeline also shows how, despite concept and theory having been formulated and proved, the technology proper had to await the invention and availability of as yet undeveloped components before it could be effectively actualized. The timeline also attests to how subsequent improvements in the 1980s came about because of the research and development work that went before.

The National Science Foundation (NSF) in the US played a crucial role. Not only funding the development of 3D printing as a technology, but also the precursor technologies that helped pave the way. A 2013 report highlights the important contribution the NSF made in transforming 3D printing from concept to technological reality, noting that the NSF

> funded precursors of AM technologies in the 1970s (development of computer numerical controlled machining and solid modeling tools) and turned early AM patents in the 1980s into proof-of-concept and prototype machines in two major commercial technology areas (binder jetting and laser sintering). In subsequent years, not only did the NSF, as befits its role, support fundamental research in the field, but it also funded application development (e.g., medical) and academically oriented networking activities. More recently, as AM technology has matured, NSF has supported research efforts related to new processes, new applications for existing processes, and benchmarking and road mapping activities. (Weber et al. 2013, p. iv)

Additive manufacturing as a scientific quest gained more than $200 million in grants (for research or activities such as conferences) from various NSF branches. The 'Engineering Directorate (ENG), and within ENG, the Civil, Mechanical and Manufacturing Innovation (CMMI)' (Ibid) accounted for about two-thirds of these grants. The NSF's role in the initial development of crucial patents and precursor technologies also reveals links between universities and the commercialization of technologies. This was done through protecting commercial interests with the patent system as well as acquiring financial help through state funding. According to Weber et al (2013, p. 137), the relationship can be seen through the references and citations of patents between the different stakeholders,

> After U.S. Patent No. 4575330 was issued in 1986, it became highly influential in developing the AM field. There are 433 U.S. patents that reference the stereolithography patent, and 25 (about 6%) of these, those filed between 1992 and 2009, had Federal Government sponsorship. NSF sponsored 8 of the 25 patents filed from 1992 to 2004 (Figure H-2). Seven of the eight patents were issued to researchers at MIT—Emanuel Sachs, Michael Cima, James Bredt, and others—who developed binder jetting or 3D printing techniques in the early 1990s (see Case Study 4). NSF awarded two grants to MIT researchers from the Strategic Manufacturing (STRATMAN) Initiative, one in 1989 and one in 1992. The eighth patent was issued to several researchers at Georgia Institute of Technology, with funding from the Division of Information and Intelligent Systems (Directorate for Computer Science and Engineering) in 2001.

This exclusive focus on a specific area of science and technology is unusual. New emerging technologies rarely manage to acquire sufficient support among policy-makers to acquire development grants. When key patents were acquired in diffusion with early adopters[21], this contributed to

[21] Diffusion of practices, means that seemingly unrelated or risky gambles on early stages of a technological development, such as expiration of patents or the emergence of new business models are included in the process of adoption and development of the technology. As I shall show in the chapters containing ethnographic material, the long-term benefits of funding small innovative firms plus the development of an internet ecosystem allowed 3D printing to flourish in industrial and cultural terms.

convince manufacturers of the potential of additive manufacturing. Additional factors such as the creation and growing of user communities, contributed to the development of 3D printing and its subsequent emergence into the main stream.

3D printing's intensive development years

As a commercial practice, 3D printing came into being with the development of stereolithography, a method for replicating a physical object through a laser beam, devised by Charles Hull in 1984. Hull founded the 3D Systems Corporation in his effort to introduce and develop the technology, which has since become a leading force in the AM world. Different techniques were being tested by different vendors in order to develop new and efficient ways of rapid prototyping. By 1994, stereolithography had been tested and developed sufficiently to allow for installations to be set up around the world by corporations like 3D Systems (now a giant in the field) CMET/Mitsubishi and others [563 Installations], Laminated Object Manufacturing by Helisys, Sparx and others [77], Selective Laser Sintering by DTM and EOS GmbH47, Fused Deposition Modelling by Stratasys and Sanders [45], Solid Ground Curing by Cubital [18]. Methods that had yet to be developed at the installation level included Ballistic Particle Deposition by BPM Corporation and Incre, Inc, Shape Melting (Babcock) (Jacobs 1992, p.10-13). Paul Jacobs, author of the first book on rapid prototyping (Ibid, p. 367), looking at the array of methods used to achieve an additive manufacturing process, was prompted to invoke an old cliché when he pronounced, 'there's more than one way to skin a cat'. Indeed, 3D printing was developed by a variety of companies using liquid-based, solid-based and powder-based methods, each in its own particular way (Chua, Leong and Lim 2003). However, stereolithography was the catalyst that sparked this burst of creative processing and spurred on the intensive efforts to develop the technology.

Stereolithography's development involved the creation and enhancement of a machine to solidify thin layers of ultraviolet sensitive polymer using a single laser beam in a fairly simple process. Patenting the method made it commercially available, giving the public access to the technology via the market mechanism. This opened the door for inventors to explore the new method for prototyping designs without the need to invest in manufacturing. With the machine at their disposal and in the same room, designers could create an object within a matter of hours or days. They could move from idea and concept to actual realization without the need of mediators ensuring investment. The process was the property of 3D Systems, which had released the world's first commercial additive manufacturing system, precursor to later popular machines such as the SLA 250. 3D Systems was not alone in developing the technology. Ciba-Geigy, a company working with 3D Systems, helped produce an SL material, one of the first acrylate resins. Other pioneers were DuPont with its Somos stereolithography machine (released in 1988) and Loctite, a company that developed Stereolithography resin up until 1993. As 3D systems machines became commercially viable, other concerns entered the market. The Japanese corporations NTT Data and Sony/DMEC released machines in 1988 and 1989 respectively while Denka Kogyo, JSR Corp. and DSM Desotech were offering resins for machines (Wohlers 2012). Up until 1990, stereolithography was the the only method of 3D printing.

Laminated Object Manufacturing or LOM, another 3D printing method, was developed by Helisys, Inc, a company founded in 1985 that initially relied on government grants to develop the process and arrive at the point where it could provide rapid prototyping services for industrial uses. Recognizing its commercial significance, the company filed for a patent in April 1987 which was issued in June 1988 in the name of Michael Feygin, who had demonstrated the method. The LOM process was among the first true 3D printing experiences, requiring 'virtually no human intervention' and, once installed, capable of running '24 hours a day' in industrial sites (Jacobs 1992, p. 367). An identical patent was filed in 1991 in Europe and again in 1994 to protect improvements in the process. Unlike other methods, the LOM process aimed at automatic development of objects using different materials. As the filed patent described,

> The laminated object manufacturing process aims at automated production of metal, plastic, ceramic, and composite parts of unlimited complexity directly from a computer generated image. (Feygin 1988)

The FDM process is probably the method the public is most familiar with. This is because of its widespread use in desktop 3D printers. Moreover, because of patent expirations, the method was utilized by universities and makers alike as they sought to develop and improve the process during the first decade of the 21st century. As the market for 3D printing grew, the time constraints of other methods became the challenge for those trying to advance additive manufacturing. Amidst all the hype, CLIP technology (Continuous Liquid Interface Production) was unveiled as a speedier and more efficient form of 3D printing. New technology introduced by Carbon 3D[22], a company formed in 2013[23], proved to be much faster (25-100 times as the company suggests) than traditional additive manufacturing technologies. The CLIP method avoids layering and is able to grow uniformly (as opposed to layer by layer) a physical object from a resin pool by 'carefully balancing the interaction of light and oxygen' (Carbon3D 2015). Experimentation with a variety of additive manufacturing technologies was boosted further when 3D printing moved on from a prototyping technology to a manufacturing one[24]. Development of this new method owed much to the

---

[22]Carbon 3D has allegedly experimented with the technology since its inception in 2013. The company partnered with Sequoia Capital and Silver Lake Kraftwerk in 2014, raising approximately $41 million in just one year. This could explain the immediate attention it received following the release of the new method on 16 March, 2015.

[23]According to the press release statement on their website, Carbon 3D aims to harness light and oxygen for growing parts that would deem the layer by layer method obsolete. Still in experimental phase, the company has not specified where on scale of 25 – 100 times faster than existing additive manufacturing processes is the CLIP technology.

[24]The main difference between prototyping and manufacturing technology is the quality of the object produced. In a prototyping situation, the object may not hold its final shape or quality -, it

collaboration of the academic-military-industrial complex. In this instance, Dr. Joseph DeSimone matched academic capabilities with entrepreneurial skills to acquire the venture capital needed to deliver the process[25]. The new method was a breakthrough not just in terms of its speed and the quality of the product but also because of the new possibilities for the development of new material (RT 2015).

The technology was not in great demand for commercial 3D printing activities at the outset. In fact, it remained in the shadows for almost 30 years, familiar mostly to practitioners and professional engineers. Like the personal computer industry, a decade earlier, 3D printing needed a quality-level, breakthrough development to gain profile and enter into the mainstream. In order to get industries to invest and bring it into the marketplace, 3D printing faced two choices: either become a consumer electronic device (never intended in the early stages) or a production technology. For the first two decades of its commercial life, 3D printing technology was relatively unknown apart from some design department circles. This began to change in the second decade of the 21st century. Despite early experiments and research by national science institutes (Weber et al. 2013), it was left to small startups to attempt to commercialize the technology. It lacked research funding and had yet to generate the anticipatory hype it currently commands. Now, thanks to the latest developments and the increasing market cap, government agencies and research institutes are showing renewed interest, especially the military industrial complex whose investment support has helped move the technology forward. 'A combination of U.S. government funding and

is a working material in experimental phase. Such objects may not exit the laboratory room or may not even end up in a finished product. A manufacturing technology is one that meets all the quality controls -- the product is expected to come out in its final form before commercial or other certified use.

[25]Dr Joseph DeSimone, chemist and founder of the Carbon 3D company, is the author of over 300 scientific articles and holds numerous patents. In 2008 he won a Lemelson - MIT prize and in 2014 was awarded an IRI (Industrial Research Institute) medal of honor - most often conferred on scientists collaborating or working within the heavy industry.

commercial startups has created a new wave of unprecedented popularity around the idea of 3D printing since that time.' (Hsu 2013)

Throughout the late '80s and '90s, a number of different companies were interested in creating or advancing additive manufacturing. Terry Wohler's table listing the pioneer companies that attempted to create 3D printing manufacturing systems shows that the initial investors were primarily in the US and other industrial powers such as Germany, Japan and China.

Company	Country of Origin	Year founded	Commercially introduced
3D systems	US	1986	1988
Aaroflex	US	1994	1996
AeroMet	US	1997	n/a
Autostrade	Japan	n/a	1996
Beijing Yinhau Laser Rapid Prototypes	China	n/a	1998
BMT	Germany	n/a	2001
BPM Technology	US	1989	1995
CMET	Japan	1988	1990
Cubic Technologies	US	2000	2001
Cubital	Israel	1987	1991
D-MEC	Japan	1989	1989
Denken Eng. Co., Ltd.	Japan	1985	1993
DTM	US	1987	1992
DuPont SOMOS	US	1989	n/a
EOS	Germany	1989	1990
Fockele & Schwarze	Germany	1991	1994
Helisys	US	1985	1991

Kinergy	Singapore	n/a	1996
Kira Corp.	Japan	1992	1994
Light Sculpting	US	1986	n/a
Meiko Corp.	Japan	1991	1994
Mitsui Zosen Corp.	Japan	1991	1991
Objet Geometries	Israel	1998	n/a
Optomec	US	n/a	1998
Precision Optical Manufacturing (POM)	US	n/a	n/a
ProMetal	US	1996	1999
Quadrax	US	1990	1990
Röders	Germany	n/a	1999
Sanders Design International	US	n/a	2000
Schroff Development	US	n/a	1996
Solidica	US	n/a	2001
Solidimension	Israel	n/a	n/a
Solidscape	US	1994	1994
Soligen	US	1991	1993
Sparx AB	Sweden	n/a	1991
Stratasys	US	1988	1991
Teijin Seiki	Japan	1991	1992
Toyoda Machine Works	Japan	n/a	2000
Ushio Inc.	Japan	n/a	1994

Figure 1 Table presenting early additive manufacturing companies Source: Wohlers Associates website

As is evident from the table, US corporations invested most in the technology and also led the way when it came to countries opting to manufacture and commercialize additive manufacturing models. The table shows the year in which each company was founded as well as the year each first introduced commercial 3D printing system. It is clear that lack of funding, or of a policy framework and application of 3D printing within the economic landscape of the booming '90s (at least for the mature capitalist countries), meant that some companies had to hold back for a time to develop their models before they could market them commercially. The internet use was still a new concept, online communities were restricted to professionals and machines were did not feature mature network capabilities.

For companies such as DTM (formerly Nova Automation), it took five years to reach the point where they could launch their first commercial product on the market. DTM is the outcome of the collaboration between then undergraduate Carl Deckard (he went on to gain his masters and PhD) and Dr. Joe Beaman, one of his supervisors, at the University of Texas. From 1981to 1986, they explored through DTM commercial applications of the newly developed SLS (selective laser sintering)[26] technology. The approach was similar to that of stereolithography, "using a directed energy beam (such as a laser or electron beam) to melt particles of powder together to make a part"[27]. After discovering a way to regulate the laser beam using a Commodore 64 computer, Beaman created a custom board to control the process while managing to house all this in the very limited 4KB space available at the time. Deckard completed his PhD at the university while trying to convert the concept into an actual machine. He and Beaman, then the Principal Investigator (PI), received a $30,000 grant from the National Science Foundation (NSF) to develop the technology, building another machine nicknamed "Betsy", to be used for academic purposes. As the commercial environment for additive manufacturing started to emerge,

[26]The history of the technology as presented on a university website is thought-provoking, marketing as it does the history of the technology in a performative narrative about Deckard's youthful aspirations to become a scientist (a profession popularized during the cold war years) and since equated with being an inventor, concepts that today are utilized interchangeably. Information such as this is presented on the website of the University of Texas as an achievement of the University, its' staff and alumni.

[27]Ibid

Deckard and two others set up Nova Automation in 1986. In October that year he filed his first patent. By the end of 1987 all licenses had been signed. With patents secured, Deckard, then met with potential investors, and a pattern was set as inventor and investor sought to capitalize on a 3D printing machine that was developed in an academic institution using tax payers' money. This is a similar process to the path many inventions had in the past. Marianna Mazzucato referred to the process as the entrepreneurial side of states (2013), using the case of iPhone technologies to argue that much of what is considered breakthrough technology has had state funding in development phase.[28]

Initial funding did allow Deckard to develop the SLS process up to the point investors began funding it through Nova Automation. However, the availability of investor funding did not automatically mean smooth sailing and a successful passage. The development process encountered several setbacks and failures. To complete the work in progress, Nova Automation had to raise an estimated $300,000 by the end of 1988. As they worked on the machine called Betsy, Deckard and Beaman and a young undergraduate of his were attempting to build a new machine, "Godzilla", to generate data required for the completion of Deckard's PhD. To finish the machine, they needed some $50,000 more than they had and required "over 6 months just to build the pressure vessel alone". The demands were too much and the machine was never built. After the failure of Godzilla, the team began designing a third machine named "Bambi" (from the film "Bambi Meets Godzilla"). More people were brought in to help integrate CAD software into

[28]Mazzucato argues that there is a myth at the heart of the "austerity politics" story: that the state is against free enterprise that the profits of companies have nothing to do with state-led innovation. In the book she discusses a variety of innovative technologies and how they were nurtured by government agencies and state funding. The message was that if business wants government to launch ambitious projects that no company is willing to take on, there must a be an incentive for the state to do so - just as businesses take profits, the state should be able to take credit for state-funded innovation when it reaches the market. In an interview with the Financial Times, Mazzucato rejects those critics who contend that what she is proposing is a socialist form of economics. "If businesses want to make profits in the future, they had better understand where profits come from. This is a pro-business story. This is not about socialism". See Ft lunch with Marianna Mazzucato

the the new machine’s control system. They were joined by Dave Bourell, a University of Texas professor (in Mechanical Engineering) who had recently collaborated with IBM on a project involving laser technology and was a specially in both lasers and material science.

The team grew in size, as more investors began looking into the company. Potential investors expressing interest early on included the chemicals giant DuPont as well as General Motors. Eventually, it was the chemicals and aerospace manufacturing company Goodrich Corp that invested. The overlap between academia and the commercial networks is evident. Dave Bonner, Vice President of Research at Goodrich at the time, was both a UT Distinguished Alumnus and on UT's Chemical Engineering Visiting Committee. His father, Z.D. Bonner, also a professor at the university, was Chair of UT's Chemical Engineering Department’. It took five years to produce machines suitable for the marketplace, a painstakingly slow, bureaucratic process starting with academic research, then looking for investors, while simultaneously trying to develop and improve the machines. Mod A, Mod B and 125s, the first commercial machines the company launched, were the first designed and created off campus, thanks to investor funding. The company spent much of the early 1990s filing and acquiring patents on materials in order to secure additional funding.

The niche market was fluid from the outset. Companies that were to become major forces in the additive manufacturing industry were bent on acquiring expertise not just by advancing the technology through their own efforts but also resorting to buyouts and takeovers, saving time and money as they acquired difficult to get skill sets and technological know-how. For example, ‘Quadrax developed and sold the Mark 1000 stereolithography system until February 1992 when its technology was acquired by 3D Systems after patent litigation that began in September 1990’ (Wohlers 2012). Goodrich which had invested early on in DTM opted to move on when the slow-to-grow infant industry did not realize the dividends hoped for. In 2001, DTM was sold to 3D systems. The birth pangs and infancy of the niche additive manufacturing market was not unlike the first faltering steps of the personal computer industry when it began to take shape in the late ‘70s and early ‘80s. Lacking a distinctive application, 3D printing struggled to find its own identity and function within the industry and was initially utilized for modelling and prototyping purposes.

These years of intensive development for 3D printing may not have generated the same level of excitement as marked the evolution of the personal computer, but they were key to the period of development that followed and which I discuss next. The potential industrial application and growing significance of “additive manufacturing” was as yet little known or appreciated outside academia and the core industries. However, different styles of additive manufacturing were developing at such a rate that the new quality level of the FDM process was beginning to draw the attention of informed enthusiasts. As I show in the next part, it is quite possible, that 3D printing might not have spread to a wider audience beyond the military-industrial complex had it not been for the involvement of academia.

2005 onwards: open source and makers’ involvement

3D printing technology began to gain recognition and popularity starting from the bottom up, thanks to a third wave, one that included hobbyists and the so-called Makers movement (Anderson 2012). This was accompanied by a lot of media coverage (Lipson 2013; Gershenfeld 2012). The emergence of the maker culture coincided with US policy to encourage students towards STEM subjects, supposedly to cover skill shortages in the existing labor market (Jacobs and Sax, 2014)[29] . This was also an attempt to restructure the economy and revitalise manufacturing industries that had declined during the global recession that had so effected the Western mature capitalist economies (a matter of dispute, according to Lazear and Spletzer 2012; Rothstein 2012; Davis, Faberman and Haltiwanger 2012). The short-fall in

[29]My argument here is that the Makers movement, or at least key figures in it, understood that there was a communication gap between what was needed and the public. It strived to communicate the key ideas of STEM education through making and creativity, using older but especially new technologies such as 3D printing, Arduino, Rasberry Pi. While the Makers movement grew, official government agencies utilized the ensuing creative dynamic to their own advantage. There was a reciprocal exchange between the movement and the agencies.

skilled and qualified workforce highlighted by Delloitte and the Manufacturing Institute (2011) generated fears that up to 600,000 manufacturing jobs remained vacant due to skill shortages. This figure has been disputed by various other sources (Osterman and Weaver 2014; BLS 2014). Following the capitalist economic crisis that first hit the US and then Europe, leading heterodox economists ascribed much of the blame to the excessive role placed on financial capital in Western economies and the gradual destruction of the ‘real economy’ (Lapavitsas 2013).

The move towards the service sector and ultimately the increasing control of economies by finance capital was of major concern to institutions and policymakers, eager to find ways to revitalize their manufacturing sector. This was especially true in the US, coincidentally the biggest investor in 3D printing (Tassey 2010). As policymakers in the EU started to grasp the importance of regulating 3D printing (European Commission 2012), voices in the UK were suggesting policymakers there do likewise (Sissons and Thompson, 2012). The underlying logic was that 3D printing offered the UK a very good opportunity to capitalize on a new technology that would enable it to retain a leading position in ‘design and online retail’ (Ibid, p.3).

Amidst these social and economic transformations, the “Laboratory for Freeform Fabrication - Advanced Manufacturing Center” of the University of Texas, published a report in 2008. About 65 people, experts and practitioners from various government agencies and university departments, as well as industry representatives including members of DARPA, attended a conference to discuss the future of additive manufacturing at the “International Solid Freeform Fabrication Symposium” in Alexandria, a small town in Virginia, US. The goal was to come up with a working plan for the development of the field in the coming 10-12 years (Bourell, Leu and Rosen 2008). The community found people willing to hear its views on additive manufacturing and thus was granted access to policy makers who wished to create education that encouraged innovation through vision and making. In 2009, President Obama unveiled his “Educate to Innovate” campaign and urged Americans to become makers once more and not just consumers:

> Students will launch rockets, construct miniature windmills, and get their hands dirty. They will have the chance to build and create—and maybe destroy just a little bit—to see the promise of being the makers of things, and not just the consumers of things (Pescovitz 2010)

The influence of the Makers movement created such a stir among younger population groups, that some media speculated it might be the catalyst needed to revive US science education (O'Brien 2011) and by extension prompt a return to big government investments. As the importance of 3D printing in the Makers movement gathered momentum and interest, so too did the technology's profile among key government officials. The US government under Barack Obama was especially interested and invested in advancing 3D printing:

> First, President Barack Obama's administration awarded $30 million to create the National Additive Manufacturing Innovation Institute (NAMII) in 2012 as a way of helping to revitalize U.S. manufacturing. NAMII acts as an umbrella organization for a network of universities and companies that aims to refine 3D printing technology for rapid deployment in the manufacturing sector. (Hsu 2013)

The new movement resembled the garage philosophy of the 1970s Appropriate Technology movement[30] (Pursell 1993) but allowing for the style

[30]This was a movement that expanded during the late 1960s, reaching its peak in the late 1970s. It espoused the use of semi-industrial and more labor-intensive technologies as opposed to capital-intensive high technology. It favored local and decentralized production which was thought to be a cleaner form of energy consumption. Its proponents advocated a simpler lifestyle in contrast to the post-war consumer societies. See an extension of this discussion in the next chapter and Hazeltine and Bull 1999.

and ways of the 21st century. The arguments as to why makers should be the driving force determining the direction of the technology were much the same as those of the ‘70s. 3D printing was (and to some extent still is) regarded as a technology yet to find a clear path within the economic framework of today’s production or consumption patterns. Just like in the ‘70s, when some tech industry experts wondered why people would ever need to buy a desktop computer, 3D printing today is seen as a technology that has yet to make itself indispensable as a primary, everyday tool. But, as will become evident in the next chapters, 3D printing can serve multiple applications rather than one specific function.

Those influencing the direction the technology takes vary in their goals and motivations. Although the Makers movement was able to experiment with 3D printing, it lacked the resources and, in some instances, the expertise to move beyond the latest information made available by well-funded research institutions. This reliance on academic and institutional support meant that some members sought to integrate the movement with existing institutions (Boden, Ludwig and Pipek 2013). The pursuit of institutional support was nothing new to makers, repairers, fixers, and/or craft-makers, who followed the example of the Appropriate Technology movement which had so successfully integrated and expanded institutional support during Democratic administrations until being dismantled in the 1980s by the Reagan administration (Sinclair 1984). By the 1990s, the movement seemed to have been co-opted. Some rebranded the cause as lifestyle choices within the market. Others, who remained true to a political struggle on the matter, have suffered defeat along with the international working class movement.

A good example of institutional support for the development of cheaper DIY machines was the State University of Michigan’s contribution to the development of metal 3D printers. By the end of 2013, academic at the University of Michigan Joshua Pearce, working with a team of colleagues and PhD students, managed to create an open source metal 3D printer (Pearce

2013) designed to appeal to the DIY community and encourage it to join efforts and promote ongoing experiments to upgrade to a better quality machine. Pearce's approach was to develop and give the public access to a professional metal 3D printing method, similar to the attempts of professional programmers and the open software movement in the late 1980s and early 1990s. The DIY metal 3D printer was cheaper than a commercial 3D printer utilizing various plastic materials to construct objects (Millman 2013). According to Joshua Pearce, the project aimed to give small and medium-sized enterprises the option to 'build parts and equipment quickly and easily using downloadable, free and open source designs, which could revolutionize the economy for the benefit of the many' (Ibid). As I argue in the next chapter, sharing technical advances with the public is never too popular with profit-driven corporations who prefer to copyright software code for licensing fees.

In the case of 3D printing, big corporations, small startups and consumers were able, for a time, to collaborate and further develop the technology, each for their own interest. Big business was not opposed to the call of makers for more open-source software and hardware, since adherents of the Makers' movement represented their future customers, perhaps even their potential employees. Also, such an alliance meant that business was in a position to tap the Makers' movement for fresh ideas. The movement promoted open source hardware, especially Arduino, an extremely affordable platform capable of introducing potential makers into programming. Meanwhile, 3D printers based on the RepRap model were seen as basic manufacturing machines that 'connect the digital and the physical realms' (Economist 2011). As the word was spreading about the concept and range of desktop 3D printers, it was becoming clear that the technology had the potential to effectively penetrate small market segments. There was growing recognition too that the new technology developments could allow companies and startups alike to experiment freely more efficiently and with less waste.

Concerns about safety have been raised by Long (2015), noting the absence of regulatory provisions governing either domestic use of 3D printing or in settings outside a professional workshop. This omission should be addressed once the technology and the related industry mature. Right now, the most pressing concern for established industries is the ease with which individuals and/or groups can purchase and use 3D printers and bring products into the marketplace while evading the existing legislative framework (Badiru et al. 2017). An assessment of the current state of the 3D printing industry presented by Sculpteo (2017), which led the company to predict a rise in skill level of 3D printing users. This means that in an everyday context, people in grassroots organizations or just individual material hackers, were able to enter at an intermediary level (higher than I did when I first started in this field back in 2014). Indeed, this is a fast-paced absorption of a technology into a grassroots culture. Evidently, while the industry's focus was mainly on developing new improved 3D printing methods and materials, the user's concern is about infrastructure and ease of use (Ibid, p.12).

One of the key issues determining the future of the technology is about how desktop 3D printing relates to and with industrial additive manufacturing systems. Just as word spread about development and growth of the personal computer industry, the word is now spreading about the concept of personal 3D printing, especially once stories from Hackerspaces and informal garages started to flood the internet via social media and user forums. While the prospect of a 3D printer in every household (Wood 2007) appealed to the hobbyist makers, designers and crafts-oriented individuals, Terry Wohler (the industry's most prominent consultant) was adamantly opposed to the idea. He pointed out that not everyone wants to become a designer and cautioned that the technology needs patient professional work in order to produce results (Copeland 2013).

> 'In terms of sales revenues, the desktop segment generating $293 million represents a small share of the overall AM market—although a small segment, however, the desktop segment posted an impressive annual revenue growth of 62% in 2015,' said Mark Cotteleer, Research Director, Deloitte Services LP.

> ‘While desktop 3D printers were earlier used by hobbyists or for limited use in the education sector, these printers are increasingly finding applications in diverse industries such as engineering, product design, art, jewelry, dentistry, and consumer products.’ (Microfabricator 2016)

In 2011, ‘approximately 62.8% of all commercial/industrial units sold were made by the top three producers of additive manufacturing systems’ with 64.4% of all systems manufactured made by companies in the US. By 2017, the EU had become a leading force in 3D printing with General Electric and Siemens playing a catalytic role (Michaels 2017). Competition is fierce as rivals’ battle for market share and acquisitions in today’s global 3D printing industry. This development stems from the expansion and growing importance of 3D printing in industrial settings. But it also owes much to the growing recognition and spread of 3D printing technology in everyday life and how general public awareness, acceptance and expectations in combination with individual innovators, home-based material hackers and garage crafts-people visionaries are helping shape the future to come. Visionaries and popular expectations drive the demand for greater investment and growth in the technology.

By promoting a culture of DIY and co-operation and by favoring small-scale local production rather than centralized industrial-scale manufacturing, the maker movement, whether it intended to or not, developed a complex relationship with the world of business. Business exploited the enthusiasm of the Makers movement and enabled the makers’ communities to gain greater access to the technology. The pay-off was the technology’s increasing popularity resulting from makers’ community start-ups and how business interests exploited this popularity to generate investments and speed up the technology’s development to expand the market for new industry products. While hobbyists and makers were serving as creative and innovative pathfinders using the new technology, charismatic industry leaders such as

CEOs and other top executives appearing at industry conferences also played a seminal role in helping develop the technology. Some went on to become industry leaders: EOS, ExOne, Fab@Home, MakerBot Industries, Materialise, Objet, Optomec, ReaLizer, RepRap, Shapeways, Stratasys, and 3D Systems (McCue 2012).

Low cost 3D printers, which began to spring up after the RepRap model was introduced, gave a major boost to the spreading technology and helped generate even more capital flow into emerging markets for additive manufacturing or 3D printing. This was seen by many as a form of democratization because it offered potential access to manufacturing otherwise unavailable to unprivileged users. The rise of IP regimes and the development of copyright laws[31], did bring into question just how much of the potential might be realistically fulfilled since arguably much of the accompanying interest could be attributable to self-promotion designed to advertise the new technology. In the end, users of desktop manufacturing[32] have the freedom to venture down the paths of innovation via bypassing the constraints of legal quotas that increasingly block their way.

The popularization of the technology and its spreading use by hobbyists and activists brought with it an upsurge of research on issues like intellectual patents (see Hornick and Roland 2013; Mendis 2013; Peacock 2014)as well as on the impact of sharing platforms on the economy[33]. The issue of patent infringement for example, is a growing problem for those who support the current IP philosophy of ‘rewarding the inventors’. In the case of 3D printing, apart from concerns about ongoing efforts to make the internet a

---

[31]IP regimes could pose a threat to the open hardware movement just as the music industry has tried to limit the spread of information during the Napster era. But, unlike the ‘90s, there was much less hysteria about sharing information and prototypes, and much more reciprocal exchange between companies and user communities, for reasons I describe in the next chapter.

[32] Low-cost 3D printers affect both the professional and consumer markets. The increased sale of these machines over the past few years has taken additive manufacturing (AM) mainstream more than any other single development. 3D printers have helped spread the technology and made it more accessible to students, researchers, do-it-yourself enthusiasts, hobbyists, inventors, and entrepreneurs.

[33] See an extended discussion of this in the next chapter.

highly controlled environment, there are real concerns about file sharing among those who want to patent their inventions and worry about how to do so effectively. Wilkof (2016, p. 145) lays out a thought case study in a paper dealing with this aspect of 3D printing:

> However, what about the situation in which what is protected by the patent is the 3D output of the 3D printer? Suppose, for example, that an enterprising dentist comes up with an invention for a new type of plastic braces and successfully patents this product. Intentionally or not intentionally, a tech-savvy dentist succeeds in designing a similar type of braces by creating a suitable CAD file. This second dentist shares the files with his friends, who share with their friends; finally, the CAD file is uploaded onto a file-sharing network. What can the owner of the patent covering the braces do? Patent law prohibits a third party from making, using, or selling or importing the patented invention. The problem here is that the person 'making' the patented braces without permission is most likely a private person. Even if the patent owner could locate such person, it is usually not financially sensible to file a law suit, where the expected monetary recovery will likely be minuscule.

Indeed, even today, with 3D printing increasingly available to mainstream users, this issue is a matter of concern to those interested in the commercial aspects of the technology. In contrast, the Makers movement and the wider public with little or no interest in offering professional 3D printing services, have a preference for the unregulated approach. Existing regulatory loopholes as they apply to 3D printing (commercial platforms and especially sharing permissions / patent copyrights) are part of a significant debate among cultural ecologies surrounding the technology. This is evident looking, for example, at the case of Makerbot, the first desktop 3D printer company to achieve international recognition after emerging through grassroots communities' such as Hackerspaces.

The initial concept and work (on a replicator based on the RepRap project) emerged from the NYC Resistor Hackerspace. The official story resembles the narrative accepted in the US. Three friends (Adam Mayer, Zach Smith and Bre Pettis which later became Makerbot's CEO) conceived an idea of desktop 3D printing and pooling individual ingenuity and entrepreneurial zeal, so the story goes, and with the help of the space provided by a grassroots organization, managed to create a machine. Their ambition was to change how people make objects and to be a driving force in bringing about the next industrial revolution. Makerbot went from a hangout to a company that in 2011 received $10 million from a venture capital firm (Feld 2011). By 2013, less than five years after the initial start-up, the company, was valued at more than $400 million, was acquired by industry leader Stratasys, which saw a major market opening for desktop 3D printers (Etherington 2013).

At some point, the company was very popular both in the tech industry and the open hardware movement. It was seen by the former as evidence of the highly innovative character of the start-up model and by the latter as a successful open hardware project which emerged from the community and was growing by its side. At that point, the company ran into a dilemma often associated with such projects -- stay close to the community or commercialize and move on. It tried to convince the tech industry that having close ties with the open hardware community is an essential part of its growth. On the other hand, it also tried to convince the community that the commercial route would be good for the community overall, since this way money would come in and the technology could be further developed. The whole project seemed to entail a juggling act between not strictly compatible interests in an effort to enjoy the best of both worlds.

From the point Makerbot moved closer to develop as a commercial enterprise, Bre Pettis, previously hailed as a leading figure of the open hardware movement, was the subject of increasing coverage for his efforts to "democratize production" by tech giants like Google[34]. It seems that what is meant by democratization of production changes depended on whether the approach was being advocated and presented by one of the tech giants, or by a private person, a university researcher or a politically motivated proponent of the open hardware movement. In the latter case, there were even further subdivisions. The consensus, however, was that all concerned took it as a basic tenet that sharing information was the quickest and cheapest way to go. Such an approach offered an open field in which all players, collaborators and antagonists alike, could work. In his Google talk about Makerbot, Bre Pettis spoke of the "next industrial revolution", a concept that was also familiar in terms of policy making[35]. "We are a company that innovates so that others can innovate", Pettis said, stressing the importance of 3D printing as a platform technology that facilitates a variety of practices. It was and is, he said, essentially a tool that can be utilized not only to make personalized goods, but personalized tools also, an essential feature for use in in professional labs[36].

> You needed to be a tycoon to make things in the past, now you need a laptop and a Makerbot and game is on[…] The first industrial revolution was about

[34]See for example his guest appearance at Google under the caption "Bre Pettis speaks at Google NY about the newest offerings from Makerbot and the future of democratized production. Leading the Next Industrial Revolution: Makerbot for Everyone". The basic premise of democratization in this context, meant that, unlike a centralized planned company, individuals and groups would be enabled to create and gain independence from capital intensive practices and firms.

[35]See for example the World Economic Forum new e-book with the title "4th Industrial Revolution" and extended discussion in the next chapter.

[36]See for example the celebration of accidental discoveries by the "New Scientist" in the issue 18, February 2017, where homemade tools and materials in combination with a slow science process led to important discoveries of the 20th century. This culture is now embedded widely in Hackerspaces in contrast to professional labs where time and efficiency is of the essence.

> everybody going to the factory and it allowed everyone to have spoons […] Second industrial revolution is officially classified as being around the railroad and transportation […] Third industrial revolution I like to talk about all those tools that are on your desktop, tools of manufacturing. A Makerbot is a manufacturing education in a box on your desktop […] So we 've built a 3D ecosystem […] We've got all this stuff around the 3D printer. In some ways getting a 3D printer is your ticket into this new world that is way more than just a 3D printer' (Pettis 2014)

The Makerbot Wi-Fi connects it to the internet and enables the user to operate it using a smartphone app, a camera, that allows the user to see and monitor the object being built even when not in the same room as the printer. What Makerbot had done with its flagship devices was embed the collected experience of 3D printing users on a machine as a way of addressing and overcoming the frustrations and setbacks community users were experiencing using less advanced equipment. Of course, individuals could hack their way to solving these problems, but Makerbot drew on the community experience as a way to create more user-friendly products for a wider audience. The 3D printing ecology (machines, software, online platforms, peripherals) Bre Pettis was promoting, was far more than the mere selling of 3D printers as consumer appliances. For early and late adopters, having access to designs and to community discussions was an important and helpful catalyst for development. Makerbot conceived and then established itself as a key digital and online platform for user activities to revolve around. They could purchase one of its replicator machines or simply express interest in sharing designs.

The eventual buyout of Makerbot by Stratasys was a clear signal that the company was opting for the commercial route it has since fully endorsed. In ideological terms, the community saw parent company Stratasys take full control and flex its muscles by changing Bre Pettis' position within the company. They witnessed Makerbot, once a champion of open hardware and software, locking down its system and not releasing the designs of its newest machines, while it also tried to patent a community developed extruder. Business first and business as usual increasingly became the order of the day. Evidently, the community did not receive the well the news for mass dismissal of employees which the company insisted was vital to its survival if it was to cut costs and continue innovating.

The case of Makerbot is important for two reasons. One, it shows that the open source hardware/software movement prefers to be pragmatic rather than idealistic in its approach. In fact, given the range of individual interpretations, the movement's ideological statements come across as rather vague for the vast majority of the users. In this context, it is reasonable to say that the Makers movement and the open hardware movement had a significant part to play in the development of the technology, particularly when it came to the desktop 3D printers. Two, Makerbot is a prime example of how an open source collective project that grew out of a grassroots organization flourished and integrated within a commercial system. The majority of individuals who turned against Bre Pettis may have done so on grounds of an individual's responsibility towards the community. Yet, on the contrary, the case is a very good example of how a grassroots project can be limited within a capitalist setting and tends to reflect these limitations in the context of production.

What Makerbot attempted, was to engage with and recuperate all the informal and craft developments, including feedback on usage, over and beyond the professional development of the machine so that the company could develop its own ecosystem of machines and software. Essentially, Makerbot sought to help create a market and gain advantage by exploiting a common pool of resources, particularly as it relates to knowledge[37]. After gaining the support of a global community of users, it promised that closing

[37]see for example debates on commons, Ostrom and Hess 2007

down certain aspects and parts of its machines would allow it to continue production in Brooklyn and create local jobs. Instead, the company started cutting jobs and concealing important features of the machine (such as a nozzle part) which understandably infuriated the community. The situation was made even worse when the company sought to enforce closure by claiming a patent for an extruder that was developed mainly through the efforts of the user community.

Indeed, this approach constitutes the logical way of doing business on a commercial basis for enterprises operating in a capitalist mode of production. The fact that a technological development is the outcome of activities conducted in an experimental space with the conscious support of a community does not mean it cannot be subject to 'business as usual' practices. As Claudio Katz observes, the artisan economy – which, as I argue in the next chapter, was becoming very appealing in many circles of the so-called 'creative industries' – far from being the opposite of the capitalist mode of production, was actually its cradle. 'Marx attributes the origins of individual property to the cottage economy of peasants and artisans that emerged from the dissolution of feudal lordship' (Katz 1993, p. 374). As 3D printing developed and its use more widespread, regulation concerns grew exponentially.

By now, there were concerns not only about developing an IP system that would guarantee profitability, but even more so about the possible threat open source and easy accessibility of 3D printing might pose to National Security (Badiru et al. 2017). Such fears were not entirely groundless. In May 2013, Cody Wilson, a self-proclaimed libertarian and advocate of gun ownership, released the design of the "liberator", the first 3D printed gun. As of 2017, with 3D printing more likely to be associated with manufacturing, education and robotics, the controversy surrounding 3D printed guns continued to threaten how the whole ecosystem works and its associated dependency on internet sharing (Cruickshank 2017).

The 3D printed gun controversy highlighted a possible threat in file sharing. It also served focused attention on the discussion about cybersecurity and the way global internet works. For the more proactive policy advisors, the UK should not fear over this issue as the UK has stricter gun control laws. However, acknowledging that '3D printers may make it possible for the people to produce dangerous items, such as guns, in their homes'[38] policy advisors urged the government to invest in infrastructure and regulators to 'find suitable ways of controlling such activities, without stifling the operation of 3D printing markets' (Sissons and Thompson 2012, p.3-4). This could be done not only through investing in a legal framework, regulating materials, and setting standards for the industry but also through the key aspect of intellectual patents. However, a problem might be that tightening up controls in this manner would jeopardize the basic sharing principle that linked makers and hobbyists – and ultimately the consumers.

The uneasy relation of the industry with the prolific making culture that pushed 3D printing to the fore can be seen in the mixed attitudes to the role played by profit motive. On the one hand, companies have a strong interest in expanding the user communities and in sustaining them since they constitute their main market. But the cooperative underpinnings of the open source movement posed a threat to the profitability of the risk-averse companies. The profit motive triggered various attempts to regulate and redirect open source activities so that commercial ends would have priority over social goals. When and where it suited them, companies continued to align themselves with the open source approach but mostly in low risk ventures with communities whose allegiance they valued.

For some companies this proved to be a deliberate strategy not merely to manage risk, but also to keep a foot inside the open source door to ensure that they would benefit from any breakthrough achieved within the group. This was especially true for desktop 3D printers and start-up companies with low budgets compared to those of major commercial concerns such as

[38]3D printed guns was one of the most popular stories surrounding the technology, after a libertarian ideologist and supporter of the 2nd amendment in the US named Cody Wilson, claimed that 3D printers could replicate guns clandestine from the state, in case the amendment was abandoned. In fact, the story became viral to such a degree, that the first question I was frequently asked about even within Hackerspaces was the guns story. See more from Record et al 2015.

Ultimaker. Companies like Microsoft and HP were starting to invest in the 3D printing field. Moving cautiously, Microsoft even developed open source software for 3D printers. Some of the bigger players sought to latch onto advancements developed by an array of people with different skill sets, skills that the companies were unwilling to invest in right then. This was the strategy that led Stratasys to acquire Makerbot since it made sense to buy the main force in desktop 3D printing that happened to be using a 3D printing technology compatible with its own. Reasoning and motivation behind the takeover were all out in the open meticulously analyzed in financial and economic publications. According to an article in Forbes Magazine (Sharma, 2013):

> The Makerbot acquisition is part of a multi-pronged strategy to enter the consumer and small business space. Competitor 3D systems entered two years earlier with the launch of Cube printers and its cloud-printing service. Stratasys attempted to break into the consumer market for 3D printers earlier by selling them through HP

Despite all the concerns about the stability and reliability of the open source movement of 3D printing, the cultures that flourished around it continue to thrive and create with an eye to the future.

To conclude this chapter and sum up: the 3D printing broke into the mainstream between 2011 and 2017. This meant that a significant growth in the sales of 3D printers and, by extension, an expanding market. According to the 2012 Wohler's report, the additive manufacturing market generated an estimated $1.714 billion in 2011. Less than half, approximately $834 million was generated through the sale of additive manufacturing systems and materials. About $642.6 million was generated through the creation and sale of parts produced from additive manufacturing systems. Many of the earlier desktop 3D printers were sold in kits and had to be assembled by the users.

Then there was also the need for spares for industrial 3D printers requiring replacement parts. Finally, $236.9 million was spent on 'maintenance contracts, training, seminars, conferences, expositions, advertising, publications, contract research, and consulting' (Thomas 2013, p. 2).

This was when the first global sustainability report was published (see Gebler, Uiterkamp and Visser 2014). The 3D printing market grew from less than $2 billion in 2011 to more than $6 billion in 2017. Meanwhile, despite the two biggest manufacturers (Stratasys and 3D Systems) slowing growth (together they account for a staggering $1.31 billion or about 21% of the industry), the industry expands at a rate of above 15% annually. 'The AM industry grew by 17.4% in worldwide revenues in 2016, down from 25.9% the year before, [..] If these two companies were excluded from the analysis, the industry would have grown by 24.9%' (Wohlers 2017). The commercial growth of 3D printing is evident not only in terms of profits generated but also in how regulated the emergent industry has become. The industry lacked a quality standard system as of 2012 and is in a process of creating as of 2017. The ongoing debate as to what constitutes the best way to regulate the industry is far from settled. Regulatory gaps might be welcome by adherents of the bottom up approach, but for the industry as a whole there is growing concern that the failure to regulate the industry's technology could end up damaging profitability (Brugger 2014).

As will become apparent in the next chapter, the third phase of 3D printing development has drawn headlines under economic, political and socio-cultural categories. The next chapter will show that such headlines tend to focus on political narratives and cultural imaginaries developed to appeal to a variety of audiences and users. Undoubtedly, the era of desktop 3D printing was inspired by the spirit of the times. As more machines are connecting to the internet, sharing of information became a feature of everyday lives while the economic crisis was a factor in pushing many creative developers to imagining alternative approaches to the present way of doing things.

3D printing enmeshing in ideology, cultural imaginaries and political narratives

> *Objects need symbolic framings, storylines, human spokespersons in order to acquire social lives; social relationships and practices in turn need to be materially grounded in order to gain temporal and spatial endurance.* (Pels, Hetherington and Vandenberghe 2002, p.11)

3D printing is a political technology to the extent that it opens the way to imagining or introducing other modes of production and livelihoods in the context of political struggles. It can challenge the status quo[39] in terms of social and material relations. Attempts to spread the use of 3D printing are ongoing. However, much of growing popularity and general interest in the technology is due to the fact that so many of the practitioners and visionaries engaged in developing 3D printing operate in everyday environments – often at the grassroots level – rather than the hi-tech, high security world of big industry. The day-to-day dynamism and accessibility of this approach is what has caught the popular imagination. As David Noble (1984) suggests, however a technology is developed, social and cultural elements play a role too, even including subjective and personal factors (Rogers 1962, 2003; Boltanski and Chiapello 2005; West and Lakhani 2008; Oost, Verhaegh and Oudshoorn 2009).

What is of primary interest in this chapter is to set the context in a historical framework and show how the emergent technology is a construct of imaginative visionaries working, sometimes interactively, from many different locations and sites, mostly - as my fieldwork revealed - operating at grassroots level. I also take into account how the technology ties in, even if at times antagonistically, with powerful institutions, popular culture and the

[39] For example, being part of formal, regulated economies including centralized factories, protective patenting systems, distinct consumer and producer alignments, as well as spatial separation between production and consumption

media. For hackers, makers and other users, 3D printing was a new tool that could allow them to create, an empowering technology (Anderson 2012). Some institutions saw it as a way to harness user creativity to challenge and disrupt heavy industries' obsolete, wasteful and centralized mass production practices (WEF 2016; European Parliament 2015).

The first half of the chapter deals with the relationship between 3D printing and public perceptions of the the technology as it came into view. Next, the questions whether 3D printing qualifies as a form of production as understood since the first industrial revolution. This is contrasted with how 3D printing was characterized at the World Economic Forum in Davos. There, its achievements and potential were portrayed as harbingers of a new, technologically-induced economic boom – a fourth industrial revolution (WEF 2016). Following on, the chapter assesses the often contradictory visions of the technology at the institutional level and grassroots sites. It reveals how communication of ideas plays a vital role in understanding the prevalence of machines in everyday life. The recurring political themes that emerged from the ethnographically informed theoretical discussions I present in this chapter, were very diverse. They included utopian/dystopian themes of a future to come; understanding where 3D printing fits into the debate about forces of production; the use of 3D printing to engage in radical political acts; and, the compatibility of art with science.

The concluding part of the chapter deals with the extent which 3D printing is a metaphor both for an autopoietic organism but also an imaginary of a social system. Perhaps the most pressing question before going further, is how and why did 3D printing become so popular and so viable an economic-political narrative?

The right technology at the right time

The expiration of key patents which sparked the spread of low cost 3D printing in recent years as an affordable experimentation machine[40], had a

[40] See discussion in previous chapter.

profound effect on users' cultural reference points many different areas. Political, economic, social even ontological claims have been advanced by a wide range of 3D printing technology users to support their views s and justify their methods, policies and visions of the future. The affordability of low cost 3D printing means that it is not the exclusive preserve of those professionally engaged in the field. As important, its ready availability enables non-professional enthusiasts an opportunity to join in discussions about the future and to have a say in everyday decisions.

This new medium's applications feature technological infrastructure and manufacturing capacity upgrades. Local Hackerspace makers can connect to one feedback on their individual efforts to implement a design and print it at a local 3D printer using an online platform. A pragmatic approach is when a user-maker faced with a problem creates a customized technology to render an end product otherwise unavailable in the stores. Such configurative adaptability and ingenuity tellingly illustrates what the theoretical work has to say about the technological advances of contemporary capitalism, its culture and its mechanisms for distributing resources and information. The role played by participatory development and decision-making is evident among users, some inspired by the principle of open hardware, who modified 3D printing technology in ways they thought it should develop and directions it should take (Soderberg 2013). It is for this reason that I consider 3D printing to represent something far more substantial and significant than just another hyped up, trendy machine. I argue that 3D printing is one of those technologies that literally empowers its users, offering not only a process of thinking, but a function that can reflect the current state of social/cultural/economic/political reconfigurations.

Such reconfigurations rarely come with exhaustive ideas about solving bigger problems. This is understandable given that everyday concerns although seem tightly connected to global problems, they are usually addressed as isolated practical issues. Specific characteristics of 3D printing – e.g. its ability to create objects with minimal infrastructure – mean the technology is likely to be projected as a potential technical fix for historical and political problems. In the geo-political dimension, renewed focus on so-called First World relations with Africa might look to replace old aid thinking with the export of cheap technology for sustainable development (Gershenfeld 2006; Birtchnell and Hoyle 2014). Gershenfeld (2006) argues the case for the empowerment of communities with inadequate state infrastructure where problems need to be addressed as a matter of priority. In cultural terms, especially in advanced consumer societies, 3D printing is no longer considered to be an exclusively manufacturing technology. It is now viewed as a versatile technology, one that enables the user to create durable objects of all geometric shapes and forms, to address and solve pressing basic needs or to operate for commercial purposes as well. A person familiar with desktop electronic devices requires very little training to operate a consumer 3D printer to make items relatively safely, with very little training (assuming one is familiar with desktop electronic devices), on an everyday basis.

Given the importance of communication in techno-cultures, 3D printing technology also functions as a medium to communicate ideas. Powerful institutions such as the British government, the EU and the World Economic Forum have cited it as a point of reference when unfolding their visions about the future of the economy or announcing policies and partnerships for reconfiguring their own technical infrastructure and economic organization. This is reflected in the growing importance of information and automation in the industrial sphere as well as the rise in numbers engaged in so-called 'service work' as jobs in heavy industry decline. Iannotta and Gatti (2016, p. 105) observe that work and manufacturing outside the walls of the industrial plant is becoming a new growth industry. As they put it, 'In present day terms, the formation of the online community that can offer 3D printers and other services for production presupposes the rapid development of a new phenomenon called social manufacturing.'

The need to rethink and re-organize work became more urgent as people affected by the economic crisis that beset Europe starting in 2007 were forced to look for alternative employment opportunities. The public debate showed renewed interest about a changing course, with more attention being paid to the possibilities science and technology might offer. Capitalist economies and societies pay more attention to technological development and advances at times of economic, political and social instability, according to Harvey (2010). Labour-saving technologies are options capitalist organization explore in times of capitalist crisis. In addition to helping ensure and protect profit margins (Fine and Saad-Filho 2004, p. 109-125), it also paves the way for introducing new infrastructure and accommodates of political interests. However, in this instance the renewal of interest was somewhat random and experimental. Industry and the general public were bent on exploring a number of technologies and the effective uses of creative machinery, in their respective search for cost cutting measures and practical applications that might address the situation they faced. If the economy and society were collapsing what might stop this seemingly never ending downturn? Technology, often described as the practical side of scientific inquiry, again began to feature as vital to re-organizing the economies of the crisis-hit societies. The aim was two-fold - to address the long-term existential problem but also how to proceed on an everyday basis to solve problems.

Similar discussions, albeit in different terms, arose in earlier periods of the modern era after the industrial revolution. Lewis Mumford (1934) finished his monumental work "Technics and Civilization" in the middle of the worst economic crisis of the 20th century, when technology was still being mostly debated in the context of what modern civilization means for humanity. There was renewed focus on science and technology and their value to advanced modern societies during the 1970s, where 'peak oil' and a wave of political unrest sparked a radical science and appropriate technology movement (Pursell 1993; Beckwith 1986). Debates about the centrality of Technoscience were conducted in a closed and protected environment, usually confined to expert and professional participants. Theirs was the professional stance that helped shape how advanced societies were to view the role of science and technology, even when it came to the introduction of new technologies into everyday use, often with an eye to the future. It is not difficult to see why such moments in history trigger debates on opposing views well outside what had been considered the prevailing norm. During times of capitalist crisis where restructuring of work occurs and new models of living are introduced, there is an opening for new ideas and opportunities to be absorbed both by the general public and in business circles. However, the discussions failed to gain momentum among society as a whole, which remained largely passive, a recipient at best recycling ideas promulgated by the industry. Thus, the issue of technology remained closed to experts (Winner 1977).

What was different about 3D printing was that a new maker movement would approach politics in a much more practical way than past social movements. Although not vocal about politics, the message delivered was that practicality is politics. It is not difficult to see why. With automation increasingly putting a strain on jobs and labour being replaced by robots, both identity and livelihoods were under threat. The third wave of the industrial revolution, as The Economist (2014) suggested, would mean an eclipse of global labour:

> more manufacturing work can be automated, and skilled design work accounts for a larger share of the value of trade, leading to what economists call 'premature deindustrialization' in developing countries. No longer can governments count on a growing industrial sector to absorb unskilled labour from rural areas.

As automation increases, much of what is considered work, at least in the Western world, moves outside the professional setting (Böhm, Dinerstein and Spicer 2010); disconnected from the process which gives primacy of political agency to professional politicians and traditional forms of working class union politics (Wright 2007), the new politics that emerged, would challenge the very legitimacy of wage compensated expertise in a very visible manner.

Politics without being called as such. This is not necessarily done through direct political confrontation as in the past, but by opening up everyday science to the wider amateur public and insisting that art and experimentation is an essential part of scientific inquiry benefiting the many and inclusive of the marginalized. Of course, it would require extensive search to find anyone who argues that such practices are not immune to the dominant ideology and the framework within which they operate. As in the case of the neoliberal narrative of rejecting ideology and politics as guidelines to betterment of everyday life (Harvey 2006)[41], often the rejection of politics altogether evokes a risk of naiveté and makes for an easy target in the medium and long-run. However, what this kind of politics encompasses and what the people involved try to respond to entails problem solving as a politically charged action. With grand narratives no longer a feature of the public discourse, and the "'End of History"' (Fukuyama 1992) no longer retaining its broad appeal, individuals began to favor a practical response to politics, usually conducted as identity politics. This was also because trade union politics[42] (McIlroy 2014) were no longer in a position to offer results that could change people's lives nor could they provide assurances for the long term. Transformations at a social level increasingly included DIY responses to the demands of everyday life, but in an upgraded form. This time the use not only of smaller scale craft methods, but also new technologies such as 3D printing boosted the ability to create objects and machines that could be replicated in professional settings. As 3D printing went into neighborhoods,

---

[41] "Neoliberalism is in the first instance a theory of political economic practices that proposes that human well-being can best be advanced by liberating individual entrepreneurial freedoms and skills within an institutional framework characterized by strong private property rights, free markets, and free trade. The role of the state is to create and preserve an institutional framework appropriate to such practices." p. 2 Harvey, David (2005): A Brief History of Neoliberalism. Oxford: Oxford University Press.

[42] For some such as the Economist, the declining membership is a qualitative evidence of the changing nature of work (see E.H 2015). For others, declining membership is evidence on how much capital power has grown in relation to labour or organisational problems of trade unions that hindered the advancement of their cause (see for example McIlroy 2014)

professional set-ups also took an interest and learned from what was produced and conceptualized (however “unpolished”’) outside their domain.

Indeed, the social transformations that emerged were a hardware version and continuation of the movements and transformations[43] that followed what was dubbed the ‘new economy’’ (De Cock, Fitchett and Farr 2001; De Cock, Fitchett and Volkmann 2005). This time, however, the name given was that of being a collaborative or circular process or both (Stephenson 2015). With the very nature of work altered, as theorists such as Negri and Hardt (1994, 2000, 2004) argued, information had transformed capitalism in such a way that relations outside the wage system had much more to say about contemporary politics than proponents of Labour Process theorists had argued in the past (Thompson 1989; 2010). The prevalence of software (Barrett 2005) is undeniably important. But for those not quite jumping onto the bandwagon of autonomists abandonment with work related politics altogether (Dyer-Witheford 2015), the interactions between wage labour and those outside the wage system led them to attempt combining both theories seeing the value outside as well as inside the wage system (Böhm and Land 2012). The case of Makerbot outlined in the history section is a good example of how a company managed to capitalize on the interaction between their commercial activities and the activities of the community which gave it a push in order to help it grow to a point where investors were interested to take it to the next level. The design and technological commons that were created through shared knowledge and pooled information, generated social reproduction that was managed by the company in such a way as to associate sharing and new types of making with the company’s value. As Böhm and Land (Ibid, p. 228) put it, this is becoming common practice,

[43] such as a general hype for entrepreneurial, knowledge-focused, new technologies and innovation in contrast to traditional stable and non-reactive business; the old economy was out of step with the spirit of the times compared to the new economy which tends to include users and takes the power of networks into account.

> Taking place outside 'work', the consumption and circulation of 'signifying complexes' is the cornerstone of social reproduction whereby a common is forged, without which communication and collective action would be impossible […] there is a new common produced through these social interactions that give rise to a surplus (collective) subjectivity. If the social interactions constituting this ethical surplus can be managed so as to circulate through a specific commodity form – a brand that becomes indispensable to their ongoing reproduction – then this process will produce an economic surplus for the owner of the brand by augmenting brand equity.

Perhaps a social movement like that of the makers is not the standard that theorists focused on autonomy would pay attention to (Shukaitis and Graeber 2007), but - to paraphrase Holloway (2002) - they do claim that their aim is to change the world without looking directly for political power. Not only do they possess the capacity to fulfill that claim[44], but it appears they helped pioneer such transformations. Although not having concrete demands and leaning more d towards an entrepreneurial ideology (Soderberg and Delfanti 2015), the movement does reproduce through its everyday practices different types of spaces and social relations between participants and users of technology. In accordance to the spirit of the times (Sutherland, Land and Böhm 2014), the Makers movement does not claim authority and does not promote a specific kind of leader. In fact, much of the movement's appeal has to do with the rejection of individual leaders and an immanent insistence on autonomous cluster groups between communities. The movement's non-homogeneity, despite issues with what Soderberg and Delfanti (2015) describe as 'recuperation from below', shows there is an affirmative element

[44] Böhm, Dinerstein and Spicer (2010, p. 19 - 20), define autonomy as 'either a process of labour self-valorisation, negation of state power' or as 'alternative to hegemonic forms of development'.

in its practices, which can appeal to people with very different backgrounds and political ideologies. Indeed, this is what Böhm, Dinerstein and Spicer (2010, p. 18) argued as the impossibility of autonomy,

> the practice of autonomy is bound up with the 'new spirit of capitalism', emphasizing autonomous and flexible forms of economic organization, including the increasing incorporation of social movement activities into the neoliberal service provisions of the state. In this way, autonomous movements must be seen as part of the hegemonic system of capital and the state. Yet any hegemony can only ever be partial and incomplete. That is, within the impossibility of autonomy there are possibilities of autonomous practices that challenge the very hegemony they are part of. Hence, our argument is that autonomy constitutes both a possible and impossible aspiration, as autonomous spaces embody and disclose the contradictory dynamics between the swinging movement between integration and transcendence

In order to engage in such practical politics of potentiality, machines are in the epicenter and create imaginaries and conditions for everyday encounters. The powerful message they deliver is leveraging on 'making' as a material force and signifier to alter social relations. Back and forth, between institutions and undermining their authority, the communities in various unscripted ways are trying to skip obstacles to developing their space and increase their resources. What I argue, is that following 3D printing in multiple sites is an essential artefact, similar to the concept of 'empty signifier' (Laclau 1996) offered to unify heterogeneous events and actions, that can aid and provide a vital component of insight in understanding this process. A concept more familiar to those of psychoanalytic background, an empty signifier is essentially a self-referential point to which many different concepts, categories and processes exist within an umbrella term only in relation to what they are negatively akin to. The timing of 3D printing imaginaries suggests an inherent quality within the technology and its uses, that functions as the tangible representation object of an ideology which focuses not on theory but practice, and can reveal much of the real changes happening in fast pace as the technology unfolds. What are these imaginaries and how are they connected to these social transformations?

A not so quiet 'revolution'

In December 2011, the Economist painted a very optimistic picture of the new movement that was pushing the dynamics of innovation to a new direction. Their approach to sharing information, using open source technologies and friendly science, evidently grew the movement and caught the eye for a variety of reasons. Members of the Makers movement, the weekly magazine suggested, were 'not just digital quilters', capable only of exchanging ideas while remaining in obscurity on the fringes. These grassroots agents were part of a much larger picture, the article claimed. The 'shock of the new', presaged a 'third industrial revolution', that would propel this new revolution using experimental new forms of organizations. After all, 'the original industrial revolution grew out of piecework done at home, and look what became of the clunky computers of the 1970s' (Economist, 2011). Their favorite hardware? 3D printers.[45] Suggesting a qualitative continuation of the hobbyist movement which was responsible for the personal computer becoming a stable machine in everyday life, the article eagerly looked to the future by describing the first steps of the process.

[45] Although as I show in the previous chapter, the additive technique had been possible for more than 25 years, factors such as the maturity of the internet and the technological environment. The Economist named 'software, standards and online communities' as the key components - allowed such machines to 'connect the digital and the physical realms'. I argue however that if software and standards was expected from industry, online communities and open software phenomenon was the result of social intercourse rather than expected factors.

> The parallel with the hobbyist computer movement of the 1970s is striking. In both cases enthusiastic tinkerers, many on America's West Coast, began playing with new technologies that had huge potential to disrupt business and society. Back then the machines manipulated bits; now the action is in atoms. This has prompted predictions of a new industrial revolution, in which more manufacturing is done by small firms or even by individuals. “The tools of factory production, from electronics assembly to 3D printing, are now available to individuals, in batches as small as a single unit,” writes Chris Anderson, the editor of *Wired* magazine. It is easy to laugh at the idea that hobbyists with 3D printers will change the world. But the original industrial revolution grew out of piecework done at home, and look what became of the clunky computers of the 1970s. The maker movement is worth watching. (Ibid)

A few months later, the imagery became even more illustrative of what the new technology could bring with the announcement of a third industrial revolution (Economist 2012). An article featured a graphic showing a man sitting in front of a desk-sized factory in an office typing. If the first industrial revolution in the 18th century was about mechanization in the textile industry and the second in the early 20th century kicked off with the invention of the assembly line, the third, according to the Economist, was about the digitization of manufacturing. Digitization of manufacturing, the article suggested, was a step towards placing ever increasing power in the hands of the individual to create just about anything from jumbo jets to small tools for craft making. The key to digitization is flexibility and customization. ‘The factory of the future will focus on mass customization and may look more like those weavers’ cottages than Ford’s assembly line’ (Ibid). Despite the projected image of a future connecting the individual with a global network of cozy houses with individual factory desks a key factor is the connectivity of individuals provided by the social networks, especially the role of social media as a communication tool. Drawing on the increasing power of the social media, so the narrative goes, the digital factor would be able to turn the factory upside down, open its doors and make the manufacturing process an even more social and accessible activity. That is, a true social activity as opposed to the manufacturing process as a professional activity.

Figure 2 An illustration from the article, The third industrial revolution, Economist, April 21st 2012

The power of the users to suggest new materials, new methods, to share their own designs and thoughts creates the possibility for manufacturers to harness not just the labour of their workers but also the power of their active consumers. It should be noted that his narrative has an important blind spot – i.e. that desktop manufacturing was supposed to turn consumers into manufacturers rather than working for them. This contradiction is not readily answered other than to suggest that big manufacturers would be better off to collaborate with individual makers rather than view them as antagonists as they did in the past. And not only in ideas and feedback since ‘firms may also copy some of the unusual business models that makers, often accidental entrepreneurs, have come up with’.

Paradoxically, the article never uses the word 'individual' in describing the process of enmeshing the professional context with consumption activities – essentially promoting a more socialized way of producing goods – yet the illustration accompanying the article saw fit to depict a lone manufacturer sitting at his desk as the best way to represent this idea. The message projected was clear: never before had an individual more power to create whatever they want, whenever they want. Therefore, any failure to be creative has to be the fault of the individual not utilizing this power. The article ends with a statement that this process I a priori justifies the standard liberal democratic tenet of 'meritocracy'. Not only meritocracy within the current dominant socio-economic system as a functional concept, but a strong belief that there is now a new way to ensure a smoother path for those deserving of attention and success who previously may have been unable to advance upon their merits. Making it easier to find winners and revolutionaries, in the view of the Economist, would help drive the economy forward and shape the future. Moreover, according to this narrative, disconnecting pricing from the of manufacturing process would point the economy towards a new form of exchange. If the state provides standard, up-to-date knowledge and skills developing a market for the sale of ideas and time, the new technology can provide everyone with a starting set.

> The lines between manufacturing and services are blurring. Rolls-Royce no longer sells jet engines; it sells the hours that each engine is actually thrusting an airplane through the sky. Governments have always been lousy at picking winners, and they are likely to become more so, as legions of entrepreneurs and tinkerers swap designs online, turn them into products at home and market them globally from a garage. As the revolution rages, governments should stick to the basics: better schools for a skilled workforce, clear rules and a level playing field for enterprises of all

> kinds. Leave the rest to the revolutionaries. (Economist 2012)

In other words, according to this view, not only the new technology redeemed the need for policies that reversed the issue of inequality, but in fact it would be wrong in all sorts of ways for governments to make targeted policies to do so. Given how diffusion works in innovation processes (Murray, Caulier-Grice and Mulgan 2010), it is not difficult to find government funding projects that went wrong or failed to deliver. This narrative of chaotic and emergent stability of the market with new tools that enable individual makers to freely exchange their products, were of course nothing new. The new process can be tireless, whereas workers have limited amounts of energy. Through the use of algorithms, it is capable of tackling more complex issues It than the human mind can conceive of.

> The 3D printer can run unattended, and can make many things which are too complex for a traditional factory to handle. In time, these amazing machines may be able to make almost anything, anywhere—from your garage to an African village. (Economist 2012)

It is easy to see why on the surface this type of narrative appeals to a lot of people. With access assured, issues like problems of structural violence or political inequality can be remedied. Arm the passive online voice with a new configuration and people are in a position to address their peers and try to solve practical issues themselves. They can even make new connections in the process, professionally or as friendships. This is especially true for online groups using Facebook or Twitter to spread news of 3D printing. One social network mentioned by many interviewees was 'meet-up', a popular platform for organizing events and locating grassroots or informal groups involved in technology, open source and entrepreneurship activities. Many wishing to use a 3D printer can search the social network, find what interests them, save it in Google calendar and even attend digital events in the flesh. Curiosity about how a technology works, can lead a person to a Hackerspace where collaboration and the exchange of information and skills happen in a more detailed and intimate way than online. Indeed, as stories flood onto social media or, even better, mainstream media reports on successful projects, makers can be seen laying the ground for new practices while big companies adjust and try to defuse their connectivity potential. Certainly, social networks provide a way for users to connect. The question is how, in what direction, and of what caliber is -- another story altogether.

Figure 3 An illustration from the article, The third great wave, Economist, Oct 4th 2014

Like the Economist, other news media such as the Financial Times began to air various claims about 3D printing. Their columnists began writing regularly about the technology. Topics ranged from changing the process of design to how the technology made collaboration easier, to views about it contributing to the end of capitalism or at least the disruption of many leading industries (see for example, Hill 2016). Another member of the financial media, Bloomberg, went as far as claiming that 3D printing was responsible for saving the livelihoods of artisan in Italy's northeast, who had been hard hit by competition from China's large industrial plants and cheap labour costs. A technology allowing the small to compete with the gigantic manufacturers had huge attraction for small and medium sized organizations. Here was a new technology that, unlike previous industrial revolutions, did not threaten to annihilate the craft skills. Within the parameters of todays globalized economy, 3D printers could, in fact, help revitalize craft making on its own terms and ensure it was economically viable.

Figure 4 'A worker at HSL polishes a lampshade created by a 3D printer.' Photo credit: Luca Locatelli for Bloomberg Businessweek

Italy's craftsmen have been undermined by competition from China– and the industrial sector has shed about 135,000 jobs—17% of its total workforce. A few years ago, in an effort to diversify offerings, one firm teamed up with an artist to create manufacture-to-order lamp shades and jewelry on 3D printers. The pieces take shape slowly, each layer fused from powdered nylon by a high-power laser. The project was a surprising success, building products that no one had earlier envisioned. Techniques such as the 3D printing have helped turn northeastern Italy into an unlikely hothouse of innovation (Faris 2015)

The hype that was beginning to grow around 3D printing made the technology a reference point not only in the financial media but also in the cultural imagination. 3D printing appeared in episodes of TV's favorite "geek" series "The Big Bang Theory" (Cendrowski 2013). In one episode the protagonists appear to be engaging enthusiastically if ironically with the technology. The episode played down the hype surrounding the technology by wittily showing some of the weaknesses associated with 3D printing, especially that of time. The dialogue between the two protagonists - Howard and Rajesh - highlights many of the issues being discussed about 3D printing at the time. In their exchanges, the two characters' touch on limited range of available materials of 3D printing, on pricing, mass manufacturing, re-shoring and competition from China's manufacturing powerhouse, as well as the technology's functionality. The two scientists (somewhat immature in their private lives) have sent their photos and dimensions to an action figure toy manufacturer to replicate. Instead, what they get back, far from being look-alikes, are seen by the pair as racist, stereotyped action figures. Angry at this development, Howard and Rajesh set out to create their own action figures by scanning and printing themselves. By owning the process, they can perhaps even create better versions of themselves. In the first two scenes, we see them in the lab, talking as use what looks like an older generation industrial 3D printer, similar to those located in universities at the time. In the third scene, Howard, the engineer, proudly shows the completed 3D printed figure to his wife, Bernadette. Her initial enthusiasm fades as as she learns about how much it cost.

Scene 1

Howard: I have always wanted a 3D printer

Rajesh: Of course you have, they are an engineer's dream. Anything you can design, the 3D printer can make out of plastic.

Howard: Yeah but they are so expensive

Rajesh: Oh, come one! You deserve one! You worked hard to find a woman who makes a lot of money

Howard: Well, the prices have been coming down...

Rajesh: True, they are practically giving them away; you know, in exchange for money

Howard: And we can make stuff we need, for work with it. Prototypes of my cad/cam designs, specialized tools…

[…]

Scene 2

Howard: Do you realize by owning a 3D printer, we are reclaiming the manufacturing process and taking jobs back from sweatshops in China?

Rajesh: I think this thing was made in China.

Howard: Eh, what can you do?

Rajesh: Ohh, I think it's done! It worked! We printed a whistle!

Howard: Amazing. Do you realize these things go for 25p a pop at a party store.

Rajesh: And we made it in only three hours!

Howard: [Whistles]

Rajesh: Sounds just like store-bought

Howard: Okay, give me a superhero pose, and I will scan you into the computer for our action figure.

Rajesh: [inhales] Oh, I wish I was in better shape.

Howard: Stop holding your stomach, I will give you a six pack with the computer.

Scene 3

Howard: … thanks to photographs and a little 3D modelling here comes the bride…

Bernadette: Oh Howie, I love these! Were they expensive?

Howard: Didn't cost a thing, I made them myself!

Bernadette: How?

Howard: Koothrapali (Rajesh) and I bought a used 3D printer for five thousand dollars (chuckles)

Bernadette: Five thousand dollars for a couple of dolls? Are you out of your mind?

Howard: Not just a couple of dolls…for as many dolls as we want…and whistles!

[…]

Bernadette: Howie, we can't afford to waste money on junk like this!

Despite the show's apparent mockery of 3D printing, the dialogue is both informative and humorous enough to appeal to users and to viewers who were unfamiliar with the technology, even as it poked fun at functionality and speed problems associated with 3D printing. Undoubtedly, the question posed about what to do with 3D printers has its parallels in real life situations. Yes, having seen what it is capable of, so what are we going to use it for? Is it for play or actually useful?

By late 2011 and 2012, 3D printing was emerging as a cultural phenomenon like few technological developments before. It featured in all sorts of TV programs but its cultural impact came largely thanks to it being featured in the entertainment media, which introduced the technology to a mass audience of millions, reaching way beyond the realm of the professionals. For example, in June 2011, Bre Pettis was invited to show the Makerbot 3D printer (then in its initial phase) on the "Colbert Report", a popular talk show. Wittily, the host Stephen Colbert raised the issue of offshoring which was very much in the news at the time. 'Right now we are relying on China for our little pieces of crap', he said whilst the crowd laughed. He continued: 'What is cheaper than a Chinese worker? A robot!' Turning to Bre Pettis, he asked, 'All we need is a design and Makerbot can make it?' 'That is right', Pettis responded (Colbert 2011). Anxiety about the

US-China trade balance was then a recurring theme for political satire. It was to reappear again n the US elections of 2016.

Aside from the cultural landscape and coverage in in the economic magazines, the social, political and economic dimensions and potential of 3D printing were also being explored in popular science magazines. Again, as in economic publications, strong though the word revolution is, it was the preferred term when presenting the phenomenon. ‘There’s a quiet revolution taking place in factories worldwide’ the “New Scientist” suggested.

> In 2013, manufacturing may still resemble old mass-production assembly lines, but increasingly, technological advance means they are producing customized items that need never be the same twice. And that is changing how designers and manufacturers think, as the focus shifts from homogeneous products to end users and their desire for individuality. Designers are now keen to have us co-design products, and even manufacture them at home (Condliffe 2013)

The “New Scientist”, a publication not particularly known for its political views, an article presenting 3D printing was more politically charged than similar coverage in the liberal ‘’Economist’’. Why would all these publications devote so much coverage to the cultural imaginaries and political narratives associated with 3D printing? The answer lies in the political narrative and the current economic system.

Speculation and promise

One of the foremost issues that arises when researching 3D printing, is the overwhelming information regarding the hype and language about its potential. Many point to a ‘’revolution’’ in the making, yet it is unclear what exactly they mean though in all cases the term signifies a radical change in what those who say it are pointing to. The function of buzzwords is to create a specific language, either for insiders or in many cases a cultural language for mass consumption, one that most people can identify with and use to communicate complex processes. A revolution for example, can be popular; it can mean either social progress or personal growth. It can mean a radical change in management, an alternative socio-economic system, a change in the distribution of goods and services or in the design process. Often obscure in nature or an empty signifier, even having contradictory meanings among the actors using it, the purpose of buzzword language is to bring on board a variety of stakeholders that otherwise may not see a connection between their intersecting interests. Other frequently featured buzzwords that are used to characterize 3D printing include for example the discourse surrounding the 'democratization of technology'[46] or policy discourse on the 'knowledge economy'. Accessing the field both in physical and virtual spaces, one cannot help but notice that 3D printers are used as an incentive to bring people into designated 'hacking' spaces and to encourage investors to make commercial applications that will develop and expand the field. But this is not the only way 3D printing it is used.

In addition, there are the cultural imaginations like the Star Trek style ''replicator'', economic narratives about the technology wiping out economies of scale, the personal desktop factory, or even more akin to the sci-fi genre, the ubiquitous nature of the manufacturing process. In many cases, choices of branding or the building process for the machines are embedded in order to resemble and encapsulate those cultural imaginaries. A case in point, naming the machine presented by Makerbot the 'replicator' in a clear attempt to link the machine to the one featured in the legendary sci-fi series (Feinberg 2016). By doing this, Makerbot sought to capitalize on an already established cultural reference in order to set the standard on 3D printing. Makerbot seems to offer everything of this new world: machines, platform for sharing, software, network. Inevitably, the question arises what is so special about 3D

[46] In context, usually means the spread of consumer devices that can be used to make things. The cases where I encountered users that did not understand democratisation of technology as individual rights of users and consumers, were very scarce.

printing and why is it being wedged into cultural relevance? Could imaginations of 3D printing potential alter social expectations and engagements, or even create social movements?

Many of the discussions I was engaged during my time in the community workshops I visited, were far-ranging and coming from a wide variety of identities. The scope of these heterogeneous elements can function under the umbrella term and historical narrative of neoliberalism[47]. Neoliberalism has a speculative relation to Technoscience, using spectacle to achieve economic activity. Szerszynski and Reynolds (2012, p. 28-29) argue that the 'knowledge based economy'[48], a term used since the 1970s about the increasing importance of information in production is key to understand why promise and imagination is important for new technologies. Financialization and speculation, so they argue, is at the heart of the way science and technology is researched and adopted. Science and technology are fields just like any other productive discipline in societies. The production of knowledge and the adoption of new technologies is also affected by the way market forces shape capitalist societies. Just like the suggestion that financialization took over the productive process and has far more power than the industrial industries (Lapavitsas 2013), science, as Szerszynski and Reynolds (2012, pp. 28) argue, since the 1970s became increasingly speculative, giving rise to 'political economies of promise'. 'This involved attracting venture capital' they suggested, 'corporate and public funds for speculative new technoscientific developments' (Ibid, p. 36). The increasing penetration of capital and thus the commodification of Technoscience, deems knowledge to be crucial and utilized in a process spread among various stakeholders from universities to small-scale start-ups and big corporations with few barriers. Despite apparent opposition to property rights, strategic use

[47] Neoliberalism understood as a regime of accumulation within the capitalist system, which emerged in the 1970s. See for example David Harvey, A brief History of Neoliberalism 2005, and The Enigma of Capital and the Crises of Capitalism, 2010.

[48] According to Reynolds and Szerzynski (2012) the term 'knowledge based economy' is a policy term that is used by the OECD and shares an uncanny resemblance with the autonomist Marxist interpretation of the new phase of capitalism based on exploitation of the 'general intellect', p. 28-29.

of open-source software (which now seems to be going in the same direction as hardware) is key for the smooth flow of such vital information and data.

> 'All this, is to facilitate the flow of knowledge between diverse public and private scientific spaces, between the spaces of its collective and social generation and the spaces of its private appropriation and enclosure'. As a reality check, Reynolds and Szerzynski (2012, p.33) however note that 'despite the proliferation of consumer electronics, the contemporary new knowledge economy has so far not produced anything equivalent to the paradigm-shifting technologies[49] of earlier industrial revolutions'. (Ibid)

The evidence that a knowledge-driven economy can work on the strategic openness of information between the various stakeholders has acquired supporters from various and contradictory backgrounds. The intellectual commons, another popularized axiom for explaining this common collective resource shared among the various actors, has the ability to spread knowledge (as its increased importance through new forms of production and extracting of value transformed it into raw material) giving rise to changes on many social, political and economic disruptions. Whilst many can remember the vile attacks of Bill Gates on the open software movement in the early 90s (See Kelly 2009), Microsoft now claims its strategic use. However, if under such a process information and data can be called raw materials, then the outcome knowledge cannot be value free as self-evident facts.

From a similar perspective, Lilley and Papadopoulos (2014) argue that disclosures and control of funding over the production of science and

---

[49] By paradigm-shifting technologies, they mean that the average household, just as life in general, contains more or less the same technologies that emerged during the second industrial revolution – i.e. 'electrical power and motors, organic chemistry and synthetics, and the internal combustion engine' p. 33

technology, mean that Technoscience has been altered at a material level. This means that to a great extent Technoscience has been a captive of the corporate world given its dependence on investments in a profit-run system of production and distribution. These interests have been responsible for increasingly creating an alternate environment where the results of a supposedly objective and value-free science have revealed the nakedness of the illusion that Technoscience is free of ideological propositions and political direction. The commons, they argue, have been altered at the material level. This theoretical position has grown in significance within the autonomist movement which focuses to reveal and describe through both empirical and theoretical studies, the importance of how people organize to use these new technologies. Their actions can give direction to the development of technologies such as 3D printing and have an effect upon the culture around it. This important distinction determines whether the openness of the new machines and software is of critical importance to the advance of social movements or if they are of less important to social change and the working environment. According to Lilley and Papadopoulos, precisely because Technoscience within neoliberalism has altered materially insofar as its development reflects the scope and limits of the system of production under which it is conducted, it is not enough to just guard the commons (i.e socialized forms of knowledge, products or means of production). Financialization, they argue, the process by which the finance industry took over the productive process, turns into biofinancialization; 'biofinantialization becomes molecularized in flesh, in code and in matter. Biofinantialization becomes fleshly, more than just the exercise of command over life and flesh; biofinantialization becomes ecology, more than just a system for accelerating accumulation' (Papadopoulos and Lilley 2014, p. 980).

How machines are integrated into software ecosystems, the decisions behind the shape of machines, the openness of software are not shaped primarily by financialization which itself alters the very fabric of material life. Instead of just guarding or engage in struggles about what is being produced, they suggest (with the assistance of Böhm, Dinerstein and Spicer (2010), autonomy could function as a way of creating alternative futures. The way forward is to participate in altering the fabric of commons towards their own ends rather than just wishing to guard them. In this respect access is a key aspect. Participation allows for alternative ways to build machines, alternative organizing within or outside the cities, and other practices and rituals of everyday life. This is the promise and potential of 3D printing in Hackerspaces, Makerspaces and Fab Labs. Community workshops within cities, however they may be called, whether their emphasis is on making or hacking or fabbing, offer the prospect of an alternative way of organizing. They are actions that belong to both worlds, the present where profit motive reigns and a future of replication and sharing. This is not to suggest that a promise or potential is guaranteed to succeed, but that at least theoretically the potential is there. The needs of the people comprising a community workshop in one city might be radically different from that in another. Moreover, there are differences in legal status as there are different ways of managing a workshop. How people choose to organize and what happens in their everyday lives is important and contributes to the variety of visions and potentials of the technology. In any situation, the direction and fulfillment of the potentials depends on the outcome of the actions of many different individuals living in different cities. But the seemingly endless and chaotic versions of possibilities that co-habit in the 3D printing universe behave in peculiar ways. The potential of a new world with the old trying to update itself seem to have different interests while also needing each other for their own reasons.

Rather than antagonizing and competing with each other, various speculations and promises about 3D printing were used both by industry and users as a form of productive diversity designed to appeal to businesses and the wider public. Indeed, the growth of the 3D printing market is in itself a success story so far (Wohlers 2017). Allowing restricted openness and access to individuals, means that users can become a viable part of the supply chain providing invaluable feedback and even as productive agents within the process. The spreading publicity about 3D printing fed both the general curiosity about the technology and the growing awareness of its significance among potential users. New online media, social media forums and groups, blogs and websites such as 3Ders.org, 3D printing industry and others, sprang up all over the place in response to the phenomenon. Mainstream media took note and in its fashion generated even more hype. The technological columns of the major newspapers and magazines fixated on the possibilities, the changes in mind-set, the disruptions at technical level. Articles on 3D printing became the new norm. As the hype grew hyper, companies were already monitoring and measuring what was going on. In 2014, Gardner, a major information technology consulting company, issued its famous hype chart showing what the hype cycle looks like in relation to actual technical and economic possibilities in a market economy.

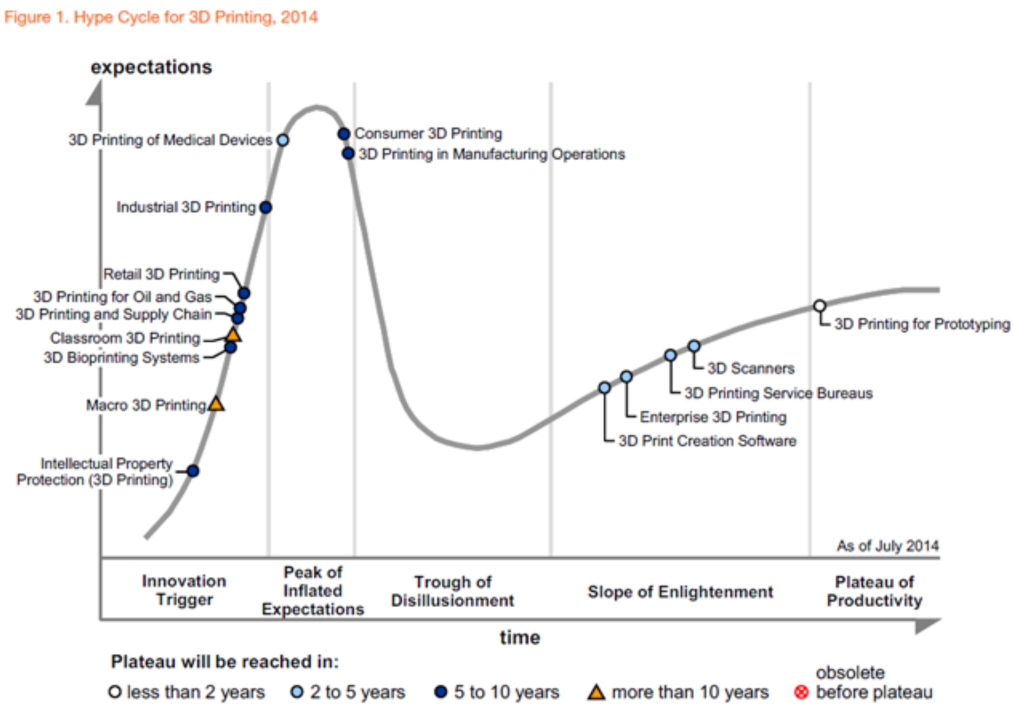

Figure 6 Gardner 3D printing hype cycle chart Source: Gardner Report

One of the problems with 3D printing development was that it did not follow the same line the semiconductor industry was following because Moore's law[50] was not applicable (see Tamburini 2014). This meant there

[50] Moore's law is the prediction given by Gordon Moore during his time at Intel corporation, by which he observed that the number of chips contained per integrated circuit is directly proportional to time. What this means, is that every year there is an increased capacity of machines to double their speed and power, allowing the possibility for more complex machines with more capabilities. The estimation is rough, as there are times at which each year the power

was uncertainty about how fast or how reliable the process could become within a scheduled timeframe. The hype cycle, however, turned the increasing imagination and prototyping fantasies of users and professionals alike into speculation, which in turn could trade and attract investment on the future capabilities of the technology. The current FDM process is not scalable (as numerous users along a variety of workshops confirm in interviews and informal conversations) and it is very obvious why; having materials that melt and cool to shape objects means there is a physical limit to the speed process. The only way to accelerate and make 3D printing more efficient is through other variables, mainly by finding other types of additive manufacturing processes such as the CLIP method[51]. Indeed, both industry and users in many public spaces have experimented with a variety of processes rather than focus on speeding up the FDM process, which is the most popular 3D printing method based on the open source RepRap model. Much as consumer vendors would like to suggest, 3D printing is far from becoming a plug and play technology. The experimental phase the technology is going through is part of its charm. In many cases, it serves as a technology used to cultivate a patient culture seen with slow computing. So why should everyday people stick to 3D printing at a time when commitment to any technology follows a trend in which unfinished products are less tolerated by users? One of the main reasons it seems, is the power of imagination: community building along with a blend of imaginations that intersect at a grassroots level with substantial and skilful encouragement from policy makers, industry and academia. One policy framework that attempts to integrate all these visions into an industrial socio-economic framework is what the World Economic Forum called "4th industrial revolution"[52]. The term carries with it a historical connotation of

---

doubles, whilst during more recent years there has been a discussion whether this time increased to 18 months, 24 months or 30 months.

[51] See the history of 3D printing chapter.

[52] I consider the World Economic Forum's concept as the most comprehensive and elaborate sociotechnical concept of all the others found in publications that have for the most part been used in order to describe radical changes rather than a policy framework plan for the future.

transformations that changed the world economically, socially and politically during the turbulent 19th and 20th centuries.

Discoursing 3D printing within the 4th industrial revolution

If the first industrial revolution was about changes both in industry and the social paradigm, later descriptions of the industrial revolutions ascribe a position of primacy to technological developments to the social organization (market economies with or without liberal democracy). The application of science and technology can foster changes so that the socio-economic paradigm (market economy) stays the same. Hence, David Noble's observation during the years of the personal computer hype return towards restating the importance of the social organization in shaping technological developments and experiences of them,

> technological revolutions are not the same as social revolutions and are more likely, in our times, to be the opposite. But the two have this in common; they do not simply happen but must be made to happen. The enthusiasm of the people who drive them must overcome the resistance of reality, that is, of other people's reality. (Noble 1984, p. 195).

The use of the term by the World Forum at Davos, the intentions of the institution and context seem obvious. Obvious, that is, given that the World Economic Forum is an institution committed to foster dialogue between a variety of stakeholders (governments, business leaders, media, civil society) for the promotion of globalization and trade between countries and other actors, essentially promoting a varied and culturally diversified version of Western values and economic goals. Differentiating itself from a dogmatic and ideological commitment to free market fundamentalism, WEF[53] presents

[53] Founded in 1971 as a not-for-profit organization, the WEF is a forum whose mission is described as striving 'in all its efforts to demonstrate entrepreneurship in the global public interest while upholding the highest standards of governance' citing its 'moral and intellectual integrity' as evidence of the good intentions of its activities. Indeed, as the international arena

itself as an advocate for a pragmatic blending and balancing between several intersecting interests for the benefit of cooperation between sometimes opposing actors through the integration of 'public and private sectors international organizations and academic institutions'[54].

As a platform, WEF calls upon individuals and institutions of power to make principled decisions beyond their short-term business interests. The umbrella term of the 4th industrial revolution suggests that a new way of managing cooperation in a globalized economy is important. While economies are more inextricably linked than ever, antagonisms at the nation state level have re-emerged. Most WEF arguments suggest there is another way to solve nation state antagonisms. That is to defend and continue promoting the liberal democratic paradigm in global affairs, which regards free market and institutions that support multinational projects as the best way to renew economic growth and foster peace around the world. At the same time, it also articulates through a variety of articles the argument of re-shoring manufacturing and the possibility of countries creating infrastructure in order to capitalize on high value technological or technologically infused products. No longer able to compete with the increasing pressure of mass manufacturing countries such as China and India, entrepreneurship and high value products are seen as an antidote to the lack of industrial growth. Ironically, WEF urges Western countries to learn from innovations and policies that these economies and other emerging economies have successfully applied through a variety of economic and technological projects[55].

---

becomes more unstable, the WEF's importance increases as a meeting place for actors with conflicting interests; it is a place where actors are reminded about the long term viability of the globalized economy and world order.

[54] According to their website, WEF suggests that there are, 'numerous factors combining to make the global environment more unpredictable and difficult to navigate. In global governance, we see the post-war balance between nation states and the institutional framework that worked to manage it disintegrating. In its place, we see the emergence of new geo-economic competition, new regionalism and new actors.' Regarded as a providing a balanced platform, the WEF, nonetheless, is linked to a Eurocentric approach.

[55] See for example the presentation of China's "One Road One Belt Initiative". What I want to argue here, is that the discourse on the 4th industrial revolution by the WEF at Davos and the EU strategy, not only functions as insight and policy papers as briefings, but also as an

Similar to the “Future of Jobs” report published by WEF, the policies promoted under the policy framework EU 2020, should not be seen as a gathering of information about the changes already taking place in industry and the social life, but rather a call for action. They are evidence of directed responses to the changes already taking place. The key difference, perhaps, is that whereas the WEF is seen as promoting the general intersection of interests (closer to the biggest power of US interests), the EU 2020 agenda is a call for the EU to take the lead in furthering liberal globalization, an indication of the ruthlessness and competitive nature of the market economy (and an acknowledgment that not all can win). For the WEF at DAVOs and the EU, the new industrial revolution presents an opportunity to revitalize and restructure the global market economy, with new markets to be created and older ones to be transformed by the cyber-physical systems[56]. Thus, the term is used in an almost identical manner to the original -- that is, the use of upgrades in technologies for significant economic growth. In essence, the type of economy and social organization are tightly linked to such developments. With discussion on inequality being very much at the heart of the debates during an economic crisis, the term ‘inclusive growth’ (WEF 2017) is a milder way of suggesting that growth by technological advancements can be for the benefit of all. The term connotes that class, race, gender divisions can be accommodated into this new round of growth through the application of science and technology in production and a new approach to the division of labour in the global economy. The supposed inclusivity of such a process, is suggested in contrast to arguments that dispute that there can be inclusive growth in a capitalist economy where

ideological frame constructed and communicated through spectacle. It is a call for international actors to unify through the concept of an industrial revolution, where all can win and have prospects of sharing the value created through trade and investments rather than the economic protection now gaining favor both politically (through the agenda of far right and neo-Nazi parties) and in economic terms in many of the traditional economic powers.

[56] Cyber-physical systems are mechanisms which embed software, physical resources and the power of collaboration between users in order to perform complex calculations and tasks such as autonomous mobile systems. They can be found in many areas such as aerospace, manufacturing or even in consumer appliances.

there is a tendency to forge monopolies and increase inequalities through the creation of joblessness.

> Recent research points toward a decline in the labour share of income around the world. This means the proportion of economic growth allocated to wages has fallen – an indication that labour productivity has increased more rapidly than wages. The 2012 Global Wage Report of the International Labour Organization (ILO) found that in 16 developed countries with available data, the adjusted labour share declined from an average of 75% in the mid-1970s to about 65% just before the global financial and economic crisis. It also found a decline in the labour share in developing countries between the mid-1990s and the end of the 2000s, a finding confirmed in a recent study
>
> […]
>
> The increased sophistication and declining cost of industrial robots and algorithm-based artificial intelligence are projected to transform manufacturing and services in a variety of sectors over the next few decades, leading to major job losses in absolute and, quite possibly, net terms. Far from affecting advanced countries alone, this new industrial revolution may upend the traditional concept of the process of economic development. Labour intensive low- and medium skill manufacturing has provided a ladder out of widespread poverty for countless countries over the past two generations (Ibid, p. 5)

Proponents of 'inclusive growth' such as the above, argue that integration and participation of individuals in the process are an improved answer to inequality than a change of the political and economic paradigm. This type of economic growth suggests that seemingly antagonistic views can share the same paradigm, perhaps tolerating different organizing types but within the dominant economic principles. For this matter, the different business and personal stories, images, projects function in a collage manner to give an impression of continuity, a whole that can accommodate each. A group of friends can work their own 3D printer and build a successful business empire while at the same time providing relatively cheap consumer 3D printers. This is the case at Makerbot. An unemployed person can sharpen their skills instead of idly waiting for employment. A company strategically uses 3D printers to shorten the feedback and supply chain by designing prototypes in the office. A garden tool or house fix can be thought through and carried out in the local Hackerspace, with the idea perhaps turning into a successful product. All these seemingly separate and distinct stories complete the collage of 3D printing which in its turn completes the collage of ideas that underpin the term 4^{th} industrial revolution.

The collage created aims at delivering signs and messages to the various publics in a manner similar to what Guy Debord (2002) called 'society of the spectacle'. I look at the 4th industrial revolution as a spectacle that 'consists of signs of the dominant system of production - signs which are at the same time the ultimate – end-products of the existing society' (Ibid, p. 3). The spectacle is 'the visual reflection of the ruling economic order' (Ibid, p. 4) that in the process of preaching its discourse produces media events, news stories, visions, strategies and images. These are by no means fake or non-existent, but their spectacle aspect means that they are detached from context, their place or logic, in order to serve the purpose and context given in the new narrative. The coming 4th industrial revolution is there 'as a separate pseudo-world that can only be looked at' (Ibid, p.2), but also 'a worldview that [is being] materialized, a view of a world that [is becoming] objective' (Ibid, p. 3). In discoursing the 4th industrial revolution 'goals are nothing, development is everything. The spectacle aims at nothing other than itself' (Ibid, p. 4), in this case creating the conditions for another industrial revolution. According to Debord, the spectacle (referring to the 4th industrial revolution) is here to lead the production of present-day society relying on established relations of power, domination and control as they have come to organize under capitalist accumulation. In Debord's (2002) words, '[t]he spectacle is the ruling order's nonstop discourse about itself' (Ibid, p.6); 'the *materialization* of ideology brought about by the concrete success of an autonomized system of economic production' (Ibid, p. 73).

What is, ultimately, the role and functionality of the discourse and spectacle of the 4th industrial revolution as it regards this technological transformation? Debord's (2002) insight into the role of the spectacle as being to establish the separation of 'what is *possible* from what is *permitted*' (Ibid, p.7); in other words, it is to alienate, to distinguish the lines, uses and decisions on how to develop and put into use the new technologies. In the case of the 4th industrial revolution, the political significance of the particular discourse is to alienate its subjects from the possible world of cyborg, bring it a tangible flavor of what is pragmatic, feasible and permitted within capitalism; with the exception of updating the organizational types to correspond to the new digital economy and ubiquitous computing. Therefore, 'the spectacle is not the inevitable consequence of some supposedly natural technological development. On the contrary, the society of the spectacle is a form that chooses its own technological content' (Ibid, p. 6) which its proponents are aiming to project. Rather, it is a constructed narrative in which it aims to predict a self-fulfilling prophecy by influencing the structuring of the upcoming future through spectacle. A slightly different version of this narrative is projected by the EU frameworks.

The financial crisis of 2007 that brought the economic crisis to Europe after 2008 'exposed Europe's structural weaknesses' as we read in the European strategy for smart, sustainable and inclusive growth: Europe 2020, published by the European Commission in 2010. These 'structural weaknesses' are assessed in comparison to the longstanding 'frenemies' -

partners and competitors - U.S and Japan and in terms of growth and the economic measures that signify it - productivity, employment rates, working population. Various aspects of what needs to be done are covered in the Europe 2020 strategy the main purpose of which is a coordinated exit from the crisis that will leave the European Union intact, if not stronger[57].

In Europe 2020, a 'single market for the 21st century' is identified as the primary missing link for the strategy to be achieved. The Single Market has been essential for the construction of the EU, even more than the Monetary Union. Upgrading it for the cyborg world (also known as the world of cyber-physical systems), further unification of space by unification of the digital space - creating a 'free space of commodities' (Debord, 2002) or extending control (Haraway, 1991). In 2010, this was part of the 'digital agenda for Europe' with the digital single market a first priority. After the last EU elections and the change of the Commission, the digital agenda for Europe was renamed the Digital Single Market strategy. The main aspect of such strategy is the creation of infrastructure to allow easy and seamless access to networks which in turn can engage in exchange of goods and services. As a way of keep the economy in touch with the new revolution, digitizing the European industry is measured in ways the market economy can expand and record growth.

> 'The measures to Digitise European Industry will help companies large and small, researchers and public authorities to make the most of new technologies. They will link up national & regional initiatives and boost investment through strategic partnerships and networks'. Further along, the question 'Why do we need a strategy?' is asked and answered as follows: 'For a smooth transition to a smart economy'; 'To prepare the

[57] Some key signifiers that are relevant are: the focus on R&D and innovation through what is called the 'Innovation Union'; the focus on information and communication technologies, data and their regulation in what was initially called the 'Digital Agenda for Europe'; and the focus on industrial policy coordination - 'An industrial policy for the globalization era'.

> next generation of products and services'; 'To boost innovation capacity across industry'; 'To increase the European GDP by up to €110bn/year'. (EC 2015)

The process aims to be able to utilize and merge the forces of production with everyday living. To include living within the realm of production. As can be discerned from the European Parliament,

> There is a need to better and more firmly incorporate social and societal aspects in the innovation process; innovation alone is not sufficient to cope with the key societal challenges in a successful way (Baroso 2009). So far, social innovation and technological innovation have not been linked in a promising way. Open innovation and open source innovation have the potential to close this gap, especially when it succeeds in bringing customers, engineers and others together in a problem-solving discourse. Additive manufacturing can only be successful when workplace innovation finds a solution to organize the human-machine interaction in a fruitful way. 3D printing, especially in the context of Fab Labs, gives a unique opportunity to make young people more interested in and aware of the potential of technologies and to overcome the expected scarcity in qualified workforce [...] Open innovation strategies provide tools to bring together large companies, small and medium companies, public authorities and customers to work out smart specialization strategies. Fab Labs have the potential to combine open innovation strategies and locally committed cooperation between makers, craftsmanship, or cultural industries. (European Parliament 2015, p. 59)

In other words, merging innovation achieved through professional sites with ideas and prototypes developed in delegating the risk of unemployment to individuals while at the same time taking ideas from their work (spreading the risk of innovation to the users rather than paying for it). As a discourse, the 4th industrial revolution functions as an attractive umbrella term under which cyber-physical systems of any kind can be placed. The reason for doing this it seems, is to be able to promote an interdisciplinary field that embedded computing systems (which combine aspects such as the internet, design, architecture, collaboration of different fields of study) can be communicated to the public. The placement of 3D printing under this umbrella signifies that the technology is a vital component in such systems, not only in terms of building cyber-physical systems but also in communicating the vision of integrating the above characteristics. In the following chapters I will show what this means in practice. For the moment it is important to explain why the forces of production discussion is significant in this narrative.

Discussing the forces of production

3D printing is one of those technologies that at times can obscure the difference between a consumer and a manufacturing technology. It has been used in the manufacturing process since the early 1990s, as previously mentioned. Yet its subsequent development once the RepRap project boosted it by launching so many different versions on the consumer market blurred the line between what is manufacturing and what is just creating something. Certainly, the functionality of the RepRap 3D printer is often cited as proof that one can make an object out of a digital file provided one has some raw materials (in this case plastics) and electricity., Yet few are impressed with the quality and speed of the process when they experience it in real time. Building an object through a 3D printer reinforces the ideal of the RepRap, that of a self replicating machine. But essentially what remains for many people after using the process for the first time is the promising prospect of what might be realized in the future. Since the development of the technology does not adhere to Moore's law in the way personal computers have [58], it is interesting that the 3D printing community remains very loyal to the use of the technology because of that beckoning future.

There are differences between industrial e and consumer uses but there are similarities too. In attempting to understand why, I tried to get access to the Manufacturing Technology Centre. Despite the hectic schedule, n February 25th, 2016, I finally succeeded, accompanying a friend to an open night introduction to the Centre's apprenticeship scheme. New cadets are offered the chance to work on confidential industry projects which private sector clients contract the Center to carry out for them. An apprenticeship could lead to a career in a high profile company with lots of exciting hands-on projects. A short presentation explaining the need for such centers preceded what was to be a tour of some of the facilities. We were told that one of the goals of the Manufacturing Technology Center, which opened in 2011, was to provide high quality manufacturing and to work with universities and businesses in order to develop manufacturing that does not compete with mass manufacturing countries, but adds value because of the level of intricacy, customization and specialization.

> As you know, in the UK, we have an economy that needs balancing, and one of the balances is to manufacture things, but not on a mass scale. We understand that technology, and the things we develop there, what Britain is very good at, supporting our manufacturing is what we need to do, and this is what we do here. We identified the skills gap and we built a

[58] Most 3D printing processes and especially the FDM (Fused Deposition Modelling) process which many grassroots organizations can afford, are not dependent on the amount of chips on the integrated circuit. Speed alone has to do not only with the nozzle being able to build layers of the object but also for plastic to cool off to keep the shape of the material. As such other features such as texture, color of the plastic, density of materials or durability are taken into account to compensate for speed. Because Moore's Law is not strictly scientific but also a manufacturing industry indicator, this maybe subject to change in the future.

> center (Aaron, Speaker, Manufacturing Technology Center, Presentation)

As soon as the introductory briefing finished, the supervisors laid on tours to show the machines and explain what was going on. Despite it being “open to guests for the night”, most of the technologies being used on an everyday basis were not shown to us because of industrial confidentiality pacts. We were shown industrial level 3D printers which used a laser sintering process rather than the FDM commonly used by grassroots organizations such as Hackerspaces, Makerspaces or Fab Labs. remaining tightlipped about most of the projects due to non-disclosure agreements with sponsoring companies and/or the type of proprietary facilities, our guides happily pointed out that the software used for CAD models in the facility was open source. In this way even the multi-million-pound project could avail of the free sharing of a software that benefits from a user community. At the end of the tour parents asked about career prospects for successful apprentices as an alternative to graduating with a degree from college or university. What was notable the limited space designated for the visit and the fact that the guides escorted the visitors throughout, including those using the toilet facilities. h, After the tour, there was no wandering around.

On the maker level, it was clear after a few visits that 3D printers are used either as a show for the potential of the technology or a way to repair or upcycle things with everyday objects. The mind-set of not buying but creating the objects is more motivational rather than a lack of resources.

> … on the printer now upstairs I have two functional holders who are at the back of the printer and they were printed on the printer. That sometimes happens with other things as well, if you have smaller things and you want to repair them (Lewis, Interact Labs, Leicester, UK)

Having printed materials for introduction to the technology applies as far as education and understanding of the process goes. However, the issue of functional everyday 3D printing is still not developed to a user- friendly level for newbies – i.e. to the level where new entry users lacking experience might anticipate results.[59]. But, even if one is not yet in a position to print on their own, anyone can conceive of the concept of desktop manufacturing. Desktop 3D printing does pose the question whether 3D printing should remain a consumer tool for crafting or become a force for production. The Hackerspace is a good place to start a prototype or test new production materials that otherwise would need professional services or the purchase of expensive equipment. This approach to production owes much to changes in the sharing culture in the early 990s, when sharing and valuing users as a valuable resource in the production process became an integral part of understanding new business models. Such models run both formal and informal in a decentralized approach, as p2p networks (Raymond 1999).

One of the new ways used to describe 3D printing culture and development through user communities, was through a discourse named desktop manufacturing. The illustration in a section above showed that major publications viewed this development favorably, to say the least, highlighting the power it gave to users to create and combine knowledge instantly using the web[60]. But the structural changes that 3D printing is linked to, that is the decentralized manufacturing of the future, had its cultural roots as could be clearly seen in the Napster paradigm a couple of decades earlier. The music industry in the 1990s had its fair share of confrontation with proponents of file sharing and peer-to-peer networks. The rise of the personal computers and many users with increased connectivity to the internet resulted in subsequent clashes between those who wanted to download their favorite music in a more personal manner whilst the record companies wanted to restrict access

[59] Between 2013 and 2017 however, user friendliness has been increased in dramatic levels as it was one of the main concern of both manufacturers of desktop 3D printers but also of users themselves giving feedback when building their own.

[60] A rather interesting fact I encountered on the field, is that with communities using consumer electronics, the term “users” is preferred to the term “consumers” which seems a more passive concept.

only through officially published records and agents. The Napster culture created an open space for artists bypassed or rejected by the record companies to circumvent their decisions and reach out for an audience directly, making a claim in the market (Mooney, Samanta and Zadeh 2010).
In later stages, the culture not just music but movie sharing as well, including photos and other digital images and files that users felt free to share music files since they could be reproduced at virtually no cost[61]. The expansion of this sharing and direct culture, led to the emergence of “the pirate bay” and further sites all of them dedicated advocates of the sharing culture. These efforts were more than successful. Sharing culture websites became the most visited sites worldwide, paving the way for the formation of Pirate Parties (Li, 2009). By refusing to allow digital content to be thought of as property like tangible products they exerted significant pressure on companies. This was happening at a time the new technology was entering into the mainstream and reaching into the daily lives of millions of people. Admittedly, whilst this p2p culture threatened ‘to turn music into a public good’ (Brionna 2014, p. 397), the music industry eventually proved powerful enough to succeed in mass litigation and lawsuits.

One outcome was that the sharing culture put enough pressure on the music industry to at least adapt to the changing technological developments and cultural trends. The emergence of iTunes and other platforms where companies but also individuals can submit and commercialize their work, provided a new framework for producing music in the new era of distributed information[62]. Naturally, this new form of commercializing intangible products

[61] That is, of course, assuming one had a computer to use and was connected to the internet. The issue of compensation which the companies were so eager to protect, made no sense either. The artist was usually given a disproportionate amount of compensation for their work whilst the companies controlled all the process of publications and media, effectively having total control over the artist and their art. Napster was a vehicle for greater artistic autonomy. Artists seized on it to have a greater say in their dealings with the music industry and more control of the whole process including how their work was being marketed. They were also to realise that it offered a more direct route to reaching their audience, enabling them to avoid all the hassle dealing with middlemen entailed.

[62] The popular platform Netflix is a newer experiment of that same culture of sharing information and files. The industry not only understood the power of streaming and the direct nature of the process, but adapted its strengths to a commercial process. Inevitably, companies also used

gave users and artists the impression that it was a more autonomous process, a tool for circumventing the barriers of the industry and the complicated laws of commercialization. Also, the direct way of producing allowed artists to sell by the piece, uploading stand-alone pieces as opposed to albums or collections. The benefits of such development in a commercial environment are many. Two stand out: the artist can release a track or single and fund the rest of the project; the artist can eliminate artwork they feel fails to meet the standard of their composition or performance (something in previous times that might have been included to finalize the product).

The cultural and technological environment relating to 3D printing takes its lead from what the Napster phenomenon introduced but in doing so has to deal with a mature sharing platforms environment. In the new digital environment however, new laws were created and policy frameworks were targeting in the process which emerged as part of what is called the Internet 2.0 (Mitchell 2013), 3D printing's place in the new "industrial revolution" is not merely about the machine. It is about disrupting the very way business is conducted. It is, about the connectivity of machines through the internet and about the integration of users within the production process. It is ultimately about what Nick Srnicek (2017) has called "platform capitalism", which identified and categorized a variety of different types, from those that capitalize on user data like Google and Facebook by selling advertisements, to those that are attempting to transform industrial process into a leaner and digitally updated version of manufacturing (such as the example given with the MTC above).The permeance of platforms' thinking seems not only to be influencing new business models but also a new way of governance in which old-style monopolies and social democratic style public social services could be managed via platforms. Some platforms seek to establish monopolies. Others target entrepreneurs and users to act more transparently, and not just in information products but in physical products too (see O'Reilly 2011). Whatever the difference, the underlying shared characteristic of such

their legal teams to try to eliminate this revolutionary threat and protect corporate commercial interests.

platforms is to be able to extract value in some form (e.g. from the artist's work) and in doing so to evade sharing as a free and public good.

The software company Shapeways was one of the first to pioneer this new business model by asserting the new organizational configurations and approaches towards the forces of production.[63] The proliferation of the platform style did not go unnoticed in circles of cultural and social theory. Before the dominance of Google and other platforms, in an attempt to understand the changing environment of platforms which at first seemed to offer a way to break free from monopolies, social movements theorists had their own take on what they called the 'social factory' (Hardt and Negri 2000; Gill 2008; Thoburn 2014). Accepting that production had escaped the factory gates, the ''new social movements'' theorists tried to make sense of what the new forces of production allowed them to create. In Fabulous St. Pauli, one of the main sites for this study, the local Fab Lab was combining social struggles about politics of the city with the practical side of 3D printing. Not surprisingly, since the users of the Fab Lab come from a variety of backgrounds within industries, they downplay the possibility that a Fab Lab can replace, at least for now, the enormous industrial centers of production. They try to use the Fab Lab and the technology to generate discussion of what kind of industry is needed and who should set the direction of the industry at the moment[64].

---

[63] Founded in the Netherlands but since moved to the heart of New York City, Shapeways created a platform upon which users can upload designs. It allows the users to either buy printed objects from them either having the design or buying one from the marketplace available to them, a just-in-time service. It started as a spin-off of the Dutch incubator ''Philips Lifestyle'', part of the famous Philips company located in Eindhoven, Netherlands. The relocation rationale was that the company needed to be where the customers or users are. Moreover, the platform needed to think more in terms of business terms after receiving an initial investment of $5 million in London, with Philips, Union Square and Index Ventures becoming shareholders. Being close to many small-to-medium size organizations (businesses, academic and research organizations) was essential to grow as an e-commerce company, whilst the platform style gave the company an opportunity to work with freelancers and designers who saw the platform as a potential step towards reaching audiences and competing with their ideas in the market place.

[64] To questions such as what should be produced, how and where manufacturing of goods should take place, Niels, a prominent member of the Fab Lab, stressed framing as important to what they do at the Fab Lab. He was skeptical about suggesting the Fab Lab could in essence outgrow the industry, but saw it as a reference point, as a signifier to contextualize thinking about the problems of the city in political terms. Resilience, he remarked, was the concept that

A 3D printer is a significant advancement that can be part of this new technological environment, both in terms of industry but also in terms of giving civilians and communities the ability to cope either with emergency situations in the short to medium term (such as the Fukushima incident) or a move towards a different production model and objects in the long term. A general discussion during the first days of my visit was whether or not desktop technologies such as 3D printers can be considered as forces of production. As a concept, Niels argued, they should be regarded as such. But the early level of development deems their status still unknown and their importance in this new technological landscape very ambiguous. As a design tool for industrial settings and grassroots communities, appreciation of 3D printing abilities depends on whether the machine is designated for industrial or consumer purposes. Industrial 3D printers tend to be larger in size, experimenting with different materials and processes while consumers usually utilize machines based on the RepRap model, using an FDM process and plastic material.

While industry searches for ways to utilize the technology for shortening the supply chain, grassroots communities experiment with installations, prototyping and cultural imagination. As the industry needs input from users and individual artists to use platforms, expand the reach of design networks and improve the 3D printing quality and experience, the grassroots organizations are interested in keeping these tools as open as possible. The industry needs the labour and imagination of users. User communities and artists need the capital intensive infrastructure that the industry can accommodate. As a force of production 3D technology favors closed systems. As a consumer technology, the preference is for a variety of open systems to create and add on commons. At this conjuncture, it seems that this quasi-alliance feeds upon the needs of each other. The result is a variety of open software, hardware and platforms but at the expense of industry

---

stands out for him. Not decentralization per se, but whether the machines are portable or can cope with adaptation, shifting from one kind of production to another and how quickly. This will be further discussed in the next chapter.

exploring new ways of selectively closing off systems in order to generate markets and future profits.

Utopian narratives in perspective

No matter how 'revolutionary' 3D printing is for many users on a personal level, politics are not conceived in terms of political engagement with issues, but rather in terms of what the technology allows the user to access and create. In contrast with participation of the public in science and technology policy in the 1970s and early 80s, participation and access to science and technology now has to do with the practice of individual and other actors[65]. This was evident in the many spaces I visited. For example, I received no positive answer when I asked about the radical science movement that has been relatively successful in the U.S, in the U.K. or in other European countries. This has to do with the lineage of the movement. As Soderberg (2013) suggested, the open hardware movement (which runs parallel to the Makers movement), cannot be understood without taking account of the history of the open software movement. Fred Turner (2006) traced the open software movement's influences back to the countercultural roots of the hacker movement. The three movements here may not be the same, but they do share similar and overlapping roots.

Understanding the culture projected by the "*Homebrew Computer Club"* and the personal computer revolution (Levy 1984) is important when it comes to understanding the motivations behind the users of newer technologies like 3D printing. A predominantly middle class movement with ties to the military industrial complex through professional and other links, hackers took an unconventional approach towards sharing information and skills because they objected to the new barriers that were introduced in the new technologies. They engaged in politics not with manifestos and policy making within bureaucratic institutions but rather in a hands-on fashion, politics with a small 'p'. In contrast to the 'radical science movement' of the

[65] The general sense was that older generations in user communities were generally unacquainted with progressive politics of the past on issues dealing with science and technology. This history however has not passed to younger generations.

1960s and 70s (see Bell 2013) which was active within social movements and the labour movement, hackers' politics that had to do with finding ways to complete the tasks they wanted needed to complete[66] rather than building massive movements and engaging in political confrontation[67]. Similarly, and in continuation with the tradition of hacker politics, the motivations behind the personal fabrication machines as Niel Gershenfeld (2006) put it, were more aligned with the access and use of the machines on the personal level 'the inspiration wasn't professional; it was personal' (Ibid, p.7). People were not motivated by politics within the professional production sphere, but rather the sphere of play and experimentation, on an individual level of aspirations.

With a few exceptions where some politically inclined groups have adopted the community workshop style, politics, for the vast majority of such workshops are not a subject to be brought to the table while waiting for a print to be completed. But despite politics[68] not being an attention-grabber among most users, issues that can be politicized are. Makers are a culture that reflects upon itself. They make comparisons to past technologies - how developed they are now, whether the early aspirations were fulfilled. It is a culture that welcomes what is possible with new unpredicted ways of technological developments, usually filled with imagination in early stages. There is a collective memory of hackers' culture and their aspirations for new technologies. One example of discussions that arose frequently (often on open nights) during my fieldwork as a member of the Leicester Hackerspace[69],

DP: 3D printing's development resembles what was 2D printing in the early 80s

---

[66] For example, finding ways to give access to a patented software to those who had no access.

[67] For example, demanding internet as a basic right of access to information

[68] Referring to traditional parliamentary and class struggle politics.

[69] Open hack nights are usually organized once a week for people who are not members to visit the space and ask questions, wander around and become members if interested. Because they can be just as tiring as exciting most spaces reserve just one per week so that the members can work with peace of mind during the rest of the week.

GR: Yes, I remember the dot matrix printer in the early days but I do not reckon a culture around it. We were waiting for ages for a print.

LS: Isn't it more like the computer culture, in the sense that a distinct culture of opening machines, reworking them when not functioning or upgrade according to needs, instead of just waiting for its development?

GR: Yes, you are right

They try to compare not just past but different available technologies - how people felt and what was expected of the future to come when new technologies were introduced. This is common given that the hacker and maker culture[70] is not only deeply committed to building and creating software and hardware, but is also in discussion a very future oriented culture. It does not necessarily mean that individuals have negative views on the market economy, but rather as practical people they like to point out the weaknesses of not delivering according to expectations. In the case of 3D printing, many makers were excited at discovering a new technology, that could alter the way things are made from start to finish. Users of the technology were more enthused and eager about what the future holds with this new technology than about what it could presently achieve. This preoccupation with utopian imaginaries was evident in mainstream media approaches to industrial 3D printing as it was among the open source 3D printing community. If mainstream media utopian imaginaries were used to attract investments, in the case of the community, utopian thinking and imagination made users stick around despite the slowness of the process. Quite a few users joked or complained about how time consuming the 3D printing process is; imaginaries served as the glue process, the ritualistic attitude that would keep users tied to the technology.

The expiration of specific patents allowed Adrian Bowyer, an engineer from Bath University, to use open source technology to create the first open

[70] Despite being closely linked to the hacker culture, the maker culture is not the same. It is a fusion of the hacker culture and the older, more multi-layered DIY movement with its distinct origins that touch upon the first but in aspects and not on the whole.

source 3D printing machine. But why would he use a political narrative to promote this machine? The important issue here was the RepRap use of a political culture to attract attention to his project. He applied the term "Darwinian Marxism" to explain his position on what the new technology would be both in technical terms and also in social and economic terms. The Darwinian part referred to an evolutionary understanding of society, whereby technology aids social change, not by political struggle through parliament or trade unions, but through evolution of practical inclusive machines. The Marxist part, referred to a narrative that desktop 3D printers as a force of production could be owned or controlled by those who work them.

> self-copying and evolving RepRap machine may 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. I have decided to call this economics Darwinian Marxism (Bowyer 2006)

As Johan Soderberg (2014) pointed out, this line of thought was in alignment with 'a long tradition of utopic engineering thinking, where the market is expected to soon be rendered obsolete by the progressive application of human reason to nature'. It was also a line of thinking that was popular earlier in the twentieth century; because economics poses as a science based on scarcity, the story goes, once the problem of scarcity was solved by the development of the forces of production, then the markets would be fundamentally deemed obsolete[71]. In my attempt to understand this line of thought from the open source developer's perspective, I reached out to developers. I emailed Joshua Pearce, a leading academic on the development of open source technologies at the University of Michigan in the

[71] There are varying degrees of this narrative, but the general premise remains that markets, without the mediation of the state favoring monopolies, would be the free exchange by producers

US, to ask what is different with open source 3D printing from other new technologies. His response repeats, perhaps more precisely, what has already been mentioned by others,

> RepRap 3-D printing in particular offers the promise of real distributed manufacturing being able to create high value products including the means of manufacturing itself. As this means of production and a great number of designs are already being shared freely it offers a fundamentally new economic paradigm of abundance. (Joshua Pearce, email conversation)

Every once a while, someone, usually an older man, would recount his experience of manufacturing jobs, of the joy of making things as well as being in a job that allowed social mobility into the middle class. In this respect, the Hackerspace could be seen as a practice of nostalgia looking to a past that faded with the widespread loss of industrial jobs. But aside from the few, the majority of the young, dynamic audience lacked this perspective never having experienced it. This lack of social historical memory, according to field experience, points to the direction of the Makers movement. Moreover, it signals different origins than previous movements, despite the fact that the technologies and even some narrative ideals were similar. This new movement is profoundly individualistic, even when celebrating collaboration. There was no shared vision of the future, no shared social goals. For the most part, the new movement saw new technologies like 3D printing as a way to expand individual options in entrepreneurial activities. The big mass manufacturing factories of the past that gave rise to a class of people who identified with each other is no longer the dominant way of identification. Instead, 3D printing narratives, for the most part encourage individuals and small groups of people to use the machines in order to fulfill their dreams. Whatever the different methods and ends, the narrative of the big powerful corporations against the small groups of people trying to provide remains. Joshua, in this respect, was very aware of the past movement and its fate. I ask him whether this new movement resembles in any way earlier attempts to appropriate science and technology for the masses.

> Yes - for my own work it is hand and hand. RepRap is an OSAT - it will allow people to pick themselves up and solve their own problems with a technology that allows them to remain in control. The 1970s AT was meant primarily for the poor in the developing world and got beat out by big money winning over development projects. This time around open source 3D printing is beneficial to everyone developing and developed world alike so we can all pull together [...] Open source 3D printing however really challenges the entire legitimacy of the whole IP system. (Ibid)

Joshua's explanation made sense in the context that the barrier between people having control of their everyday lives is the lack of having open source machines. By having a RepRap then the responsibility falls on individuals and groups to make arrangements to solve their own affairs. This line of thought, although from a different original perspective, is similar to the power to the individual strategy, making it popular to capitalist and mutualist narratives at the same time[72]. Adrian Bowyer's concept of "Darwinian Marxism" may not make much sense to a sociologist or political scientist, but it resonated well with hard science people and designers, who saw a liberating narrative in this. The concept although referred to as Marxism, is more akin to a more populist view of capitalism, where small property owners and groups of people can circumvent the power of big corporations, the type of narrative that could also be seen during the 1970s.

[72] Utopianism that is associated with engineers, usually entails a mixture of both capitalist and mutualist narratives to some degree.

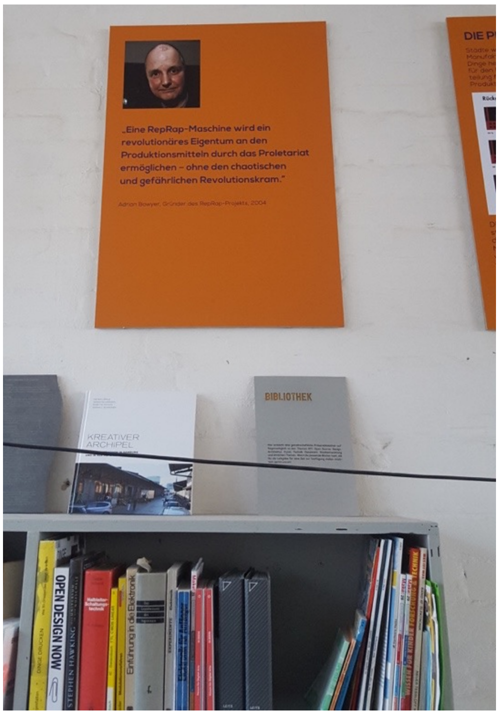

Figure 7 Adrian Bowyer and his Darwinian Marxist concept inspired Fabulous St. Pauli members, enough to earn a place on the wall in the middle of the workshop.

James Albus's 1976 book "People's Capitalism" was a characteristic example. Albus used a popular 1950s Cold War meme that was used to imply that America could achieve freedom and a classless society with capitalism as opposed to the Soviet system (Castillo 2010; Hixson 1998). The central tenet in his argument for people's capitalism was Jeffersonian Democracy, meaning that 'ownership of the means of production should be widely distributed amongst the electorate' (Albus 1976, p. 2). He deemed that it would be possible in a post-industrial, post-scarcity society to 'distribute dividends from high technology robot factories on an equal per capita basis and the rest of the economy would be a fair game for competition' (Ibid). Albus, gave a very accurate example of what the RepRap project would proclaim almost 30 years later. Specifically, that the application of computers to control most industrial production will generate new types of machines which will be able to reproduce themselves, generating wealth without humans.

In any case, the RepRap project could use 3D printing technology to distribute manufacturing in such a way as to resolve conflict about the emancipation of human labour. Taking from biological imaginaries as the name suggests, the Darwinian Marxism of Adrian Bowyer served to pass two basic ideas. First, Marxist rhetoric served to signify that inequality is a problem and that now having the means for everyday reproduction of ourselves, deems us powerless against the mega-machines of the factory owners and other capitalists. However unpopular during the mid-2000s, the use of the term Marxism seems uncover much about Bowyer's generation narratives. Secondly, the term 'Darwinian' serves to signify a concept that the vast majority of the scientific community and establishment can agree on: that evolution is a basic characteristic of whatever understanding of nature one can ascribe to.

In this sense, Bowyers' attempt to marry the two concepts into one and create machines that could create the narrative tackling both inequality and follow the nature path of replication, is a grandiose cause. Since the 3D printer could print almost all its parts and could be distributed amongst the masses, there is a good reason why this type of narrative became popular. Replicating nature, giving the sense that this is not a logical path but also the natural one; indeed, this is where the name came from, as RepRap meant self- Replicating Rapid prototyper. Unlike the pro-capitalist argument made by Albus in the 70s, Bowyer's vision was closer to a leftist idea of alternative industrial production based on cleaner and safer technology. One that would allow autonomous production places to be linked through a series of peer-to-peer networks (Bauwens 2005). Not surprisingly, when the community started entering the mainstream, this idea that was shared amongst the initial circle close to the inventor was dropped for milder versions. The maker community promotes itself as a noble political vision to those whose interests extend beyond the technology to the social effects. However, the Marxist narrative seldom features when it comes to the practical aspects. This milder (to the Marxist centralized command economy) vision of an economy based on p2p networks resonates with the concept of autopoiesis, which we will discuss below. As the technology and the maker scene exploded into the mainstream, the narratives being used were closer to other cultural interpretations of the phenomenon.

Naturally, because the maker community is building on the idea of 'geek public'[73] (Kelty 2008) and not a specific community with unified goals and visions, there were spaces that accepted versions of this vision, if only in part or not at all. Each space seems like an island, a republic of its own. And, while the legal framework that governs their existence is country specific, the internal rules and visions of the spaces are completely dependent on the shared visions of those who run them. The walls of Hackerspaces are usually visual signifiers where one can find hints at what the creators and users of the space are interested in. As such a variety of names decorate the walls of spaces such as Nottingham Hackerspace, where the ability to modify and re-appropriate technology is dominant. The place is heavy on space factories, science fiction imaginaries and the playful joy of making stuff. Some point up initiatives such as the blog Boing Boing, the culture that the space represents, or the influence of people like Cory Doctorow, the science fiction writer whose interests intersect between post-scarcity economics and the maker's movement. Science fiction is not only an interest, but also a practical genre that gives inspiration to the members and users of the technology.

[73] See Christofer Kelty's (2008, p.3) defining explanation 'A recursive public is a public that is vitally concerned with the material and practical maintenance and modification of the technical, legal, practical, and conceptual means of its own existence as a public; it is a collective independent of other forms of constituted power and is capable of speaking to existing forms of power through the production of actually existing alternatives'

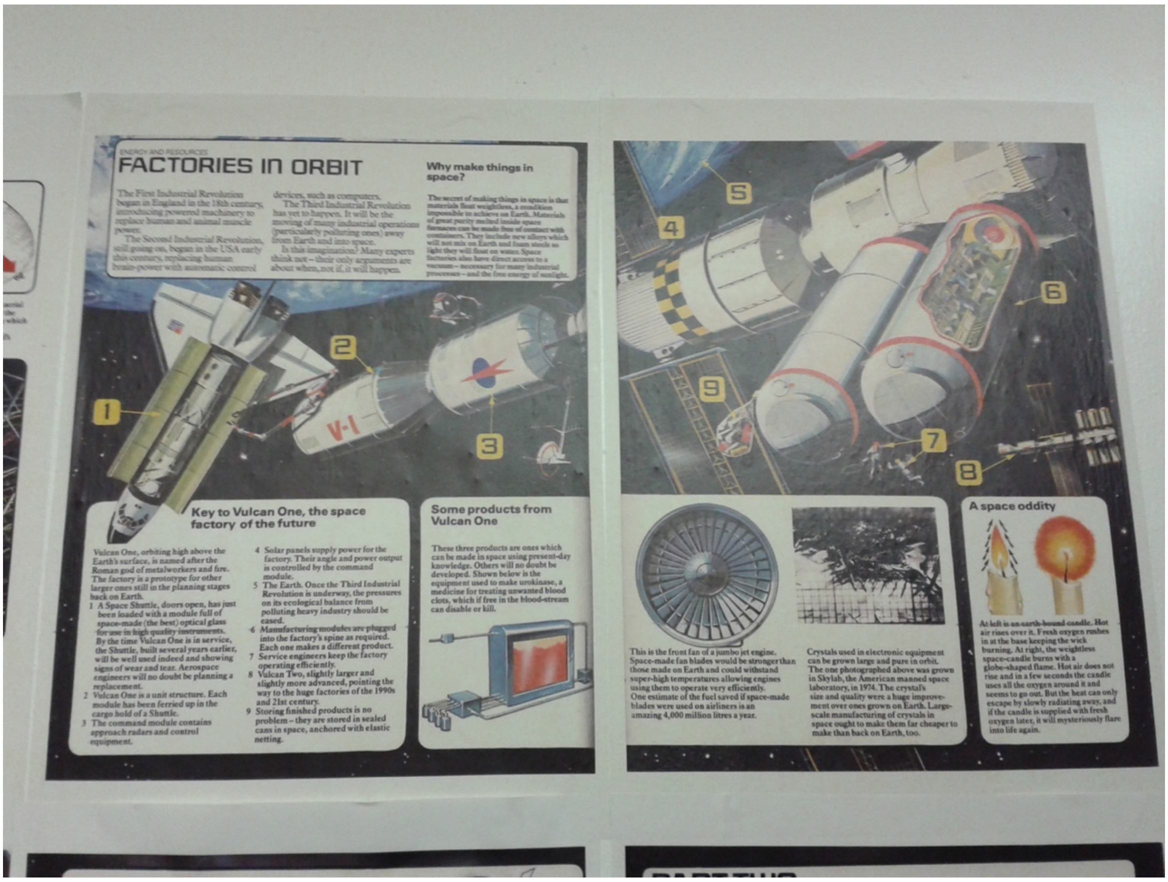

Figure 8 Nottingham Hackerspace hosts on its walls utopian comic images of manufacturing in space, signifying the culture of utopian thinking of some of the users of the space. 3D printing is a source of imagination for space manufacturing. Photo Credit: Leandros Savvides

Everyday Science Fiction

The utopian aspirations of popular culture have also stirred some imagination at the grassroots level. During my visit to Hamburg, I met at Fabulous St. Pauli Johnny, a 13-year-old who was living nearby and spent a few afternoons each week at the Fab Lab. Johnny had a YouTube account with quite a few followers, with whom he shared his newly learned skills in software and hardware and his fascination with creating things. Like many of his peers, he was very much into sci-fi culture through a variety of popular culture mediums, especially cinema. The day I met him he told me that he saw “Elysium”, a science fiction movie in which exoskeletons were used by workers to do difficult and heavy tasks, in a dystopian near future in which the advancement of technology did not liberate humanity. Ironically, in the movie, workers were using exoskeletons to create robots to supervise and control them at work and in everyday life. But aside from the cultural critique, what intrigued Johnny was the exoskeleton of the main character.

Portrayed by Matt Damon, the character, after an accident at work and suffering a terminal health problem, used the exoskeleton not to build control robots but to transport people of the underclass from earth to a high tech space ring orbiting the earth where the rich had migrated to to escape their overpopulated planet. The Damon character's experience has changed his attitude towards unjust laws and motivated him to join a team of outlaws bent on bringing members of the underclass to the ring for free health care. Inspired by the exoskeleton, Johnny, learned the open source program "3D inkjet" and started printing his own exoskeleton. The cultural impact of science fiction in everyday activities is sometimes explicitly straightforward. At other times it may take other paths be it in shapes, ideas, aesthetics, premises or otherwise. In this case, a 3D printer ecosystem (3D printer, open source software, Fab Lab, internet, online communities) made available to a teenage boy allowed him to creatively express himself and satisfy his curiosity through learning. As the parts for creating the 'exo-hand' were not freely available or available in cheap price, he decided to use a glove in which the 3D printed parts were going to be tied on the glove. His goal was to build the exoskeleton hand and share it on his YouTube channel for others to replicate. After the various responses, he would take feedback on how to make it even better. As this would be a lengthy process, he used the time o start other creative endeavors on his laptop as well trying to explain to me in plain language how all these work. From time to time, the uses of technical language unintentionally made him rethink how to best explain to an outsider just as one would expect from a professional talking to a user.

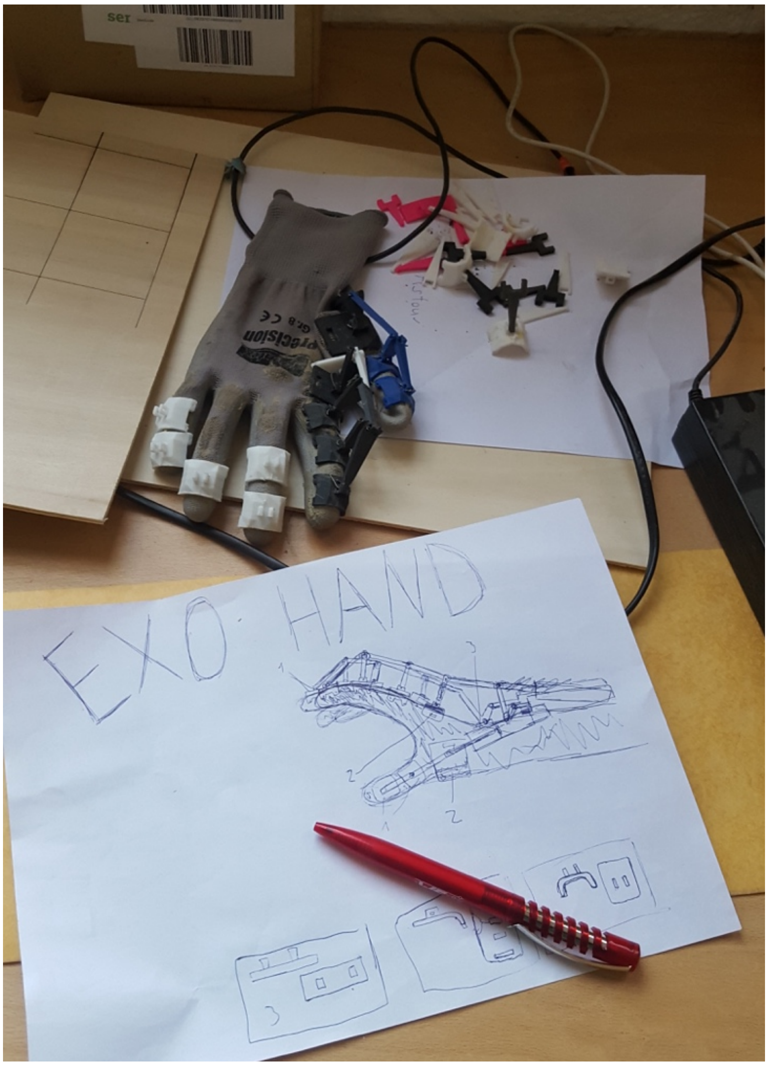

Figure 9 Still in early stages, but the power of imagination seems to be a primary motivating factor at least for younger users.

Johnny's generation, born around the start of the new millennium, was not the only one who used imagination to predict and play with the future. It seems that each generation (especially during the consumer cultures of the 20th century) has its own aspirations, its own goals and visions of what the future holds, often tied to the broader context of popular culture and imagination. Earlier generations which grew up after the Second World War, responded to the centrality of the military industrial complex and the security language that prevailed with everyday technologies and appliances being integrated into everyday life. Imagination was not only filtered by the audience but government programs and television were actively promising a future with flying cars and automated cities. These preoccupations were mirrored in popular magazines and in marketing with images and stories of an imagined future where 3D printed robots take all the jobs and 3D printed cities would become a reality on Mars in mere decades. In an essay, David Graeber questioned the future of the 50s, 60s and 70s that never came. Where are the flying cars, where are all these technologies that would liberate humanity?

> A secret question hovers over us, a sense of disappointment, a broken promise we were given as children about what our adult world was supposed to be like. I am referring not to the standard false promises that children are always given (about how the world is fair, or how those who work hard shall be rewarded), but to a particular generational promise—given to those who were children in the fifties, sixties, seventies, or eighties—one that was never quite articulated as a promise but rather as a set of assumptions about what our adult world would be like. And since it was never quite promised, now that it has failed to come true, we're left confused: indignant, but at the same time, embarrassed at our own indignation, ashamed we were ever so silly to believe our elders to begin with.
>
> Where, in short, are the flying cars? Where are the force fields, tractor beams, teleportation pods, antigravity sleds, tricorders, immortality drugs, colonies on Mars, and all the other technological wonders any child growing up in the mid-to-late twentieth century assumed would exist by now? (Graeber 2012)

Imagination, thus, of a future to come is not a new phenomenon. The high-tech industry is using such imaginations to keep tension and expectations high and to offer the people a beacon of hope for a future drawn by their inspirations. But in the context of the culture emerging after the maker publics developed, the science fiction genre, created to imagine future and other worlds, today looks more like a marketing campaign. It gives the impression that the accumulation of objects and narratives serves as an excuse for the creation of commodities embedded and presented as culture through a variety of media such as cinema, posters, toys and the like. After Graeber saw the undelivered future of his generation childhood dreams, he warned of this bubble and if the new generation would also fall for false promises. The marketing techniques drawing on science fiction usually expand on the possible in order to project fears and hopes, political narratives and existential threats. By definition, a machine that aims at altering material components and turning digital files into objects, biological tissues or even cupcakes has an element of science fiction. Not only because such technology is at the moment at least theoretical in relation to what exists as accessible to the public, but also because there is an illicit understanding that renders such technology as deterministic, as an evolving infinity where the audience remains in awe, its actions limited in fulfilling this deterministic future.

For policy makers and popular culture elites, there is a twofold character of science fiction: one, to either make familiar technoscientific projects that are already taking place; two, to make a literary or political point. Such is the power that can be unleashed with certain technologies, as is evident in 3D printing. The popular imagination surrounding 3D printing went far beyond the fans of science fiction movies, but the cultural references made a significant impact. One of the most powerful images representing the image of a 3d printer was the closest image of the Star Trek replicator, the machine that could fabricate the composition of materials on command. It is no coincidence for example that Makerbot named its desktop 3D printer a “replicator”, a move that aimed at capturing a science fiction feeling and integrating it with its own commercial machine.

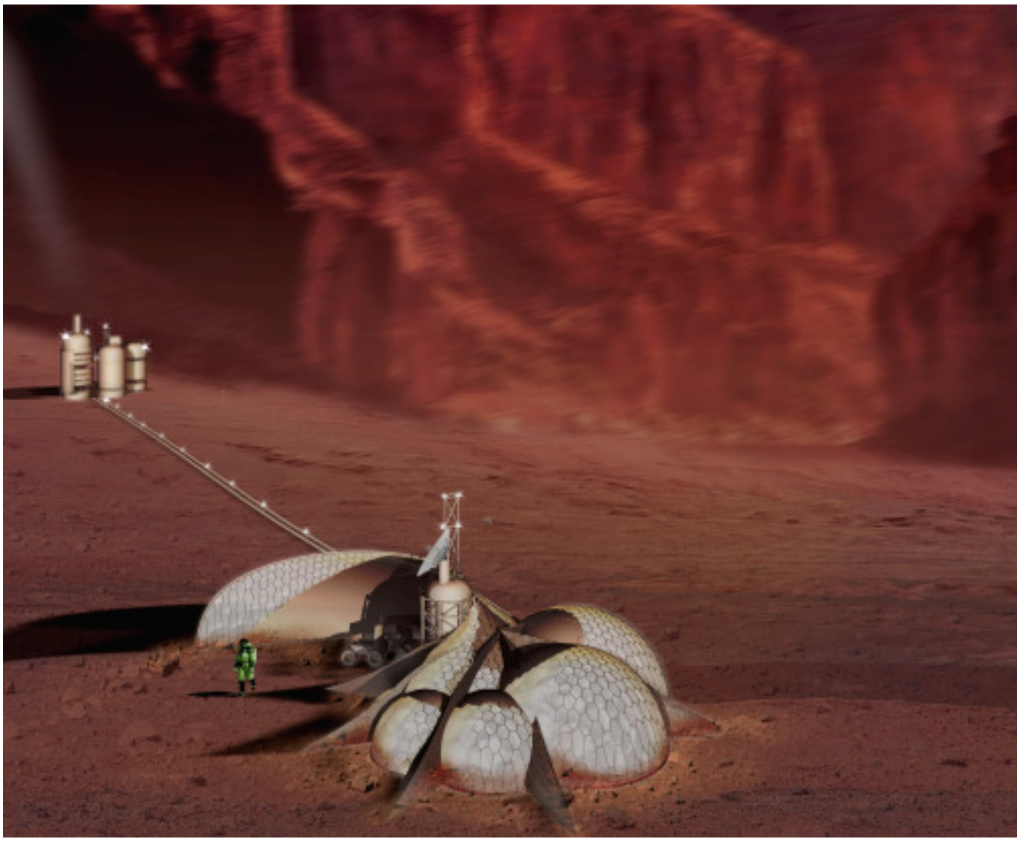

Figure 10 Marsapia, a 3D printed habitat design on Mars, for NASA 3D print habitat design challenge Source: 3D Printing challenge website.

Besides the cultural references about the lone entrepreneur on his desktop machine, the rebuilding of the nation through 3D printing manufacture and the changing nature of the relationship of the user-producer, there is a stronger imagination being projected, mostly among the technological columns, which at times plays with existential issues for humanity. In the 1990s the everyday popular science fiction questions were about The Genome Project and the "Biotech century" (Rifkin 1999). Today's everyday science fiction includes exploration of other planets and space, building machines of existential value to humanity, 3D printed exoskeletons for people that have been injured in battle, or want to upgrade their bodies, matter that knows how to think, and even printing humans in outer space (Neal 2014). By harnessing the power of the imagination of the users, even government agencies such as NASA have started campaigns and national programs where they ask to 'turn science fiction into science fact'. Such adaptations of the cultural imagination into concrete scientific inquiry show a blurring of lines between reality and imagination which incites experimentation and participation in scientific projects outside the work environment. Not only outside the narrow walls of a laboratory. Children and teenagers and younger, are emerging from this process as equal thinkers and problem solvers alongside the adults. Meanwhile, with a push start of such imaginations, government agencies as well as companies are instilling doses of fantasy and playfulness in shaping opinion, directing people to science careers and attracting capital investments to encourage and allow g ordinary people to participate in this process.

Material ideas: Between Art and Science

Having discussed the generative narratives that give shape to the 3D printing universe, it is time to explore the characteristics of the technology that give context to these grander ideas. A question that was always of interest was if 3D printing is a technology unlike any other, what are the characteristic that differentiate it from the others? Without a doubt, many inexperienced participants (others too) are taken with the concept of ideas being materialized through a medium.

> My first encounter with 3D printing was watching it on YouTube around 2013, then I saw it live at Cambridge Makerspace. It was a Makerbot replicator 2. I must say it was an extremely interesting concept to me, because an object was created by a machine without the human hand, that was not there before. It is a technology that is not familiar to me. If I can say that most of the machines in the Makerspace introduced to me were so intricate that they needed an experienced person, whereas this was something more familiar, controlled by a desktop computer and did not need supervision all the time. (Mario, Cambridge Makerspace)

For a philosopher, such as Mario, the concept of a material object to create a material object without human intervention opens up a whole new category for thinking; a grandiose moment. This is not to suggest that the user is not aware or minimizes the importance of human interaction in the design[74]. There is always that ecstatic moment the design is finished and the print button is pushed when it is as if we were watching the material giving birth to its own kind. Conventional technology until now, insofar as it helped human muscle or the mind to create something, related and responded to muscle or mind. 3D printing is one of the technologies that does not ascribe to this analog environment. It moves beyond the muscle and mind dichotomy and becomes a combination of both. It is software as it is hardware. Mario's first print for example, was a downloadable design from *Thingingverse*, then an open platform for RepRap users.

> We downloaded a design and then put it up for print. We inserted the material to the extruder and that was it for us. I watched the object for 25 minutes with fierce passion. I was extremely impressed. For the first time, I saw materials working other materials. The technology pushes you to rethink certain issues that seemed to be sorted out in the past. What is a material? What is it with respect to philosophical concepts? (Mario, Cambridge Makerspace)

The moments he watched the print become a reality, effectively ended the certainty of answers to issues that Western philosophy for one had stopped debating for years. After the human intervention is needed to sort the codes and insert the material in the extruder, the act of watching an object emerging from a 3D printer, is a ritualistic experience. It also gives the impression that that machines are no longer straightforward tools, created just to mimic human movements, which can now take different shapes and styles of producing. Unorthodox geometry, software-induced imagination and creativity shape the initial door to a new vast universe that users are now only beginning to explore. It can bring ideas into matter and the other way around

[74] We discussed jokingly many times how algorithms design on their own for their own sake

in ways that humans see in nature, but do not necessarily identify for doing themselves.

Following the non-conforming nature of 3D printing to the dichotomy of ideas and matter, conceptualization and then practice, the process draws more comparisons to art processes than ever before, stimulating the users' creativity endeavors. For this reason, the cultural industry has been aware of 3D printing for quite some time. The changes in thinking and methods of producing promised inherent in 3D printing have not gone unnoticed. What does this mean for cities where industrial activity has moved on, where the concept of the factory has changed, where information has become a valued precious commodity? This is evident in a London exhibition that proclaimed:

> The boundaries between designer, maker and consumer are disappearing with a growing movement of 'hacktivists', who share and download digital designs online in order to customize them for new uses. In a highly experimental move the exhibition houses the first 'Factory' of its kind where visitors can discover how 3D printing works and witness live production. (Newson 2013)

In grassroots organizations such as Hackerspaces and Fab Labs, there is a strong cultural reference to art. Much of what is done in those spaces are hacks, that is clever ways to circumvent the original design or planned obsolescence of an object. Chris Kelty (2008 p. 182) specifies,

> Hacks (after which hackers are named) are clever solutions to problems or shortcomings in technology. Hacks are work-arounds, clever, shortest-path solutions that take advantage of characteristics of the system that may or may not have been obvious to the people who designed it.

Indeed, because of the nature of the activity that is being carried out in such spaces, those activities require imagination and a break up of standard scientific procedures that apply in institutional sites. In St. Pauli, Niels argues that this feature is something that can be politicized, to confront the rigid thinking that holds technology and art are distinct and even opposing activities. He suggests that, contrary to such thinking, technology and science require a fundamental element of art.

> We have to break from thinking that art is only about painting and sculpture and old matter, and technology is about nuts and bolts and transistors, hard metal stuff and they have no connection. (Niels, St Pauli, Hamburg)

Figure 11 Joseph Beuys is an inspiring figure for Fabulous St.Pauli. His philosophy of humanistic and artful production of objects through the concept of "Gesamtkunstwerk" resonates well in circles where art and science can be intertwined and ultimately political.

Indeed, art, as well as communication and meaning is everyday practice using 3D printing. For artists Morehshin Allayari and Daniel Rourke, 3D printing as it is understood today represents a possibility for empowerment and addressing the problems of modern society at the same time. A metaphor to transcend both concepts of utopianism and dystopianism, they use 3D printing to explore the boundaries of the digital and the physical which concern our age. As Daniel explains, what they do not like about 3D printing is the speculation of liberatory narratives viewing the 3D printing hype similar to what happened with other technologies in the past. They are not interested in a utopian future as proclaimed by various forms of 3D printing futuristic visions. Instead, they use 3D printing to hit back at mainstream dreams and expectations.

> We were both frustrated with the discourse where the radical had become co-opted by Wilson liberator gun[75]. If anyone talks about 3D printing its not only that is the first thing they always talk about, but that became the symbol of what was radical about the technology. And it is so simple, so violent how the media portray this. It is ridiculous as it is simplistic. (Daniel, 3D Additivist Manifesto, Interview)

Morehshin's previous work "dark objects", I am told, dealt with objects which were either banned or taboo in her home country, Iran. By merging two objects with such qualities, she created new surreal objects. As new objects were forged, the artists wanted to open up the discussion on what they were and why these objects carried such meanings as well as how they could be broken and opened up for new interpretations. Since the new objects' status was undefined, questions arose leading to a discussion about the subjects. In addition, along with a 3D printing component, the objects had a peculiar presence. Objects that were illegal to transport across borders in physical form, could be allowed to move easily in other forms. Suddenly, a USB stick

---

[75] The creation of a 3D printed gun by libertarian gun activist Cody Wilson reflected institutionalised fear against 3D printing. Whilst the general claims of being able to print a gun were legitimate, in the US any individual could buy or have easy access to a semi-automatic weapon. The hype created around this story, seems to have broadly benefited 3D printing as bad publicity nonetheless advertised the technology.

with files of designs flowing into computers could subvert the border control when physical objects could subsequently emerge through a 3D printer. What the artist stressed was that this type of flowing physical objects from the digital form to the physical and vice versa, was available for mass use.

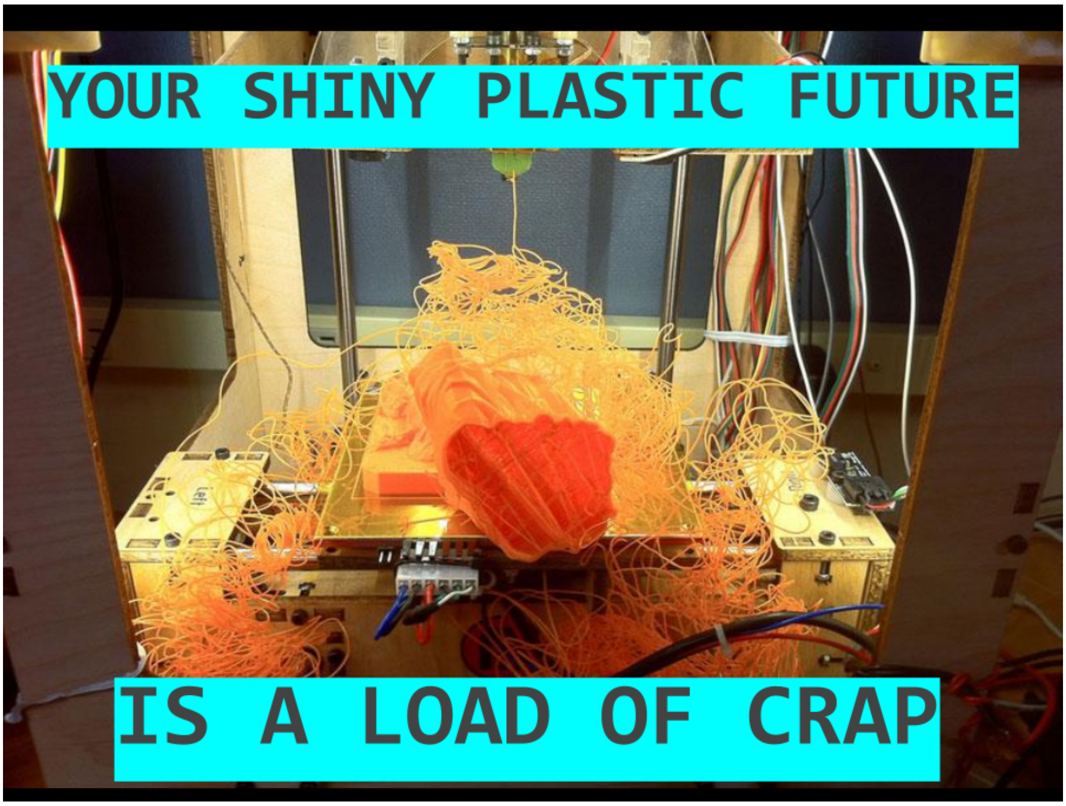

Figure 12 #Additivism, post by Daniel and Morehshin on Instagram, raises issues against mainstream utopian thinking.

In the art project “3D additivist manifesto”, Daniel and Moreshin became fascinated with the idea of co-producing along with “many other people”, a 3D print cookbook. The idea came from the Anarchist Cookbook written in the 1970s by William Powell. The purpose of the book was to give dissidents knowledge about how to manufacture explosives, rudimentary telecommunications and other objects and elements as a protest to the Vietnam war (Powell 2013). Although criticized by anarchists, and despite the Powell’s turn to Anglicanism (thus deserting his previous ideas) within a few years, the idea of a politically motivated cookbook was born.

> We can gather all those objects that are out there, and gather them here in the cookbook. So the initial idea was to collect objects. But as we were thinking about

> the project, we thought we did not just want to collect them, but we wanted to call for objects (Daniel, 3D Additivist manifesto, Interview)

Eventually, Daniel says, the cookbook could be a good tool also for tutors at schools and universities in order to engage in critical education. This is meant to combine creation with technology while at the same time critically discussing the issues of creation. This could be a radical act. With the Additivist manifesto they tried to create a project similar to the Anarchist cookbook.

> If me and Morehshin were in the 1970s, we would probably have written a manifesto for the photocopier. [...] We have this industrial level technology that has been around for a long time by the 1970s it has been co-opted by business and it first started to trickle out into the high street. When it comes into the high street and it becomes user level, that is when it starts to become radical. People used the photocopier to produce punk zines and political pamphlets and to copy books from the library and distribute them. The Anarchist cookbook was possible because of the photocopier that passed it around. The potential of that technology was only exposed when it met the people. The question for us is that: The 3D printing has all this potential, what are the factors limiting it in order to become a tool for radical acts? What is a radical act in the contemporary world? (Daniel, 3D Additivist manifesto, Interview)

So, the use of 3D printing as a metaphor lies at the perception that the communication achieved by the expectations of the technology can be used for critiquing the existing world. For Daniel, 3D printing's use of plastic and the materiality of the technology was an important factor on why they choose the technology as a reference point. “Plastic that is made of crude oil” he said, dead organisms that for millions of years were lying beneath the earth before humans exploited them, says something about our epoch. “The plastic that we use now, will be here for millions of years after we are gone”, so, there are politics of materiality here that need to be discussed. Evidently, the fascination of artists with an industrial technology takes many shapes but the relationship of artists to 3D printing is quite practical. Ideas can be visualized on software, shared along different computers, peripherals, internets, and become materialized by the artist having full control along the process. Considering the creative concerns of artists such as Moreshin and Daniel, who question the future of an industrial plastic-laden environment, something that involves scientific inquiry, 3D printing seemed the most appropriate format to express their art.

Neotechnic technology and decentralization of production

The discussion around a more democratic organization of society through technology has been a central focus of the modernity era (Feenberg 2010). This has been a re-emerging discussion every time an essential technology or a new paradigm has been introduced. In Hackerspaces, most members can reckon a few of them. Examples include the original printing press which made the spread of books possible, the personal computer which allowed information to be processed in far greater capacity than ever before or the internet which allowed the global spread of such information. It is only natural that 3D printing a technology that combined personal computer information processing and the internet to spread this information through the web, would garner attention, especially since 3D printing brought the added dimension of production into the combination. It brought into question the binary opposition of the world of art with that of technology, the question of autonomy and autarky of production, making it possible to reframe the question of size, and ways of organizing production and communities. Hence, the widespread slogan on ‘democratization of production’ that came from all sorts of perspectives (see Rundle 2014).

The development of a user-friendly technology for community use in a smaller size introduced the the possibility of ‘technology with a human face’, serving the users, and, at least for the general public, free from the faceless anonymity of industrial-scale mass production. This made Lewis Mumford’s work relevant once again. Mumford identified the start of the contemporary technological production mode not in the industrial age but actually during the medieval ages. In ”Technics and civilization” Mumford (2010) suggested three overlapping stages of technological progress from the time of the medieval ages: the eotechnic, which was associated with decentralized production of skilled craftsmen in free towns; the paleotechnic, the result of excessive growth and development as certain towns became metropolitan cities requiring a new centralized state including industries closely associated with it such as mining, iron, coal, and stem power; and the neotechnic phase which questioned the centralization of the paleotechnic industry and the authoritarian institutional culture that came with it, maintaining at the same time the need to economize on power.

Mumford made the case that in fact the big factories, big machines and the big steam engines that characterized the paleotechnic industries were not actually efficient and resilient enough and had to be replaced by a higher stage of technological development that would enable people to access everyday technology. He named the transition from the paleotechnic as ‘coal and iron complex’ (Ibid, p. 156) to the neotechnic ‘electricity and alloy complex’ (Ibid, p. 110). Friedrich Engels (1978) described a key characteristic of the capitalist mode of production was that it centralized production and thus made work a social product from isolated workshops and the anarchy of production. If the scientific socialism paradigm was keen on working with the socialization of production through using the centralized system inherited by capitalism, the Mumford approach was in contrast with such an approach. He insisted that smaller production facilities were possible through new technologies that would allow production friendlier to humans. This approach of smaller, autonomous individual or collective production workshops was popular among technicians and craftsmen whereas scientific socialism was gaining influence among industrial workers. Not surprisingly, this view was politically espoused with considerable success by Anarchist groups[76] and the Narodnik movement[77] between the end of nineteenth century and the start of the twentieth century, where industry was something new and developing in a mostly agricultural country such as Russia. From then on, Russian Anarchist ideas profoundly shaped discussions on attitudes towards revolutionary strategy and economy within the global anarchist movement[78].

Returning on technologies that enable decentralized workshops, Mumford suggested that the invention of certain prerequisites that would enable electrical power such as "the dynamo, the alternator[79], the storage cell, the electric motor made production possible in small shops and even household production. With no need for gigantic machines, electricity, essentially, altered the logic of the factory system. There was no need for people to gather en masse in specified places in order to use power. Rather they could have it in their neighborhoods, households, workshops and freely associate with one another in order to produce. Mumford proposal to produce in a decentralized fashion went beyond the purely ideological, maintaining it would increase efficiency and lower the power losses that the plants were known for. Production of food for example could respond to the needs of the locality and there would be none of the waste that was a feature of mass production, including the energy-sapping need to transport and distribute to distant markets. In a similar fashion, at the height of the crisis in the 1970s,

---

[76] For detailed analysis on the politics of Anarchists groups at the time and their tendency towards the economy, see Avrich, P (2005) The Russian Anarchists, AK Press

[77] See for example, Pedler, A. (2011) "Going to the People. The Russian Narodniki in 1874–5." *The Slavonic Review* 6.16 (1927): 130–141, and Von Laue, T. H. October 2011."The Fate of Capitalism in Russia: The Narodnik Version." *American Slavic and East European Review* 13.1 (1954): 11–28.

[78] The influence of the Russian Anarchists on the Anarchist movement around the world including the industrial countries, is also evident by the supply of theorists such as Piotr Kropotkin and Mikhail Bakunin two of the most iconic figures the various strands of the movement are basing their ideas.

[79] An electrical machine which turns mechanical energy to electrical through alternating current.

Alfred Chadler (1977) suggested that what made the next paradigm of distribution of goods possible was the next wave of new technologies. The development of communications and transportation technologies to transfer goods in long distances, derived from the reality of centralized production practices for single or multiple markets.

> The revolution in the processes of distribution and production rested in large part on the new transportation and communications infrastructure. Modern mass production and mass distribution depend on the speed, volume, and regularity in the movement of goods and messages made possible by the coming of the railroad, telegraph and steamship. (Chandler 1977, p. 207)

One can see the argument in reverse; once a social paradigm starts to gain momentum, technologies are developed to fulfill its potential. Not being able to push a specific agenda with a clear vision and direction, for those interested in concepts such as decentralized or smaller technologies, it is important to inspire and inform through practice; to show this alternative vision by creating through decentralized and smaller (than industrial) technologies.

Today, such an approach on decentralized and local production is also gaining momentum through the use of technologies such as 3D printing. Having Eric Schumacher as one of the iconic influences at fabulous St. Pauli, for the people comprising the Fab Lab, adds luster and importance to their local production. In the 1970's, Eric Schumacher's (1973) "Small is Beautiful" was an iconic book which captured the spirit of the times during the peak oil crisis. However, for people in the Fab Lab interested in Schumacher ideas today, they don't translate into a direct copy of small enterprises scattered around. Rather, they signify a rediscovery of ideas that question the dominant paradigm. As I observed, certain people around the space valued local production in many ways. However, they were not utopian in the sense of having unrealistic views about what a Fab Lab could or should do as an autonomous community workshop. People with experience in industries frequent the space, so there is an increasing pool of knowledge of how industries work and what a pragmatic critique of the idea of ‘’small’’ can do. In the case of the Fab Lab in St. Pauli, expressing the idea of “small” means to better organize the big industrial plants and help ensure a smoother relationship with smaller town and community workshops that can take on r tasks the industry is either too inefficient or unable to implement (for example local or personal technologies). If the people can get an idea of how low- to-medium technology works and what it can do, I learn from Andreas, a member of “Fabulous St. Pauli”, maybe a social movement challenging the ownership and existence of big factories can be better equipped to discuss the future of machines and the organizational structure of the spaces they are assembled in.

> When we did the phone workshop, we also invited some people to give talks there. One was by a professor who started a laser centre around here. They have the high tech machines for additive manufacturing, laser cutting and he collaborates for research with big companies. What he said to us, is that what we do here at the Fab Lab is the same as there; you have to find members as we do, but our members is the industry. You are doing what we do in a smaller scale. I heard him speaking before about bigger industries and smaller workshops and their role. In his talk which I thought would be more abstract as is the case on such occasions, he really said the latest stuff they are doing in the industry. He laid out where they are in terms of additive manufacturing and where they want to go and at what speed, really far from the

> technology we have here. But the interesting part was - of course, people were so lucky to see and compare the additive manufacturing and 3D printers in their neighbourhood – that there were many more steps in the slide, as well as the people who work in his setting cannot reflect on the ideas they are developing. I thought he attracts all these smart people from universities and the industry, which I genuinely think that they want to do good stuff, want to use new cleaner technologies and sustainable like additive manufacturing, but they simply cannot do it there. For instance, is it really needed to develop a part or keep on developing this process. This is why a low volume production is important; for them, it is unquestionable, they cannot do it. It is really important to have such a place to decentralise production, make things slower and reflect upon them, if things are going the right direction for the people […] I think society has to decide has to decide what they want to develop, big power plants or tourism or energy production. It is a decision whether we want a high end product or a more resilient setting (Andreas, Fabulous St Pauli, Interview)

The reasoning behind this was the awareness of non-European experiences some people from the Fab Lab had in terms of infrastructure and goods; such awareness coincided with what was already familiar and was reflected in the work of Schumacher. His work challenged the idea that colossal power plants should be used to reach every area in vast countries as is the case of India. This is also evident in Niel Gershenfeld's work (2006), where he articulated a grassroots approach to solving everyday problems through personal fabrication. The main problem in his own travels in India was to be able to give technologies that will give grassroots organizations in rural areas the possibility to create their own conditions of life, as opposed to the very big government development projects that were not sufficient. It became apparent, after reading Gershenfelds' work, and talking to Niels who was familiar with it, that 3D printing in rural areas in countries not yet fully developed, was a survival technology. It is a technology that can fulfill potential education gaps by making or, in urgent situations, making it possible to provide practical problem solving. Such a context is markedly different than what cities like Hamburg, Leicester or Cambridge are experiencing. In the case of the latter, the the practicality of 3D printing seems more of an option than a necessity, a better and more playful way of doing things than an urgent problem solver. Most cultural imaginaries are composed of attractive stories. Not surprisingly, the technology is popular with people who may have an industrial background but the nature of their work involves a certain degree of autonomy or at least the autonomy that is lost through excessive control in their environment. 3D printing presents designers with a tool enabling them to control the process of their work, hence the Fab Lab being a popular place for conducting their projects.

The concept of neotechnic technology, to be able to have cleaner, smaller and more flexible technologies, is what links people from various background experiences, whether they come from rural underdeveloped areas or post-industrial cities in the West. 3D printing is a good candidate to embody this transformation. As I was told by Andreas, the RepRap project was important, in the sense that it can stimulate the discussion about how the technologies of the future would look. A few widely available parts, such as motors and open source electronic platforms along with free online information but also available workshops at Hackerspaces, Makerspaces and Fab Labs make 3D printing a unique domestic neotechnic technology.

> What we have here are motors that are very common and you can use everywhere, a few plastic parts and Arduino that you can also use for other things. You see that there are relatively few materials (components

> comprising a RepRap 3D printer). Ok you have several components but compared to the other machine (an industrial 3D printer about 10 years old), its really hard to do something out of this, because you don't know how it works and the protocols that go with it. In my opinion it is bad to have such a machine, maybe it was a good solution at the time they made it, but you can see that such a machine is made out of so many resources. After so many years, either the technical environment does not apply or spare parts do not fit. So you can see, that for the same result, you have a more efficient solution and I can imagine other machines going through the same transformation in the future; for example, why buy a new cell phone every couple of years? (Andreas, Fabulous, St. Pauli)

The fact that many RepRap 3D printers lack a lid or cover, leaving the machine transparent is good symbolism as well. You can see the different parts and how is done, unlike the culture of design for other closed source consumer products such as laptops these days. The new transparent machines show that with a few minimum shared resources, new machines can be built, redesigned and rebuilt with the same resources or with printed parts. A neotechnic technology is not one that presents itself in a small package, but one that can alter its components. It can function as a network, and it can be reinvented at will. As Lewis Mumford put it (2010, p. 226), 'bigger no longer automatically means better: flexibility of the power unit, closer adaptation of means to ends, nicer timing of operations, are the new marks of efficient industry.'

Autopoiesis

Throughout this chapter I discussed the political and cultural imaginaries around 3D printing and the characteristics which allow such narratives. In this latter part of the chapter, I discuss the economic system presented as being compatible with such narratives and critically analyse the aspects that apply to 3D printing. We have seen that as the much broadcasted ‘revolutionary technology’ of 3D printing entered the mainstream, a diverse mix of uses started to flow into the public sphere. From 2012 onwards, it seemed as if a new application of 3D printing was found every week. But aside from the imagination of its users that 3D printing has enjoyed to date, it needed investment and time in so that it could be institutionally utilized. In chats and among users, the word is that that there has to be a “killer app”, one application that is developed specifically for the purposes of using this particular technology.

> If you look at the history of new media, the new media always starts by copying the previous one. Television copied cinema, cinema before that copied theater and photography copied painting, and digital photography copied analog photography. It is not until the new technology goes beyond copying the previous one that it becomes unique in its own right. So, I think that 3D printing as a medium does represent a new way of making things, but often what happens, people often just make the same old things that they used to make without the 3D printer. It is not until we get the 3D printers out there, in the hands of people who bit by bit stop doing the same old things and start doing things beyond what they are used to, that can lead to new kind of aesthetics. Then we will understand if 3D printing is this new radical way of doing things. (Angus, Leicester Hackerspace, Interview)

Neither the CAD models, nor the microprocessors, or the USB sticks and the sharing of information were distinct about 3D printing. Although some users were less than impressed after a few tries with the technology, especially some who were serious about prototyping and developing professional objects, others tried not to see 3D printing in a vacuum and static. Materials will improve with greater use of the technology as there will be more feedback and better and more efficient ways to print will emerge. What is needed, I would hear in the Leicester Hackerspace, is an application that takes a technology from a nice and ritualistic technological consumer culture to a vital process of sorts. For example, in the early stages of personal computing there was a general feeling in the tech industry that the idea of having a personal computer at home was unlikely to resonate with the public. Then came the development of the spreadsheet. What the spreadsheet was for personal computers, such narrative suggests, 3D printing is still missing. But I argue that what made 3D printing so popular was not that it is a technology which can speed up the manufacturing process, but because it can alter the process in qualitative ways. One of the bolder claims about 3D printing is that the wished for killer app could change social and productive communities (Unruh 2015). In other words, thinking 3D printing as metaphor for a social and economic system.

In qualitative terms, the new ways of manufacturing and engaging with materials that 3D printing brings forth is the structure of a social organism[80]. What the RepRap project brought from concept into practice (having digital files as materials), the practice of printing does with the ideas that come from the feedback. In policy making circles the term is 'circular economy' (EC, 2014) but I argue that the concept of social autopoiesis (Cooper 2006; Razeto-Barry 2012) is closer to the understanding of grassroots community workshops. A system that could self-reproduce. It was first coined by Chilean biologists Maturana and Vaarela in 1972 as a way of introducing how living cells communicate and replicate between each other.

[80] Notice how many biology metaphors there are on 3D printing such as Darwinian Marxism and Autopoiesis. The reason being, one can assume, the insistence of their proponents on evolution. In contrast to other production technologies that seem an external force to nature, 3D printing is presented as if it is a technology in accord with natural reproduction, therefore sustainable and clean.

> An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network. (Maturana and Varela 1980, p. 78)

Recalling the 'Darwinian' part of the RepRap project, a 3D printer conceptualized as a social system is thought of as a system where it uses the various components to achieve replication and upgrade its existing model. In this respect, humans are but a component of this system, a vital processing organ in the feedback loop just as the microcontroller sustains the temperature of the extruder for prints. But the positive connotation of this biological metaphor has a historical framework, at least as it relates to discourse. This perspective is in line with the feminist cyborg theory of Donna Haraway (1991) in which she proposed understanding the fusion of machines and biological organisms to create hybrid mixtures. Taking a critical stance on cybernetics theory (Weiner 1948) of the Cold War, problematized sociobiology as a communication science, she argued that the specific discipline emerged as a way to explain advances in biology in accordance with the domination of the capitalist system.

> 'A communications revolution means a re-theorizing of natural objects as technological devices properly understood in terms of mechanisms of production, transfer, and storage of information.' (Haraway 1991, p. 58) The theorization of existing social order in scientific veil entails the danger of understanding the existing order as natural. For Haraway (Ibid, p. 59),

> understanding the social as biology (and biological systems as machines) 'nature is structured as a series of interlocking cybernetic systems, which are theorized as communications problems. Nature has been systematically constituted in terms of the capitalist machine and market.'

In other words, understanding a 3D printing system in biological terms, as a closed circuit with feedback loop, endangers the possibility of not being able to overcome the existing social structures rather than alter their sequence in thinking. As such, arguments in which individuals having the means of production directly linked with each other, risk the possibility of not taking into account the failures of markets on the whole rather than just some aspects of having monopoly power. However, it is not difficult to see why the natural and biological is an attractive term for the use of the technology. As new recycler machines produced, the 3D printing systems seem like a prototype of a feedback loop organism, similar to the argument that Buckminster Fuller (1968) called 'Spaceship Earth'. Recyclers, although not available in the early stages of the RepRap projects, were created in order to address the issue of printing material. Since much of the material used on an everyday basis is made of plastic, a machine that could be able to turn plastic bottles into 3D printing material (Crew 2015) could be a breakthrough. Experience and frequent use brought up the matter of what happens with waste, something many enthusiasts are keen on developing. Thinking 3D printing as a closed loop system, the recycler idea is conceived by various users as a step towards a technical system that can reproduce itself. As is usually the case, most of the new machines came out of the universities but the news is widely distributed in the makers' communities. The synergy between the grassroots communities and academia is in many cases direct since many of the people engaging in the making culture are either directly involved in academia or indirectly as former staff now retired.

My field engagement with this idea of autopoiesis or circular economy concept, past the academic literature, was in Leicester Hackerspace. I was supposed to meet Angus at an independent cinema in the cultural quarter of Leicester near the “Leicester Hackerpsace” which was also a member. Angus, is an artist who tries to make a living more on “things he liked”, meaning using machines and intricate new technologies to produce art. At some point during our discussion he brought up the concept of autopoiesis. Later, the way he explained his thoughts matched some of the features of an emerging economic paradigm, the idea of circular economy. This is used both by grassroots organizations and increasingly by institutions such as the EU as a metaphor to describe an economy which aims to alter the ''take, make, use and throw away'' culture of production. What this new paradigm does is bring up product development, extraction and recycling of raw materials between manufacturers or producers and consumers. Sometimes, producers and consumers are the same people.

> I think it is part of a bigger picture, 3D printing isn’t the solution to all problems [...] but it is the idea of repairing rather than replace maybe that will become political. Many objects are designed with planned obsolesce and also there is artificial obsolescence with fashion. Very usable objects but people get rid of them because it’s out of fashion, not because its broken, but because it doesn’t fit with their, < lifestyle >. I think the maker community is a reaction against that. Things that are perfectly good can be adopted, upcycled or whatever (Angus, Leicester Hackerspace)

For Angus, the real task of furthering 3D printing is not only to find new and better ways to develop the technology, but the social outcome of what this means. As such, for him an important part is strengthening bonds between users, finding ways for people to find each other and be linked with concepts or tags rather than clear cut categories of going and buying a product. The currency for engaging in widespread production of such a social autopoietic system, it seems, is access to information, raw materials and time. Of course, this is the first step in autopoiesis in which feedback on the system is the second step. The second step is addressed through the networks of people that feed information and feedback to the community. As a third step, an autopoietic system becomes aware of itself, a quality which is yet to be addressed looking at the 3D printing environment.

People like Angus, are not interested in the epistemological terms or the historical context of metaphors; rather, he is genuinely looking to work with what he has in practical terms. The concept of autopoiesis he is suggesting seemed closer to the Cybernetic machines of Allende in the 1970s (Medina, 2011), than an abstract ideal. By extension, developments in the social realm, of ascribing more social meaning to interactions or incorporating social meaning into productive relations has had some impact also in academic circles. For theorists such as Vasilis Kostakis and Michel Bauwens (2014), 3D printing is at the heart of Commons based peer production, an alterative social autopoietic system of production and distribution, similar to what I have been describing in the Leicester Hackerspace. In their view, 3D printing could be a CBPP[81] artifact insofar as it displays characteristics such as,

> (i) they have a low cost of acquisition, due to the absence of strict copyrights and patents; (ii) they are sustainable as they can be (re)produced socially and designed to last for as long as possible; (iii) they are adaptable to local needs; (iv) as social products, they are being supported by many global volunteer communities which are capable of providing help to the users. This means they can be implemented anywhere in the world and improved by anyone. (Kostakis and Bauwens 2014)

[81] Commons Based Peer Production

In this respect, 3D printing and the concept of open source desktop manufacturing could be used not only as a machine that could allow practical recycling processes but could function as a symbolism of a progressive social system itself; an open source social system (Gonzales, Rodriguez and Kostakis 2015). They contend that whereas in the past a unified ideology or the worker identity was the unifying factor for a political engagement to shape social transformations, today this is not the case. Understanding and defending the heterogeneity of the movement, they argue that the new imaginary which emerges through commons based peer production is that technology could function as the unity of completely independent 'individual or organizational) actors with different, even competing social understandings within and beyond capitalism' (Ibid). Technologies such as 3D printing, could accelerate a social landscape where mass participation would enable centrifugal forces from centralized systems of governance and production that causes the rethinking of what a producer and a consumer is, how and why production and making is done and organized.

Closing on this chapter, I argue that the very diverse and at times conflicting imaginaries and narratives popular among users of 3D printing are essential to the development of this distinct culture. The spread of 3D printing seemed to be the right technology at the right time since it is a technology built upon a recently expired set of patents and a networked environment in a time of economic crisis. For this matter the hype generated gave too much public coverage to the technology in order to encourage individuals to use the technology but also as a way of creating hope that individuals could create and that in fact 3D printing and related technologies constitute the new type of the forces of production. Politics under this framework become something elusive, with traditional parliamentary or trade union politics replaced by politics through practical interventions carried out in vision of new technological imaginaries, housed under the umbrella of the 4th industrial revolution. The new political process that emerges from 3D printing, is built upon a more technical language to carry out its practical ends, create maker's communities and strengthen communication and sharing processes. There is no division between participants in utilizing the technical language as when discussing politics.

Where political discourse bids to offer a social explanation through ideology, theoretical and political narratives, the people who use such technologies are more concerned to expand cooperation. Cultural and technological imaginaries, apart from creating hype around 3D printing, are the narratives upon which individuals and groups understand their actions within frame. The main imaginaries I discuss in this chapter, include exploration of space, the promise of desktop and decentralized manufacturing, science embracing and acknowledging its artful part, neotechnic technology and autopoietic social system. These imaginaries function through engaging more people to participate. They unite rather than create divisive identities. Everyone involved can also gain in the short term by sharing experiences, skills or files. In the next chapter, I will analyze the relationship of 3D printers to the spread of Hackerspaces, how such spaces function as organizations of their own version of politics and how their infrastructure redefines the relationship of these communities within their respective cities.

3D printing in Hackerspaces, Makerspaces and Fab Labs

In the last chapter, I discussed how 3D printing can be situated within a variety of imaginaries and how its characteristics help it to be so. Moreover, I discussed how it manifests itself as a promise and a science fiction at the same time, how it captures the spirit of late capitalism and how neoliberalism uses such imaginaries to enlarge the 3D printing market whilst the grassroots public see these characteristics from a different perspective. In contrast with the last chapter where I used information from a variety of sources including film and popular culture publications, in this chapter I focus on ethnographic accounts of the use of 3D printing in grassroots spaces such as Hackerspaces, Makerspaces and Fab Labs. The ethnographic material will present aspects of such spaces which contribute to the spread of 3D printing usage. Such spaces are the most probable access for an individual to a 3D printer, because of their availability for free or low cost trials one can experiment with.

Hackerspaces, Makerspaces and Fab Labs are spaces of production but at the same time they are places of leisure time, autonomous and self-organized. They arose at the fringes of leisure and production from the development of late capitalist networks of production and consumption practices (Castells 2000; Banker 2006). In this respect, Lefebvre's (1991) understanding of the city and the production of space through a complex relation of practices and symbolisms can be valuable for understanding the ideological positions and associations of the different spaces. Because these grassroots community workshops[82] are intersecting between the worlds of consumption and production, the institutional and the informal, they embody many of the contradictions of social relations that exist within their own societies. Such spaces can be thought of as places that exist but are being addressed as counter-sites to either a factory (as a production place) or a mall (a distribution and consumption space), 'a kind of effectively enacted

[82] I use the term grassroots community workshops referring to Hackerspaces, Makerspaces and Fab Labs.

utopia in which the real sites, all the other real sites that can be found within the culture, are simultaneously represented, contested, and inverted' (Foucault 1967). They can be thought of not as established sites, since there are not solid rules but as 'temporal situations, events, which occur in particular places that open up the possibilities of resistance within society to certain marginal groups or social classes (Hetherington 1997). This is not to say that such spaces are not used by members of the middle classes, but that in many situations, their intra-class inclusive status is a frame for what kind of people can be seen there.

The focus on 3D printing allowed for visits in spaces that might look similar at first, but can differ a great deal when viewed more closely. The four spaces I discuss further in this chapter were part of fieldwork that included observation, formal and informal interviews and participation in the everyday life and planning of some of the spaces. The spaces take up parts of a cultural imagination that are aimed at the members. But ultimately, the ordinary people in grassroots community workshops are motivated more by individual issues rather than the ideology being overlaid onto in such spaces. As the prevalence of desktop technologies in general has gained ideological hegemony, many communities and individuals have tried to create spaces for hacking and making that will enable them to work in the most practical way. Gaining skills that would potentially make someone employable in the future, develop a prototype that could later be commercialized or join up to socialize and network whilst making (something which was impossible in garages) are themes that emerge from my field notes. Nonetheless there are users and members of these spaces who are reflecting upon practises, adding context on cultural imaginaries. Many find themselves in familiar places, as their work involves part-time contracts, desktop computers, small machines and a situation where space is not as constant as their USB stick.

For a technology which is resilient enough to become a tool for popular culture and in some instances DIY production, such spaces provide the framework within which individuals become users and become familiar with 3D printing. The aim of this chapter is to provide a closer look at the spatio-temporal configurations of such spaces and the place of 3D printers within them. Through fieldwork within such spaces, I engaged with users of 3D printers or just members of these grassroots workshops, in an attempt to provide an insight into each space dynamics. Such situated analyses will also be interrogated in accordance with broader perspectives of resilient technologies within metropolitan areas and their importance in the production and reproduction of objects, practices and ideas. Naturally, the first question that presented itself naturally was where and why such grassroots workshops flourish and what is their relation to the development of 3D printing?

Conditions of 3D printing culture in Hackerspaces

Why look at a Hackerspace for 3D printers? From a surface reading of the cultural hype both in publications and word of mouth, it was very easy to discern: Hackerspaces and 3D printing, 3D printing and Hackerspaces. If you want to see a 3D printer, go to a Hackerspace. The embracing and development of desktop 3D printing was related to the opening of these new spaces, either because these spaces were good opportunities for people to become familiar with 3D printers, or as ways of getting the idea of 3D printing out to people who are not necessarily already part of a DIY or maker community. To an outsider to the culture, this development is evident when we look at the case of the Makerbot desktop 3D printer developed on a RepRap design at NYC resistor[83]. For a couple of years, the team of a few friends that developed one of the first consumer 3D printers available, becoming 'the darling of the Open Source Hardware movement' and 'the poster child of a new economy where anyone could manufacture hardware' (Benchoff 2016). The case was a popular example of what a Hackerspace can do; that is, create relationships and carry out innovation that can even compete in the market, which was ultimately the reason why the community it helped create was furious at its corporate business model that followed and which detached itself from the maker movement. Looking at a wider

[83] See the discussion on Chapter 2 concerning the history of 3D printing.

perspective, rather than the 3D printing culture, Makerbot remained an example of the possible new world. It is an example of what is possible in such spaces, a whole new way of developing and prototyping machines in shared workshops. Moreover, these new machines developed by users, are built in such a way to cater to the needs of users and their communities.

As such, the development of 3D printers is affected by users; that is, usage is also shaping how 3D printers can be hacked to fit the purposes of these new semi-institutional or informal spaces. This also shows the relation of the Makers movement and desktop 3D printing, is a story of co-development. When discussing with a prominent member of Leicester Hackerspace, an art director in the region of the UK's Midlands, he argued that he considers 3D printing to be at its very early stages of development, but it is also directly linked to the opening of spaces where people can find such machines. In order to draw a parallel, the original printers, Angus argued, started to interest makers as it "started to become more consumer friendly". "The 3D printing and the maker community have risen at the same time [...] for many people, 3D printing introduced them to this broader making community, but also the maker community has made the 3D printer more accessible" (Angus, Leicester Hackerspace, Interview).

As the technology develops further, he argued, both the technology and material will become more available to the general public. Although there are doubts about whether specific companies can deliver, the discussion did not end up questioning the ability of the market to deliver the technology to the masses. The development of the technology for him is following the path of other technologies that broke into mainstream, but with an alternative twist. Instead of businesses fearing the community of users and open source fixings of their products, they should remain open to the maker community, as they could also benefit from the community's innovations on the machine. In particular, small companies and start-ups have many opportunities to build on existing machines and solve problems. In a distributed way but within markets, new and better materials as well as machines can be delivered. After all, the use of personal computer a few decades ago grew exponentially, making software and tech companies enormously successful, whilst delivering on the promise of having a personal computer as a desirable machine in people's homes.

New ways of building machines and a new type of relationship with staff and customers offer faster disruption cycles, as within this type of environment users are increasingly becoming part of the production and feedback process. Companies find it increasingly hard to have fully closed ecosystems, with enormous amounts of R&D funding still needing that extra user involvement if they want to utilize the experience and competence of their consumers (Prahaland and Ramaswamy 2000). On the other hand, the open source and hardware movement followed a rather different path than an outright rejection of the corporate world. This became evident as the experience of the open software movement matured, focused on ways of implementing its practices, utilized pragmatism (Postill 2014) and managed to create a space for compromise between users and companies in terms of allowing at least parts of their products to be accessed by the user communities, which could also be a source of innovation (Weber 2004; Goldman and Gabriel, 2005; Capra et al. 2010).

By the time my fieldwork started, grassroots communities such as Hackerspaces have metabolized and included this open source compromise with other sets of ideas surrounding such spaces. These ideas were common in all types of spaces, with some variations depending on the different cities and contexts. Despite differences, the important aspect of this context is that this movement does seem to be of global significance. In some areas the communities are called Hackerspaces, in others Makerspace or Fab Labs, but whatever their formulation or naming, there is a strong sharing and open source culture. There is also a set of technologies including 3D printing which are essential tools for starting to reproduce themselves as a cultural phenomenon through the projects and stories of the participants. This pragmatic compromise allowed many such spaces to find these new machines (which despite a lower price than at first, could still cost several thousand British Pounds/Euros/Dollars) and members, through network channels and evangelists of the new technologies. The strong correlation between Fab Labs and other workshops with industries were part of the strategy to develop many more projects that perhaps could not find their way in the innovation management of companies and which individuals still wanted to develop for personal reasons. This seems to explain, to a certain extent, why there were many more such spaces in the countries of Global North, which until recently had or still have mature manufacturing industries. As Andreas from Fabulous St. Pauli told me,

> The one thing is that the space such as the Fab Lab has the potential to develop smart regional ideas, so if someone has an idea for something it is more likely they will develop it here, they do not have to rely on traditional production sources or sales markets etc. This is not guaranteed though, there is a potential but it is not a given. Innovation management for example, in big companies, they collect hundreds of thousands of ideas and then pick up one or two that they keep on developing. It doesn't mean that you will have a product out this, but just more development of this idea. So, in a Fab Lab there are so many days we are open that someone could develop something on their own. If you compare to an innovation process itself, that out of hundreds of thousands of ideas you develop only a few, I think it is likely in a Fab Lab, one good idea could be developed, albeit a small thing. And because of the character of the space, it could have community characteristics with a regional touch; you can also share it on the internet and have it developed more as well. Maybe every tenth Fab Lab, you will have something big developed, such as what the "Ultimaker" team have developed or something that started in the

Fab Lab and then developed somewhere else. So this is one potential thing. (Andreas, Fabulous St. Pauli, Interview)

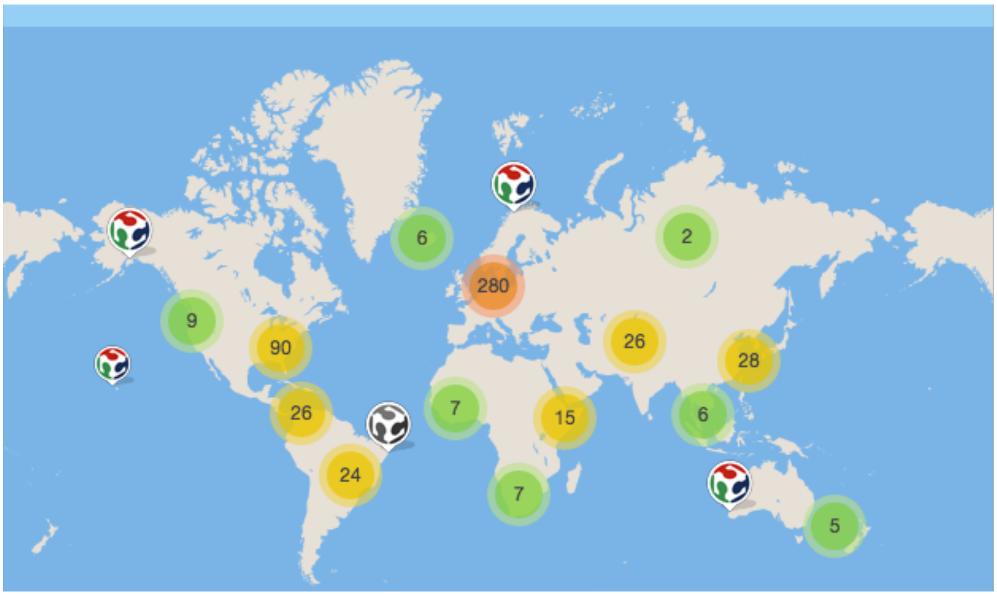

Figure 13 Fab Labs as of 27 January 2014 Source: Fab Foundation Website Accessed: 15 February 2016

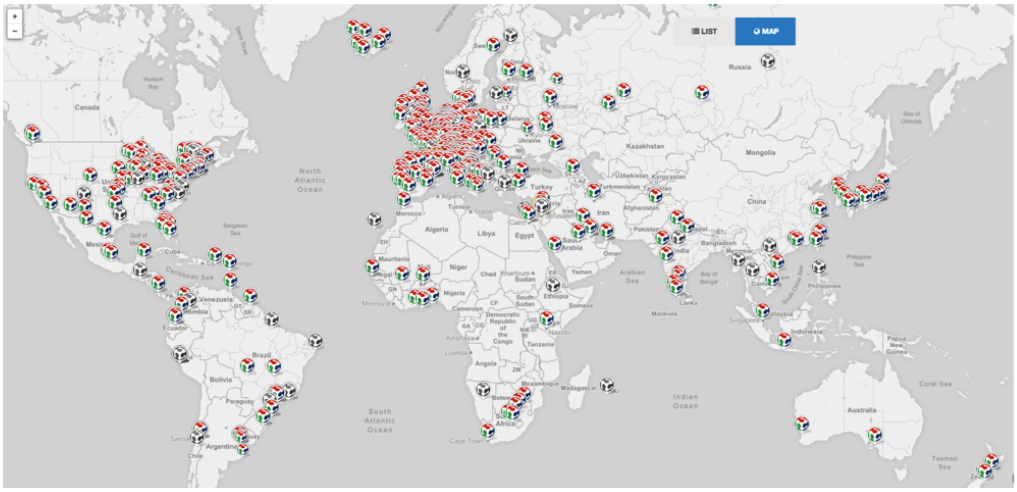

Figure 14 Fab Labs around the world as of February 2016 Source: Fab Labs Website Accessed: 15 February 2016

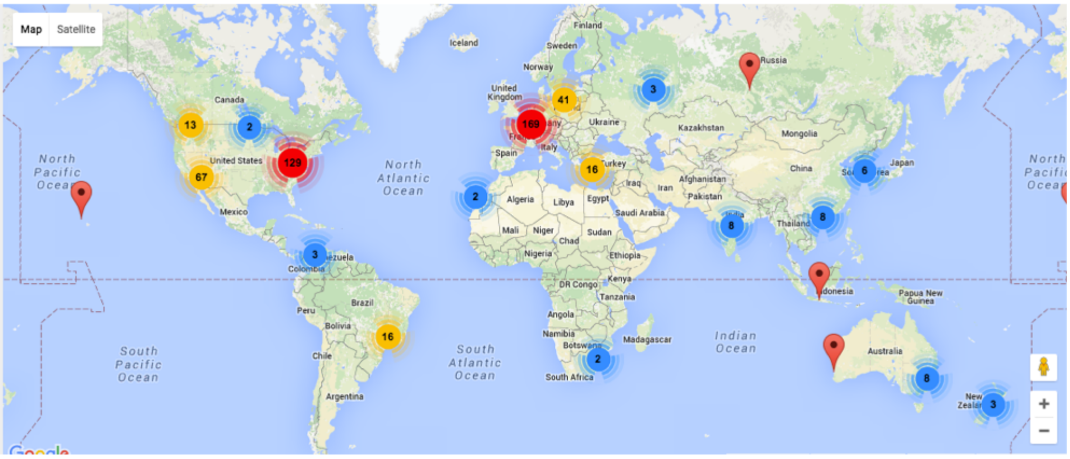

Figure 15 Hackerspaces around the world as of February 2016 (indicative number, these are 500 out of 2000 Hackerspaces) Source: Hackerspaces.org Accessed: 15 February 2016

As represented by the above images, the explosion of the Hackerspaces, Makerspaces and Fab Labs shows that the geography of this culture is an important aspect that is often overlooked. They are especially popular in Northern Europe around industrial and former industrial cities and in the US around the coasts, where creative industries are growing. From the 609 Fab Labs around the world, 109 are stationed in the USA, 64 in Italy and 60 in France. The seeming abundance of tools and skilled individuals are coupled with incentives that can be quite visible in just a short visit to these spaces or when looking at their location and legal status. An example of such incentives can be programs of 'cultural squares' which I will explain below. In an attempt to merge the nostalgic feeling of former industrial glory with artisanal practices, cities in the UK have tried to attract businesses and start-ups in close proximity for the purpose of exchange and connection between them. In such quarters, small entrepreneurial businesses have been able to rent at lower prices, make arrangements for lower electricity in some instances or label their activities as services whilst still performing light industrial activity.

One characteristic example of such a space is Leicester Hackerspace. It is located in the 'cultural quarter' of the city of Leicester, a label that follows an attempt by local authorities to regenerate former industrial parts of the cities with new 'start-up'-like businesses and local organizations. The aim of such a programme in the city of Leicester, for example, brought 'a new venue for the performing arts, Curve; Creative workspaces for artists & designers, LCB Depot; and (opening autumn 2009) a Digital Media Centre'. One such creative workspace was the Makers Yard, the space where 'Leicester Hackerspace' made its initial home[84]. The Makers Yard was a former hosiery factory. Originally it was one of the factories built to house parts of the hosiery industry which before that time was done in domestic spaces, as it moved from an informal to a regulated business.

> Framework knitting was traditionally done by domestic knitters in their homes. They would rent their frames from their employer and be given a set amount of yarn with instructions on what to make. The finished products would then be collected as the next set of yarn was delivered. John Brown built the first part of the Makers Yard, 86, in 1854 as a warehouse for his goods. He would have employed domestic knitters and rented the frames to them. Employers like John Brown began to build small factories to house their frames and have more control over the knitting process and their employees. He built 82A in 1860 to house his frame shop.[85] (MakerYard leaflet)

[84] In July 2016, Leicester Hackerspace moved to the Innovation Centre, which is part of De Montfort University, in an attempt to overcome operational problems and increase the capacity of the space in terms of technological tools available to members. In December 2017, Leicester Hackerspace moved yet again to be housed in the Faircharm Industrial Estate, a move which increased its capacity for more energy-demanding machinery such as laser cutters. Each change aimed at addressing operational costs, influx of new members and a greater range of available machinery.

[85] The 'creative quarter' in Leicester which has been developing recent years includes alternative cafes, an independent cinema and a big venue for cultural events. It is located in a parallel street to the commercial city centre, just a few minutes' walk further on. As with the commercial centre, people do not 'hang out' for no reason, except with a small yard between the cafes and the cultural venue in which skateboarders practise. It is a place where small independent films are sometimes shot.

Figure 16 Some historical facts on a wall next to the entrance of the Makers Yard, reminding the present users of the interesting history of the building. Photo Credit: Leandros Savvides

After a long tradition of making garments, passing through wars, and keeping up with the ever-changing (both in terms of technology and fashion) garment industry, the place remained empty until 2002. Following the actions of certain people, English Heritage listed the building in 2006 because of ‘the rarity of this kind of small factory where a number of knitters would work together for the manufacturer and warehouse owner rather than working individually at home’ (Ibid).

Figure 17 Support for the refurbishing of the building was provided by the EU, part of the EU regional funds. This inscription is located at a central wall inside the Makers Yard. Photo Credit: Leandros Savvides

Putting different projects in close proximity, the space has been refurbished to house designers and small enterprises, as well as the designation of a room as a Hackerspace to allow individuals to hack and work on individual projects but in a sociable way. From the Hackerspace community perspective, this co-habitation gave low rent for the community's first steps and its co-existence with other artisans, giving the "Makers Yard" a title worth of its name. Hacking in such a space involves both the individual desire for projects and the need for finding skills and knowledge in a more social context than the house garage. Although the Hackerspace is characterised by sharing resources, materials and human skills, many of the projects are driven by personal reasons, a reversal of the reasons for the building's original use:

> I tend to do things myself, when I can, I can do certain things up to a point, I can certainly do a bit of engineering. 3D printing means if I can think about something, it means I can print it. Whereas I would spend a lot of time in my garage sewing and drilling

> making the exact shapes of aluminium, plastics and even wood up to a point […] If I would do all these things alone, fantastic, that is the best. But when I start to make a device that may require high levels of skills I do not have like electronics or to some extent computing (I do not want to learn a complete new computer language for instance, even though I am good with programming), this is when other people are needed. It is difficult to deal with a part analogue, part digital device and know all these things, so in a sense I try to shortcut. (Dave, Leicester Hackerspace, Interview)

As the above quotation suggests, Dave thought of the Hackerspace as a place that would help him develop a tool for accurate radiographic imaging. The individual drive for a project, connectivity through the internet using various social media and the lack of all the skills required to complete a task are principal reasons why somebody can come to such spaces. How these spaces are formed or funded, remains an issue of members to decide and vary according to each case. But it seems to be a general pattern that this type of culture connects the dots between existing public infrastructure, knowledge institutions and the spirit of the times. Despite the fact that such grassroots communities retain some form of autonomy in organisational terms, they nevertheless depend on an ecosystem of institutional help, coming from local authorities (e.g. city councils), academia (e.g. universities) and sometimes even the business world (independent and connected entrepreneurs in creative industries or corporate donors).

Where can I see it first?

Having no expectations except a rag-bag of imaginaries for this new technology, I decided to go to a 3D printing introductory workshop, as it was a mandatory process if one needed to use the 3D printer at the Leicester

Hackerspace. The workshop was given by a local artist on the first floor of the local independent cinema just one road away from the Leicester Hackerspace. In two hours, the workshop was designed to introduce both theory and practice of this new technology to an unknown audience. I say unknown, because the workshop was open for people who either knew something about 3D printers or nothing at all. The workshop was taking place at the artist's studio, whose older 3D printer model was sold to the Hackerspace. Arriving at the reception, the person responsible for selling tickets called someone to come down and escort us to the workshop area, as fobs were needed to enter. Interact labs were located in the first floor of the cinema in which the artist studio was housed. This is a registered charity which supports local creative projects and artists. Once in the studio, the room was filled with art projects and microcontrollers; a studio filled with technologically-induced art.

The workshop attracted about five people who came during the first hour and three more that joined us during the second hour, apparently knowing that the first hour was more of a theoretical background on the technology. As the workshop started it took about one hour to cover the basic idea and a couple of imaginaries of 3D printing. The people who came during the second hour were the ones who had a 3D printer at home and came to ask specific question on its functions. It was evident from the expressions of those who had never seen a 3D printer before that the technology needed patience. The first design we were shown was a simple cup, smaller than a tea cup; design time was about five minutes and about one-and-a-half-hours to print. after noting that PLA and PVA[86] used in the specific model were not in any case printing a usable cup, the artist mentioned 'Shapeways' as a possible platform that one could use to create a ceramic one, although it could cost about £20, whilst the plastic made by the 3D printer cost about £2.50 of material. The specific ceramic that we had in front of us was printed by Shapeways and given to each member of the group for physical examination.

[86] These are widely used materials.

Moving on to the practical section, the introduction involved performing 3D printing tasks at the most basic level. As a few members of the group were of older generations and not very familiar with USB sticks, STL files, CAD models, “g code” and microcontrollers, the workshop was aimed at a completely ‘newbie’ audience. The practical side of printing also involved tips on how to print rafts for supporting the objects[87], how to achieve the right temperature for the extruder, how to prepare the designs on the desktop and get them ready for printing, what software to use that is open source and thus accessible for free, where to find designs (‘Thingingverse’ was the preferred destination) and how to orient the hotbed in order to start the print. All these were important prerequisites for attempting printing, but even knowing these would not guarantee an inexperienced user that their print was going to print correctly. Thus, these tips should be combined with experience and printing objects; with more correctly-printed objects, the user gains confidence and experience to print more geometrically challenging objects. The Hackerspace certainly made it possible for members to climb the experience curve relatively quickly, since the 3D printer is available for a very cheap price (about £1 for a half-hour print). Some of the users who are interested to use them more than the Hackerspace allowed would then move to buy a printer. At the Hackerspace, one can also find information about the latest deals on crowdfunding campaigns on new machines and where to find materials.

The considerable growth of the makers’ movement has been in an open relation with the development of 3D printing and socio-economic processes such as crowdfunding and the proliferation of Hackerspaces, Fab Labs and Makerspaces in cities of the Global North. The outcome of this relation is the extension of digital culture in physical spaces. Such grassroots organizations function as the physical space in which resilient technologies, both new and older ones, are located. As such, a culture experimentation seems to continue on the path of early internet communities. Online forums

[87] As some geometric models may not be able to hold the shape of the object, rafts are extra prints used as bed adhesions, in order to stabilize printed objects or to build strong foundations upon which the printed object can rest until the upper layers of the object are built. Rafts are particularly common with 3D printers which use ABS and PLA materials.

and peer-to-peer sharing are aspects utilized by such physical spaces, with participants sharing skills, information and tools to implement their projects. Although the presence of such culture is noticeable in mainstream reports, it requires some guesswork try and make sense of the technology and culture that sustains only by looking at figures or institutional documents. That is, despite the massive flow of information on social media, internet forums and news publications reporting many aspects of these communities, there is nonetheless a cultural language which reflects the everyday uses of the space and the technology that remains out of the frame.

The enthusiasm this culture generates owes part of its appeal to the importance that users place on their having control and autonomy over their machines and process. As the familiarization of users with 3D printing becomes more widespread, it seems that their feedback, either in voice or in practice, becomes a directing force of the maker movement and its influence on the technology. This is not a movement that preaches a specific way of reading a doctrine. Rather, it seems that the central idea around it is the expansion of practice; expansion of practice means more workshops, more people engaged and more technologies being available and connected together. The rest can take shape on their own. In the places I have been conducting observations and interviews, not many people feel confident in predicting where the development of 3D printing as a technology and idea is heading. However, there are at times discussions on the prevalence and spread of such spaces all over the world as a goal worth achieving for its own sake.

Indeed, theses spaces are so dynamic in nature that members are usually reserved on expressing ideals and a grand purpose. Rather, they work project by project, meet people who like to create in their own style, expressing their own ideas through making. The purpose of being in such a grassroots community is usually either to complete a project, craft something that is not available, fix or alter devices that are already bought, and (in many cases) have a good time in doing so. The political aspect given to them by the series of interested actors, whether they be entrepreneurs, economic policies or politicians are not of importance to such spaces. This is why what raises eyebrows in terms of the outside world is whether practical terms can be addressed; whether there is an opportunity to lower the costs of the space, bring in more people as part of a government or business scheme and ultimately things that can help reproduce and grow the community. But growth, as much as it is wanted, has to take into account and respect the values of members of the community. In some ways these spaces are reflecting the interests of the people involved that are using much of their time in acting within or taking care of the daily issues of the space. In some others, they do create the possibilities for members to engage in discussions about the current production paradigm in their own countries, alongside an attempt to critique existing social and economic structures. In the context of this study, because the production system exhibits similar characteristics to the places – a capitalist economy, gentrification close to and in the city centre, the rise of creative industries, lack of industrial and stable work for educated individuals, fragmented workplaces – although in different spaces I have found different ways of organizing, many of the themes which concerned the members and visitors were familiar across cities and countries. In such diversity, I have encountered the spirit of entrepreneurship and innovating enthusiasm, as well as the attempt to use technology in order to inspire engagement in social struggles; all these through the same practices. As such, action, practice, or whatever it is named in each case, is the distinct characteristic which drives this incredibly diverse movement.

Locating the political: Representational machines and spaces

One evening, as I was preparing to visit Leicester Hackerspace for an open hack night, I was greeted at the door by my neighbour. A greeting and a chat revealed something that touches on discussions that usually take place at the Hackerspace. "Where are you going?" he asked; "To the city centre", I replied. "Try not to spend too much money then!" he jokingly remarked. Confused at first, I soon realised that at the back of his mind the city centre was equated with the purchasing of goods. Despite the strong correlation with purchasing, there in fact various was of consuming in the city centre that far surpass the purchasing of goods and services. Laaksonen, Laaksonen and Huuhka (2008, p. 8) point out that the consumption of the city centre can be thought of as a 'platform that gives to a consumer an access to the world of social interaction, symbolic consumption, and holistic experiencing.' The city can then become a lived space, filled with 'social, relating type of experiences, they are colored by the individual's behavioural and emotional experiences' (Ibid, p.6). This short conversation touches on the heart of what Hackerspaces are ontologically producing; the idea that the city centres are far from simply being malls and other spaces of consumption. These spaces are a miniature way of showing that the city is lived space, an ever-evolving organism, rather than a collection of objects produced in a laboratory or a factory far away and consumed at the point of exchange. Cities, with the presence of Hackerspaces, Makerspaces and Fab Labs are also about inventing new ways of coping with living. The reproduction of everyday life, in this case identity creation and problem-solving through making, has made the binary opposition between consumption and production a much more convoluted matter. The availability of materials in the cities (for example one can buy PLA material for a 3D printer at relatively low prices and have it delivered very quickly) allows individuals to engage in varieties of activities that would normally have either been carried out in professional workshops, individual garages or not at all, due to the lack of information, tools and space.

Going to the city centre to visit the Hackerspace, a member of the Hackerspace would undoubtedly consume a number of different usable objects. Using the space, they consume snacks that are available in the spaces for a low cost, electricity for the use of machines, plastic for the use of 3D printers. The consumption of the first two can be identified as passive consumption practice. The qualitative change in the latter is that the very act of consumption is a productive activity in itself. What alters the equation in this respect is the consumption of plastic, more specifically the consumption of plastic for the purpose of building a prototype, which is a grey point which blurs the line between the consumption practice and production of objects. It is the activity taken which enables the individual or group of people to act in order to create, to make something that is useful to someone in some respect. Consumption in the Hackerspace resembles the ability of craft to give meaning to social activities through an active form of consumption (Dormer 1997). Such spaces become representational spaces and reflections of a new emerging cultural phenomenon called 'prosumption' (Ritzer and Jurgenson 2010); a culture of sharing reproductive activities, in other words, of creating meaning, solving everyday problems and sharing values through craft and making. So, where is the political element in this equation?

Aside from the conventional politics of certain people within the universe of makers and hackers, the most political elements are the lived experience in space and practice. At this point I would like to take a theoretical break, away from fieldwork narratives, because I think the issue of what a Hackerspace, Makerspace or Fab Lab represents is a set of practices and lived experiences that surpasses its actual function as it is configured this moment in history. Such spaces are what Henri Lefebvre described as 'Representational Spaces' (1991, p.33), described as:

> Space as directly lived through its associated images and symbols, and hence the space of 'inhabitants' and 'users', but also of some artists and perhaps of those, such as a few writers and philosophers, who describe and aspire to do no more than describe. This is the dominated — and hence passively experienced — space which the imagination seeks to change and appropriate. It overlays physical space, making symbolic use of its objects. (Lefebvre 1991, p.39)

Taking the concept and furthering the discussion of 'representational space', Hetherington argues that a representational space is one that opens up possibilities for alternative ordering, for imagining a different path than the one already in place.

> Such spaces, therefore, are not sites as such but temporal situations, events, which occur in particular places that open up the possibilities of resistance within society to certain marginal groups or social classes. (Hetherington 1997, p. 22)

Nevertheless, Hetherington argues, these practices and social spaces are not completely autonomous, since they operate under the capitalist mode of social reproduction. Yet the contradictions and fragmentation of capitalist production presents possibilities, at least experimentally, of what could be a more successful form of organizing and making within cities. If for Lefebvre these spaces of potentiality seem to be equated with freedom itself, this is not the case for Hetherington:

> …spaces of resistance are also spaces of alternative modes of ordering; they have their own codes, rules and symbols and they generate their own relations of power. (Ibid, p.24)

Indeed, this is what I have encountered in my series of fieldwork sites: potentiality, the very alternative way of coping with space, daily practices and producing things within such spaces contains within itself contradictory elements within the respective society the individuals live and act within. In other words, what is often overlooked when equating such spaces with freedom, are the limitations of such experimentations, which a closer look brings to the surface: time and availability of resources are constraints which are not questioned on the basis of class societies (Olin-Wright 2015) but as practical problems that need to be hacked through openness[88] and

[88] See for example the work of Nathaniel Tkasz on 'Wikipedia and the politics of openness; (2014) as he describes the problems of the online Wikipedia community. The fetishism of virtues such as openness coming from digital utopianism reflected on the Silicon Valley culture, when translated into politics, uncover the ideological framework of the concept.

participation from the members. A characteristic example of this culture was reflected by the perceived notion that when problems of access to the internet arise (issues of infrastructure, resources), the reflexes of the people in a Hackerspace is not to politicize this but to "find a way around it, to hack our way in order to solve any problems" (Lewis, Leicester Hackerspace, Interview). In many such spaces, Hacking[89] in abstract terms is a substitute for politics or the way of doing politics, and machines are practical substitutes for theoretical debates. Naturally, for places where a political culture is bred, hacking can be thought of as political practice, but usually the underlying assumption is that of negating politics altogether.

> Personally I don't see them having a political voice, they are too disjointed. Some people who are politically inclined maybe they will have some influence to bend it slightly or whatever, but I can't really see it a s a big political movement. In a Hackerspace people come here to hack, I don't see many political people here. (Lewis, Leicester Hackerspace, Interview)

As spaces beyond the production facility offer the possibility for the creation of altering social orders inside but also contradictory to the logic of capitalism, so it seems with 3D printing as a machine. Whilst the connection of cyber-physical characteristics and the networked restructuring of production as envisaged by WEF (2016) in the 'fourth industrial revolution' [90], this need for a change of system coincides with a variety of activities that give a character of potentiality to the emerging practices; a potentiality related to another social ordering in the social reproduction paradigm or even the production itself. The political element that seems to be missing from most spaces is an explicit political discourse. In relation to this I would argue that

[89] I use capital H in this case to denote Hacking as a formal idea. I use lower case when refer to hacking as a verb, 'to hack'.

[90] See the discussion on the 'fourth industrial revolution' in the previous chapter.

the politics of Hackerspaces and other similar communities can be discerned through an understanding of the cultural narrative and how it is appropriated within each community, the space and its position within the city. Indeed, no-one would expect Hackerspaces to perform themselves as political entities, but the lack of a clear political vision in terms of the nature of hacking and their purpose is also what gives a dynamism to the space because it allows the members to focus on practices and projects.

I consider 3D printers as representational machines that can do the same, including in their dynamic culture a variety of experiences, practices and choice that enable new ways of understanding and building machines and ultimately producing. The concepts are open enough to include competing narratives and purposes which the members and context can fill with their presence and actions. This means that the direction of the space to a large degree is determined by the most dedicated members, since, at least to member-led spaces, the only barrier to influencing the space's cultural representation is their commitment and initiatives taken. The cultural hegemony of symbols and ideas of each space can be understood in terms of its legal status, the way it receives its funds, the perceived purpose of the space, the availability of material, the time allocated by the most dedicated members[91], imagery and the position of machines within the space. Ending this theoretical pause, I should point for the purpose of clarity that representational spaces such as Hackerspaces, Makerspaces and Fab Labs are potentialities that reveal two aspects, an alternative way of doing coupled with social order[92]. As Hetherington (1997 p. 70) argues, while the concept

[91] The composition of such spaces, in contrast to earlier forms of precarious labour and informal practises (see for example Eloisa Betti 2016), seems to be consisting mostly of people with a higher education degree background who have free time to pursuit such activities as part of their leisure time. They are spaces which emphasise the importance of play and stress-free time with peers and other enthusiasts. Although some projects are aimed at commercialisation, thus being officially identified as labour after the prototype phase, many of the projects remain as 'free time' activities. As such, this composition is also reflected in the values of the space as well as in the practises themselves.

[92] Hetherington refers to 'social order' as a specific set of rules, theories and practices which correspond to space and time in a historical period. As such, especially during transition times within a totality (for example from feudalism to capitalism), the accommodation of such practices seems to be ambivalent, to contain traces of the future to come. These may be

'is too caught up with the romance of resistance and transgression, as is the more general notion of marginal space', one should not forget the social order aspect, which is the inclusion of marginalized space and culture into the social order[93] through ambivalence, as a process. By clarifying this point, we can move to understanding the central political element of hacking, which is practice.

Practice as politics

After a few attempts at printing at the Leicester Hackerspace, I met Harvey, who was also interested in 3D printing. He was part of the initial group of people at the first workshop where I was introduced to the 3D printer that was available at the Hackerspace, only he was part of the group that was interested in the practical side of 3D printing. As such, he was part of the second group who came late during the second hour. I noticed his questions during the workshop; they were very precise concerning how to operate a 3D printer, where to find the best deals in materials and machines and what are the most efficient ways of operating the software. All questions were to the point, in the context of a larger group that was more interested to see if the demonstration got their attention to such a degree that it would influence them to look into 3D printing more. The reason for this was because he had rushed into buying a 3D printer at home due to all the hype, but was still unsure how to operate it. He was in the midst of a learning process. The practical questions at the workshop extended its time span from two hours to three hours, which forced the artist to stop at some point due to exhaustion

---

organizational structures that do not correspond to standard practices or alternative cultural language that cannot justify or legitimize the existing totality.

[93] Hetherington (1997) furthermore argues that instead of seeing potentiality as synonymous with resistance and change he proposes 'seeing places of Otherness neither as panoptical spaces of total control nor as marginal spaces of total freedom' (p.18). Clarifying the argument even further, 'This is not to suggest that things will always return to the same order and that resistance is futile. Ordering is not just about fixing things in an established way so that things make sense, it is principally about ways in which social activities are arranged and distributed and the contingent effects of those arrangements' (p.35).

both on his side and the great majority of the group. From that point onwards, whenever I was visiting Leicester Hackerspace, Harvey was almost always around the 3D printing machine. We discussed a few times his fascination with 3D printer, especially after seeing that time-frame and waiting process that accompanies making with 3D printers. Imagination, he said, played an important role for many people to be drawn into 3D printing but on his side it is "more a practical tool for making, mending and developing things" (Harvey, Leicester Hackerspace, Interview).

As I was talking with Harvey one day, I realized why such a diverse group of people can act in what looks like a social movement. Practice is a key aspect that fills the gap of a political aim, the common ground. This means that such spaces do not usually have an explicit political ideology which is more developed than a generally progressive outlook aiming at secularism and inclusiveness and being open, as is the case of the politics of Wikipedia (see Tkasz 2014). If for Wikipedia the important tenet denoting its political inclination is openness, in this case we are talking about practice. In the case of Hackerspaces, Makerspaces and Fab Labs, instead of arguments in online forums by digital peers, the culture emerging is combining the online forums with having to deal with people in real live. As such, making decisions about the infrastructure or how the space should be run becomes political in its own terms, with members and visitors having to deal with their gaining experience in decision-making and collaboration by their chance meeting triggered by their interest in the technology. In trying to provoke a response I stretched the argument to include a hypothetical event in which the internet is cut or electricity is increased for Hackerspaces. His response remained practical indeed. "People will find a way around it or go back to the use of other technologies. It's a way of saying, alright, if you don't let us. I can find another way then" (Harvey, Leicester Hackerspace, Interview).

Indeed, the yearly four-hour long general assembly, discussing how the Hackerspace could be open to the greater community or where to find new premises that would encourage more people in the space to use it in an affordable way, is not perceived as formally political. Neither was the discussion what is to be done in an event of theft in the premises, related to the question of whether to install security cameras. These are questions of practice. Interest in technology, hacking and making unites individuals on specific issues, usually in expanding a sense of community values. In places where members happen to be more like-minded, projects, workshops and events with a specific context take place. In both cases, the focus of the community is not to become a beacon of political activity but rather to focus on everyday issues, such as habits or having to learn to work as a team. Practices and behaviours that were previously rigidly assumed to be the norm can be disrupted by the emergence of these maker and hacker communities. How education can alter completely, how information is distributed, overcoming problems of division of labour or reproduction, opening up of knowledge to non-professionals are some of the many issues that such spaces brought to the table, with the help of technologies such as 3D printing.

People involved in such spaces often function as distributors of a new cultural language, one that does not have an ultimate source of 'holy scripts', but has a very powerful message: experiment! Other than experimenting, very few rules are stable. Repair, hack, upcycle, play, developing a prototype, general understanding of electronics, microcontroller knowledge for solving specific personal or community issues that arise, are all legitimate reasons why a person wants to join such a place. Even the words themselves do not mean the same thing for people standing next to each other. In fact, there are instances were certain individuals involved in the same project do not hold the same values in terms of the aforementioned language. For example, a designer meeting with an engineer to engage in a project do not have the same understanding on the concept of practicality. As a frequent visitor to Leicester Hackerspace said, many times he "prefers to work alone, but in some situations, where help is needed it is better to go slow with others, rather than being unable to start the project" (Duncan, Leicester Hackerspace, Interview). Some may express grander visions on the state of their actions, such as developing low-cost environmental technologies in rural areas, others just do it for the fun.

What the maker movement lacks in ideological and political clarity in terms of goals (Soderberg and Delfanti 2015), as it is also understood by many members and visitor enthusiasts I have encountered, it makes up for in the generation of a plurality of concepts and practices that have the potential of disruption of some sort. A disruption may be political, economic, technological, management innovation or any other kind. Personal convictions and motivations play an important role in what projects are chosen and how a person can understand the variety of activities completed and their meaning. In this respect, although the frame by which such spaces function is part of a larger global context, each is one community in its own right, in which the members have a personal interest in developing.

The classification of spaces into either Fab Labs, Hackerspaces or Makerspaces has to do with the meaning and the organizational purpose of the space. For example, it is understood that Hackerspaces were the natural outcome of the open hardware movement, as were 'Hacklabs' in the 1990s as a natural outgrowth of the free software movement. However, as Maxigas (2012) suggests, Hackerspaces have quite a different historical emergence from Hacklabs. Makerspaces, as Tom from Leicester Hackerspace tells me, resemble more "places that the individual wants to build something from scratch", they usually do not project any explicit ideological origins in terms of politics, except in good practices[94]. In addition, there is the Fab Lab Charter, which are general rules that Fab Labs have to adhere in order to be recognized by the community. The rules include the ability to provide 'access to tools for digital fabrication', whilst it does not exclude the incubation of activities and prototypes that can later be commercialized 'beyond rather than within' Fab Labs (Fab Lab Charter 2012). As such, understanding the relation between the space, the ideas flowing and the practices within them, designates the use of 3D printing and its position within a context.

[94] Fab Labs on the other hand have a very specific origin, coming from the work of Neil Gershenfeld as I discussed in the previous chapter.

As such, what is being carried out in the case of these grassroots communities resembles more of a lifestyle attitude that sometimes engages in contentious politics[95] (Tarrow 2013). If a lifestyle is a way of expressing individuality (Featherstone 1987, p.55) through 'everyday practices, tastes, consumption habits, leisure activities, modes of speech and dress' (Haenfler, Johnson and Jones 2012, p.1), the 'Makers' movement' seems something more than an individual self-expression. Rather, it engages in 'individualized collective action' (Micheletti 2003, p.24) which promotes a way of being, in this case making, through individual self-expression and way of life. In this sense, what Harvey understood (with my interview question) as the political course of Hackerspaces and 3D printers was in relation to contentious politics, in which politics is understood as 'political action and protest events' (Staggenborg and Taylor 2005, p.38) whilst not including in 'politics' all these questions of how to run such grassroots communities and how these communities evolve in practices, in other words not taking into account the reflection of politics in such cultures (see Snow 2004 and Taylor and Van Dyke 2004). Certainly, the way the Maker movement is cultivated, its direction and distance from the corporate world and the way it is managed on a daily basis constitute a political action within the movement itself rather than in its purpose (see for example Zald 2000). In other words, the purpose is the action itself. This will become more evident as the chapter progresses.

Political consumerism

Hackers and makers involved in the movement in any way are not, as already mentioned, thinking about their actions as inherently political. However, these actions, particularly ideas around opening up and sharing information and machines can be understood as a form of political consumerism. People are choosing carefully what machines they are buying, considering factors such as open software, open materials. As such, there is

[95] In short, contentious politics refers to a wider range of practises other than institutional, which are used to denote a political stance, e.g. the use of open source software at all times. Contentious politics are collective and public and are usually associated with social movements.

a sense of moulding an identity with choices made according to their values. In contrast with contentious politics where we can see organisations structuring themselves around the aim of carrying out a message within certain institutional confines, political consumerism is broadly defined as actions done by consumers 'with the aim of changing ethically or politically objectionable institutional or market practices' (Micheletti et al. 2006, pp. xiv - xv).

That means that what hackers and makers are undertaking is by definition political consumerism, even if when carrying out their actions, they do not plan to concretely explain their actions as political consumerism. Adjusting this to what can be done with a 3D printer and altering the configurations of objects using 3D printing is a promise that users I encountered felt is worth noting. "One of the most important aspect of 3D printing is that it gives existing objects a new lease of life", Lewis from Interact Labs suggested. But the technology is not the critical factor in this; the machine is only a possibility that the Maker culture materializes, a culture that promotes an individual's agency for collaboration as opposed to a collective understanding of the individual. Each space has its own 'mind-set' and set of collaborative skills. Leicester Hackerspace felt like a collaborative environment between artists and other independent individuals, sometimes promoting the idea of networked start-ups. In the case of Nottingham Hackerspace, the atmosphere felt closer to what Raymont Malewitz (2014) identified as 'rugged consumerism', a derivative way of practicing political consumerism, describing the culture cultivated at the premises[96].

As soon as I entered Nottingham Hackerspace for the first time, I noticed something on the board next to the door. It was a copy of something called 'The Fixer's Manifesto'. The central tenet of this manifesto was that if one was not allowed to open the machine or object to see and be able to change things, that meant that it was still owned by the manufacturing company. A practical guide focused on positive outlines, the Fixer's manifesto pairs well with the narrative of making as an active force for

[96] See 'Rugged Consumerism in the Digital Age' in the introductory chapter

positive change, portraying mass-produced objects and devices as the main problem neutralizing creativity in everyday life. Advocating such an active stance on making, the Maker Movement aims to inspire people through a collective imaginary of individuals changing the world.

> I am very excited about the Maker Movement. The more I look into it, the more I believe that it's very important to America's future. It has the potential to turn more and more people into makers instead of just consumers, and I know from history that when you give makers the right tools and inspiration, they have the potential to change the world […] The creations, born in cluttered local workshops and bedroom offices, stir the imaginations of consumers numbed by generic, mass-produced, made-in–China merchandise. (Bajarin 2014).

The inability to fix, repair or modify objects because of some law or company policy is considered as scandalous to a culture whose existence is predicated on being able to manipulate the hardware and software of whatever objects users can get their hands on. Having considered the words of Lewis from Leicester, it became apparent to me that this kind of thinking is not that of an artist, but more of a collective imaginary that exists within the Maker and Hacker culture, at least in the areas where I conducted fieldwork. The imaginaries are usually shared amongst the different spaces across countries, with variations, since the internet and high mobility of the members and shared past configurations of social systems increase the capacity of ideas being shared. Thus it seems no surprise that by geographic proximity, the ability of members of Leicester Hackerspace to go and see the Nottingham Hackerspace has produced some similar thoughts on the matter.

> The whole point of 3D printing after a while, is that you start to think how you can print stuff rather than having to go and buy stuff. I think this is what 3D printing can

> do, perhaps objects that are thrown away, it gives the opportunity for a new lease of life. For example, I printed a little holder for the cables because they knotted, the manufacturer was selling them about £10, so I designed one of them, it was very easy, and printed it up. (Lewis, Interact Labs, Leicester, interview)

Having in mind this type of lifestyle or anti-lifestyle stance, if it can be thought as such, ‘The Fixer’s Manifesto’ reveals a basic framework of collective individuality and political consumerism.

The Fixer's Manifesto

from the makers of Sugru, version 2.0

1. If it's broken, fix it! Everyday practical problem-solving is a beautiful form of creativity, and just a little subversive. **2. If it's not broken, improve it.** A tiny tweak can transform how something works for years to come. **3. And if it doesn't exist, make it.** Everyone is inherently creative—even if we don't think we are. **4. Give your stuff a longer life.** In a world that's full of waste, every fix counts. **5. Disposability is a choice.** When we double the life of our things, we halve what goes to landfill. **6. Resist needless trends and upgrades.** Fixing frees us from the tyranny of the new. **7. Embrace the stuff we already have.** Let's use our imagination to keep it, use it, love it, fix it. **8. A fixed thing is a beautiful thing.** Every fix tells a story. **9. Nurture curiosity.** Anything can be learned by doing. **10. Share your ideas.** With each fix, we build a global movement for positive change.

Fixing is good.
It's good for us, and good for the planet.
So, let's make it a way of life.

Figure 18 Fixers' manifesto as it appears on the website. A printed version of this is located at the entrance of "NottingHack"

A general guide, 'The Fixer's Manifesto' is an orientation for people to embrace making and an apotheosis of individual expression through making. It problematizes issues of everydayness, such as throwaway culture as a lifestyle choice, thus potentially raising a political problem. Such a stance politicizes consumerism on two levels; firstly, by considering the ability to alter consumer electronics and machines as a right of the user. Second, perhaps not by intention, the politicization of fixing reframes the city centre from a space of passive consumption to as a space where active consumption and user rights are exercised.

“What are you up to Friday night here?” …*making is connecting*

Awaiting a 3D printer to complete the task can at times result in waiting for hours. But the function of Hackerspaces is characterized by both being spaces of production at the same time as social centres. As a social centre, these grassroots community workshops are open for community gatherings; as spaces of production, they provide tools (sometimes of industrial or semi-industrial quality) for groups or individuals to produce prototypes or unique personalized objects and machines. Another dimension is the innovating ways in which the space is organized according to the needs of the community. The personal involvement of members in designing their space and the choice of machines that will be available reveals an emotional element which sometimes takes a central role in the running of the space. By not being a professional site in which behaviour is coded and performative, in grassroots workshops the mingling of personalities can be dynamic or a barrier to the growth of the community. Connecting in such cases requires a mixture of materials, humans and non-human elements. There is emotional connectivity between participants, i.e. finding people whose making or hacking time can result in enlarging their social base or connecting people with each other in order to increase collaboration of any kind (either to build products or create objects for makerfaires). Finally, there is the connection of physical entities (such as people, plastics and other materials) with hardware and software entities (Cloud, USB sticks, personal computers, Arduinos etc). Making and hacking at a Hackerspace is about understanding the city centre as something more than a consumer space, something more than just a space for coded behaviour and therefore as a place that mingles connections and emotions.

The first time I set out to visit Leicester Hackerspace on an occasion that was not an open hack night, I was unsure what to expect. At an open hack day, people notice newcomers and there is usually a responsibility for certain members to show people around and there is a chatty environment. Therefore, there is not to be done in terms of hacking and making since the space has limited capacity. It was Friday night, and to my mind, it was a good occasion to test my skills on 3D printing. I assumed that no-one would be at the space, since Friday nights are usually reserved for other activities in the city centre. Many pubs and clubs surround the area next to the ‘creative quarter’ which makes the prospect of seeing people heading for parties as the most likely possibility. My calculations were not far off – however they were not exactly true either. As I arrived at the Hackerspace, I saw another member who I recognized from previous “open hack nights”. This was a person with high technical education, whom I have seen most of the times I visited the place. He likes to spend his free time at the space learning about new technologies and hacking as a hobby rather than coming only when he has a project to carry out. He is also one of the most social and welcoming people in the space, which in combination with his knowledge, makes him the person many newcomers feel is the right person to talk to. Due to his broad knowledge base there are always helpful insights or information he can share, and he is keen on helping others.

“Hello,” he said with some surprise, “what are you up to here on a Friday night?”. “I came to print an object,” I confessed. I had finished my second introduction to 3D printing just a few days earlier with Lewis, a session which was carried out by the same person, and which took place this time at Leicester Hackerspace. After two three-hours sessions, I felt confident enough to begin my first print attempt of my own object. Tony’s surprise was based on the assumption that on Friday night the Hackerspace would be empty. The welcoming note and gestures suggested that he was pleased to see somebody trying to make something instead of just looking around. My presence alone would not be a reason to win more than just a warm welcome. But an attempt at making something opens the door for long discussions amidst experimentation. As I attempted to start my printing, I realised that the theoretical introduction that we were given at the sessions were not sufficient to be able to print objects. Despite detailed note-taking, much of the practical side was done by the instructor as procedural task performance, rather than by us. It was obvious that I needed some time to print on my own rather than be shown, in order to gain experience.

Additionally, it was evident that printing the design I downloaded through Thingingverse was not a straightforward download and print task; the download window itself had a section with comments in which the initial designer and the rest of people who printed the design had notes on their problems according to which machine model they were using. I had to level the bed layer, to find how thin I wanted my print, what temperature was needed in order to print the specific object shape. Ultimately, I had to take into account the nuances of this specific machine, as crafting the machines means that problems arise on an individual basis. My difficulty in calibrating and connecting the software eventually caught the attention of Tony.

Tony spent much of his time trying to learn with me about 3D printing on that night; he himself was not very familiar with the specific technology. What followed was a night were the discussion led not only to a practical understanding of the 3D printer and the process in the Hackerspace but also to an understanding between the two of us. Whilst some members of the Hackerspace had some difficulty recognizing me, time spent using the 3D printer had an impact on members getting to know me personally. The space and context provided the breeding ground for engaging in lively discussions about other technologies within the space as well, but also on other issues. Trying to complete a task using 3D printer in a Hackerspace turned making from a personal to a social activity. This became apparent in my interviews as well, as Andreas from Hamburg and Benjamin from Leicester articulated that their own way of creating objects prior to Hackerspaces were important to them for various reasons; for Andreas, it was part of some alone time, and for Gareth part of his conception that working with others decreases the pace of the projects. But the reverse also happens for many of the members, for whom, being introverts, social activities in the Hackerspace turn into personal connections with those around them. That Friday night, it became apparent that in exercising their right to fix software or hardware or to make an object, makers and hackers are connecting not just through skill in order to complete a project, but as communities growing and developing through emotional bonds too. Of course, this aspect has advantages and disadvantages, as personal entanglements can foster greater co-operation between members but can also hamper organisation if people do not get along on personal terms.

But connecting in making through 3D printing can be more than emotional; it can also be about connecting individuals and communities between them and circulating ideas. Such connections are most expected to take place in increasingly popular Maker faire events. The members of "Derby Silk Mill" seemed very proud of the "Derby Maker Faire", which is growing each year. That means that as people from around the city are more interested, there is an increase in collaborations and the attention of Derby as a viable place to present creations.

The concentration of 3D printers in Maker faires and in Hackerspaces is laying the ground for prospective users to follow these spaces and events in order to experience this new technology. Even individuals who have the ability to purchase a 3D printer for home use usually lurk around Hackerspaces, Makerspaces and Fab Labs as a way to gain access to new skills and tips on how to use the machines. The Maker faire can be a place of connecting with various individuals and projects that may not be aware that they exist. It is also expected that communities and individuals will browse through a wealth of projects in which they may join or just get inspired.

Implementing a project, presenting at a Maker faire, just participating or being present there, all entail connections of some sort. For some, it is a way to meet potential customers, for others fun, and for corporations it is a very lucrative way of advertising their needs and technologies for potential customers and future employees. The value of connecting is amplified by the events themselves, where activities to engage the participants in visible spaces, either physical or virtual, take place. The goal of such events is usually to create a circular environment in which all participants can access as much information as possible, but also to be able to see how these individual projects are connected to the larger picture. By the end of the event, some of the participants will be inspired to create their own projects, join a team project or a community or get information about a university department, or become accustomed to new ideas that emerge within the Maker movement. But the general sense one receives at such an event is that a Maker faire, apart from connecting, is about education through making; education through abundance of information, which can be received by anyone participating. There seems to be no hierarchy and authority; the events are planned to convey that all participants, whether individuals, communities, universities or corporations are participating on equal terms. Whether this is true seems of no importance, as the collective goal is to promote (for their own terms) making as an important facet of education.

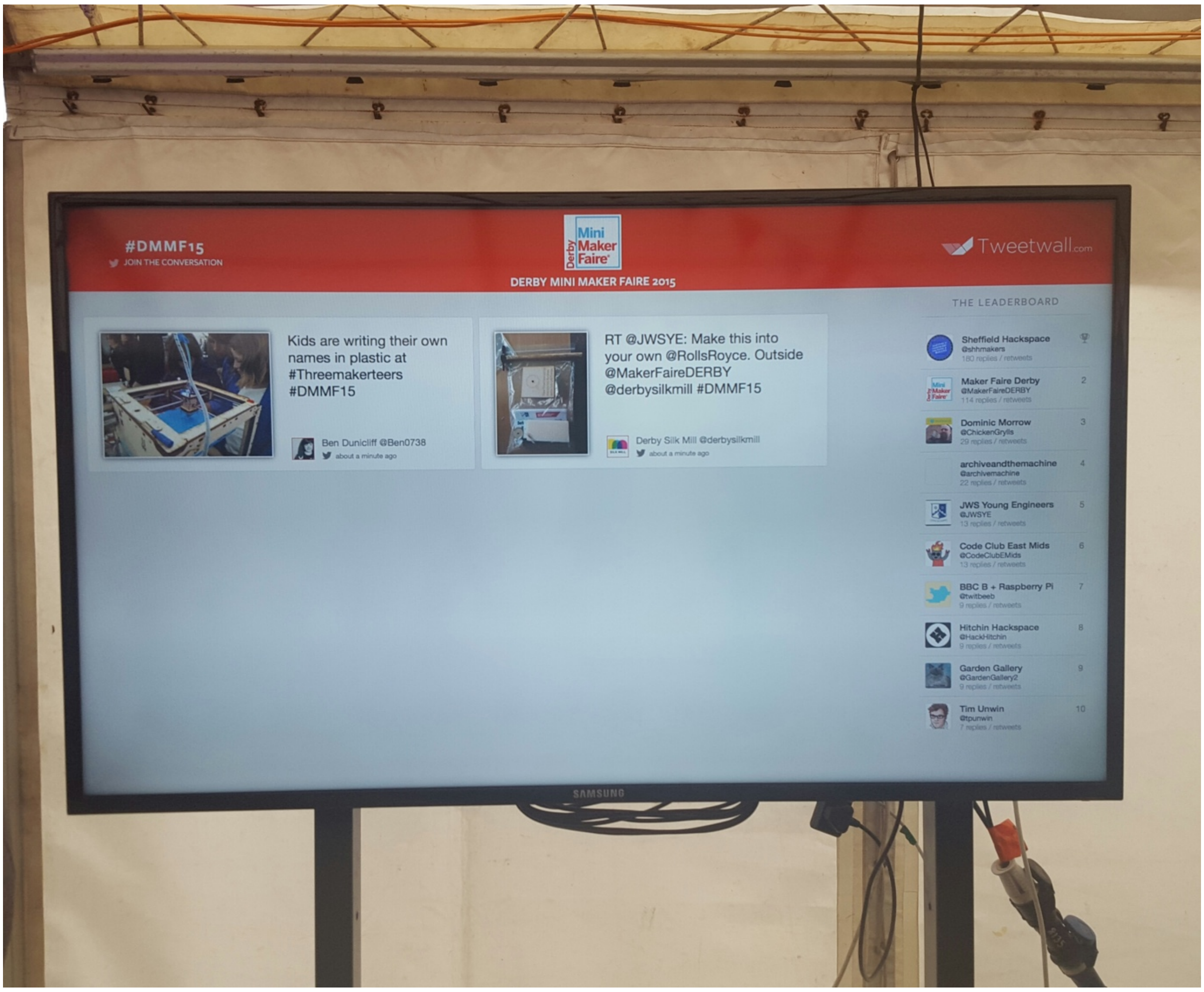

Figure 19 A digital board shows the tweets made by the people who are present at that time at Derby Maker Faire, as a real-time surprise map of creations within the space. Photo Credit: Leandros Savvides

Educating and the circulation of information in a Maker faire takes a rather different form to professional or even educational institutions. In such context one can give important informational tips on something they are not an expert on by profession. This gives extra resilience to the process whilst giving a sense of equality to the people involved, that their insights are welcome even when they are not supposed to know the whole process. Educated guesses on materials, knowing where to find information on the internet or just asking an outsider's valuable question to those who know how to operate the machines are important parts of the process. The organization of people and the space takes into account the best possible route for promoting collaboration and interdisciplinarity, in which members who might be interested in the most unconnected of topics can find something in common to share or even create. For this purpose, disseminating events, projects and the skills that people carry in the space is a crucial task. As shown by the above figure, this type of virtual connectivity is aimed at attracting physical connectivity; in other words, aimed at bringing people to see, have a taste and perhaps experience the capabilities of machines through learning from others.

Positioning and purpose of 3D printing in four different spaces

The cultural imaginary of empowerment through 3D printing cannot be overstated in some instances. As already mentioned, 3D printing provides an excuse and attraction for the new spaces to attract people into the spaces, and conversely, the spaces provide the physical entity where socialization and experimentation with the technology takes place. The argument I want to make in this section is that the position of the 3D printer within the space usually points to the imaginary of the space and its function within it. This is because, as much as 3D printers are part of the Hackerspace, the Hackerspace is much more than just a 3D printer and as I was told by Lewis (Leicester Hackerspace, Interview) 'the Hackerspace existed before 3D printers and will exist after it, but maybe 3D printers need the Hackerspace more than the other way around'. As it happens however, "[The] 3D printer is the glamorous device everyone wants to know about". Lewis was trying to make a point about why, despite the fact that in some instances people may not find 3D printing useful for their work, it nevertheless stands out in the imaginary of what it is and what it can do in the future. “I think the most important thing about 3D printing” Lewis says, “is that it excites people. It makes them want to come to places like Phoenix or to go Hackerspaces. It is exciting because it engages people.” (Lewis, Leicester Hackerspace, interview)

As I have been traveling back and forth between Leicester Hackerspace, Nottingham Hackerspace. Derby Hackerspace, Cambridge Makerspace and the Fab Lab located within the inner parts of the St. Pauli in Hamburg, I noticed that despite the common denominator of practice (meaning making or fixing) attitude towards 3D printing was particular to each space and reflected different communities with different goals. For small spaces such as Leicester Hackerspace, 3D printing is a good way of generating activity and interest in visiting rather than a fully functioning facility. The 3D printer occupies the space opposite the stairs, so it is one of the very first things guests and members are facing when they fully enter the space. The community make sure to eliminate most barriers to using 3D printers, with some exceptions, for example if an individual wants to use it alone, they have to take the introductory workshop, which normally costs between £10-15. From then on, the cost in 2015 was about £1 per half-an-hour print[97].

‘NottingHack’[98] is located very close to what is called the ‘creative quarter’ of the city of Nottingham[99]. Like Leicester Hackerspace, it is a non-profit, community-run and funded space whose purpose is to ‘provide infrastructure for our members to learn and hack’ (Douglas 2000). It is housed in a former Victorian lace factory and warehouse, now a building

---

[97] To give a perspective on prints, a standard plastic whistle takes about 20 to 40 minutes to print, depending on percentage filling. Similar mass manufactured whistles can be found in retail market at the city centre for about 20 pence each.

[98] Nottingham Hackerspace is called ‘NottingHack’ by its members.

[99] The Nottingham City Council website mentions the creative quarter as part of the efforts for generating [economic] growth in the city through start-ups and other technology related businesses. “The Creative Quarter (CQ) is a cluster of start-up and established businesses and independent retail in the historic Lace Market, Hockley and Sneinton areas of the city centre. The CQ is home to clusters of technology-based companies in Nottingham’s growth sectors of life sciences and digital content.”

which accommodates light industrial facilities as well as ‘office suites, studios, workshops’ or even ‘a mailbox service for companies that need a business address without the physical space’ (Ibid). I had the opportunity to meet one of the founders of the Hackerspace, who explained their personal experience of the story behind the space. An environmental engineer, interested on issues between environmentalism and electrical engineering systems, Alastair went to the Philippines for a year through an NGO after he finished his PhD researching off-grid devices at Loughborough University. Specifically, he mentioned “off-grid remote power supply systems, generally for rural farming communities, very small, within the realm of 100-200 people.” He was doing things such as “solar water pumping, wind water pumping, solar battery re-charging, hydro-powered milling machines”. This experience brought in a large social aspect. This was the main barrier in that environment, as he suggested: “it’s a bit about access to education and technology. But money and politics are as big challenge, if not bigger than the technical aspects of the issue” (Alastair, Nottingham Hackerspace, interview). Returning from there, he attended a talk on open energy monitoring by a friend of his, at London Hackerspace. This is where he started getting interested in finding a Hackerspace in Nottingham. Realising that he was the second person to be interested in such an endeavour, he met the other person to discuss the possibility of creating such a space in Nottingham. The time seemed ripe as others joined the venture, after a few meetings at a pub which then housed their idea under a cheap space temporarily. After some time, they moved to where it is housed today. For Alastair, the Hackerspace is a place that he is highly involved in; as he is self-employed, he uses a lot of the tools available for his own work.

Like Leicester, ‘NottingHack’ has an open hack night that non-members are able to attend, either to see the community and facilities to join or in order to create something and use the space on the day. Upon entering the building, walking up the stairs, you enter through the lounge. This is a space where members and visitors can sit in comfortable sofas, play with music, read books and other literature on a variety of topics – making, hacking and including social science books The room is separated by a thin plastic curtain, which is the next room. Here one can find working tables and graffiti on the wall that shows the ideological leanings of the space. It is next to the administration office, the kitchen, bathroom and the workshop. It is the main room which besides connecting all the rest is the one hosting knitting machines and 3D printing next to each other. The workshop floor has a section of microelectronics, woodwork, painting, metalwork and a very busy laser cutter. It is where injuries can happen, thus it is unlikely one can see people in the workshop floor without a reason, as happens with the lounge room and the open-plan working tables room. The general feeling is that a 3D printer is an entry level making tool, classified as an educational playful technology with no age restrictions, rather than a semi-industrial tool that can deliver compact objects and prototypes.

At Cambridge, things were different, as the Makerspace was an extension and a meeting of the academic community and individual makers, usually with prior experience on either hardware or software. After some time discussing 3D printing with a member of the Cambridge Makerspace, I was invited to be able to see it in person. In the case of Cambridge Makerspace, where the space is part of an attempt to foster innovation and give tools to different individuals and groups to create things, the 3D printer is a machine that signifies the ability to 'do things'. The meaning of adopting such a stance is twofold; first, the fact that people do not wait for top-down approval for doing things. Secondly, the machines are the means to apply a motto where the act of doing is also the goal. The sometimes untold connotation is that machines such as 3D printers are enablers to active engagement, both as individual achievement but also as participation in social gatherings. Doing something is what matters, what propagates the meaning of the space and the community's growth. As such, finishing something for the purpose of consumption is deemed as boring and procrastinating over the issue that needs to be tackled; that is, an alternative way of thinking about labour as play and consumption. It is also a form of participatory decentralized system of organizing that refers to the name adopted by participants in technology cult festival Burning Man (Chen 2016). As such, the cultural imaginary of the space seems to be more about the enabling of individuals to do their own project using the tools available to them. This utopia is not a distant future to be attained but rather a state of doing that the space makes available.

Figure 20 This board is located in the Central kitchen room of Cambridge Makerspace. In the middle is located a note on 'Do-ocracy', which is a core functioning mindset. Photo Credit: Leandros Savvides

The difference between Cambridge Makerspace, NottingHack, Leicester Hackerspace and other spaces I have visited in the UK in contrast to Fabulous St. Pauli is that they utilize 3D printers along with the rest of the machines in order to develop and maintain a recursive public [100]. As will be discussed further in the chapter, St. Pauli shares cultural values of the above, but engages in social movement politics as well.

[100] See previous chapter's discussion. In addition, see Christofer Kelty's defining explanation 'A recursive public is a public that is vitally concerned with the material and practical maintenance and modification of the technical, legal, practical, and conceptual means of its own existence as a public; it is a collective independent of other forms of constituted power and is capable of speaking to existing forms of power through the production of actually existing alternatives' (Kelty 2008, p.3).

Figure 21 Cambridge Makerspace's room for reading and presentations. There are books for help as well as inspiration on the walls. Photo Credit: Leandros Savvides

Figure 22 Figure 11: Sponsors of Cambridge Makerspace next to the entrance. Photo Credit: Leandros Savvides

St. Pauli's space has a different understanding of what the space and machines mean than Cambridge Makerspace as well as the other UK spaces I have visited. It is the place where I had my first encounter of a place where the community had embraced explicit and particular political visions of 3D printing and a space within a city. It is a space where 3D printers are prominent within the space, where the 3D printers are not only enablers of doing projects but also incite a theoretical discussion about a number of issues, such as technology, capitalism and gentrification [101].

Figure 23 Some woodwork being done at Fabulous St. Pauli. The room in front of the woodworkers is used to create things with microelectronic components. Photo Credit: Leandros Savvides

"Our Fab Lab in Hamburg is a bit different because we started it from a right to the city context, out of the Hamburg Right to the City" said Neils as he welcomed me at their space. Not only a Fab Lab, but also a political space, or at least a space that was shared by people with a political vision, "I want to show that he has a political vision about RepRap, it is not just tinkering. Why are we doing that, what would we like to achieve in the long run?" (Neils, Fabulous St Pauli). As I entered the space, I saw the figures inspiring the initiators of the space. Underneath the inspiring figures, there is a bookshelf that includes books and brochures on open design, environmental issues and architecture.

[101] For a more detailed analysis on this, see 'Entrepreneurship and Social Justice' section later in this chapter.

Figure 24 Fabulous St Pauli. Adrian Bowyer is the first plate starting from the top left. Second to right, Neil Gershenfeld, academic at MIT and founder of Fab Lab movement Photo Credit: Leandros Savvides

The working space is open-plan; on one side there is a heat press machine, a laser cutter, three 3D printers (two bought and one assembled by members) and a manual craft machine. These are separated by a table in the middle for meetings and learning activities. On the other side of the working space are semi-industrial woodwork and iron cutting machines. The electronic machines are usually used to introduce members to certain technologies, or in some instances to help members and visitors with their projects. Perhaps the most important aspect of 3D printing usage under such setting is its introduction alongside the artistic and industrial imaginaries that link this particular Fab Lab to a wider understanding of social transformations that take place using such desktop technologies.

Figure 25 Introduction to 3D printers at Fabulous St. Pauli. On the left, a laser cutter - on the right, a bookshelf and in the middle, a working table. Photo credit: Leandros Savvides

At this point I should point out another factor that may be overlooked. There is not yet any official study about health-related problems that 3D printers may be involved. In Hackerspaces, because the setting is determined by the users, industrial health and safety regulations do not apply. The more organized a space is and more industrial-quality machines are available, the more pressing health and safety issues seem to be. In some cases, as is the case of St. Pauli in Hamburg, the authorities did not inspect the space on such issues. As far as the users are concerned, the authorities might not even know what exactly happens in the space. “As far as they know, we just rent a place, they have no idea what is happening inside”, I am told by Hardy, another member of Fabulous St. Pauli. when I asked how the space meets health and safety regulations. This gives some sense of extra responsibility for members who do know how to operate the machines; mistakes can lead to accidents, which can then drive people into thinking of the space not as a creative place but as an amateur one with dangerous facilities.

In bigger and more organized Hackerspaces such as in Nottingham there is a growing emphasis on health and safety regulations. Due to the availability of mid-range industrial machinery, most of the machines need induction in order to be able to use them. But whilst in the UK there is an almost instinctual approach to health and safety regulations, coupled with the basic rules these spaces are obliged to perform by law, in the case of St. Pauli authorities do not bother the community with such issues; therefore they need to think such issues by themselves. As such, the location of the 3D printer within the space falls under the category designated by the community, either as a fully safe machine or a machine that can be placed along the lines of a light industrial one.

Figure 26 Basic first aid kit at Leicester Hackerspace Photo Credit: Leandros Savvides

Despite all their similarities, the different spaces I mention in this section have some considerable differences. Whilst all share a general positive attitude towards making and hacking, there are spaces in which a 3D printer is part of a starter pack machines that can fit into small space whilst attracting new members (Leicester Hackerspace). Other uses include a child-friendly machine where playful learning can be practiced (NottingHack), a tool that can help create innovative tools as part of academic research or a start-up business (Cambridge Makerspace) or a machine that can aid us in new ways of understanding design and social transformations (Fabulous St. Pauli). Priorities set aside, 3D printing uses can overlap between spaces and thus seem quite similar to an outside visitor. However, as such communities develop, the purpose of 3D printers seems also to evolve according to the needs of the community; hence, the community makes its choices according to what 3D printers to buy or create, what kind of materials to use and where to fit them within the space.

Maker infrastructure I: internal organisation

On 12 March 2015, I attended the general meeting of the Leicester Hackerspace. During a general meeting, the members are asked to contribute beforehand any the important issues they want to put on the agenda, and bring with them any thoughts on secondary matters. At the end, there are elections of the new board members, the people who will take on most of the caretaking-related activities during the following year. The interested individuals usually present themselves with the vision they intend to work with and what kind of qualifications they have to enhance their chance of succeeding. As was expected for a new Hackerspace, after arranging the next meeting first, the meeting opened with a discussion of the economics of the space, where the financial figures for the year were presented. Charts were projected on a screen to show the costs, and since the space is member-led, -funded and -run, there were answers on how the community managed to run the space. The agenda included a discussion around membership and ways of accessing the space, a discussion on whether a new space should be found, how to find new equipment and possible donations, IT issues, communicating through social media and the involvement of people who might be able to conduct workshops and events at Leicester Hackerspace or elsewhere representing the space.

The infrastructure built around the city is a factor worth having a debate on, as many such maker spaces are dependent on institutional support, either directly or indirectly. For example, in the case of Leicester Hackerspace, the availability of the aforementioned building with relatively cheap internet is a must in order to start considering basing the community workshop there. Another problem that is worth considering is the compatibility of electricity type with the machines intended to be part of the community. Large machines such as laser cutters require a lot of electricity power that not all buildings are able to provide. Another issue to take into account is the accessibility of the place for the community intended; in other words if the members are aiming to attract people from all socio-economic backgrounds. Being close to the city centre with bus stops nearby was ideal in this case. Along with the physical infrastructure, which proves to be the most difficult, online infrastructure is the other part of the story. Having access to already-made digital infrastructure (for example large platforms such as Facebook and domain providers for website hosting), what remains to be sorted out is labour time and organising in the form of volunteering, in order for the community to reach people through social media, Google groups, websites, and so on. These are the basic elements that provide the material and immaterial basis for the existence of such spaces. The lower rent of the space than in spaces designated for commercial purposes gives the initial group of people the opportunity to start the project, with the help of the members.

The method of contributing was the 'pay as you feel' or 'PAYF' scheme, which is one of the most equal forms of contribution. Taking into account that not all people coming to the Hackerspace have the same economic status, this particular community has decided to take into account socio-economic criteria and allow members to pay as much as they want and can for using the space. The economic crisis is another reason why this method may seem attractive to members, as having an open way of contributing generates more inclusion for lower classes. The personal contact of people allows to know with few exceptions the relative socio-economic conditions of each member, how much each person is using the space and for what reason. This model is also predicated on the projection that membership will surge in relatively short amount of time, within months, giving the space the money it needs to cover its expenses. At the same time, this approach will give freedom to the members from thinking about membership issues in terms of whether they will use the space as much for the designated amount; 'pay as you feel' allows the people regulate their membership on their own according to their use and capability, knowing the needs of the community and taking them into account when making decisions. At times, if the expenses cannot be met, an accounting logic [102] may overshadow the members' decisions as well. Increasing the profile of the Hackerspace is the pathway that usually gains ground (as in this case), which speculates in bringing more potential members, skills and resources, solving several money-related issues and taking the Hackerspace to new levels of development.

Understandably, in such spaces which are conducting their first steps, opinions are varied about how the space can survive the first few years until a sustainable solid infrastructure can be put in place. A growing community means new ways of organising and new directions may be taken as well, which any plan must allow. Leicester Hackerspace's original members had an informal but well-articulated vision of spending the first two years in Makers Yard at the time of the research, and have relocated twice since then. During the first year, the people involved spent time to learn each other's needs, and manoeuvred between different visions of the space. Inevitably, the discussion focused on the question of who is considered a member, considering that being a member of a maker and hacker community requires a degree of trust. Consequently, there was a discussion whether if someone was a paying member of the space (but did not socialise with others), whether they could be considered a member of the community. The answer could be crucial to resolving issues of who has access to the space; the goal was to be as inclusive as possible but allowing those who were already members to have peace of mind about who could have access. One of the reasons for this was that, with the equipment being on site, a possible theft would endanger the trust of the members which the whole community culture presupposes. Such was the case, for example, in Cambridge Makerspace, the situation being resolved through a new arrangement of expensive equipment in a new room

[102] By 'accounting logic', I mean looking at things as a cost benefit analysis. Sometimes, Hackerspaces struggle to balance between making and the need to increase money for paying expenses. This might include taking actions which are not necessarily promoting making but are bringing money into the space. Sometimes however, these two can be intertwined, such as creating more Arduino events or 3D printing introductory courses, which not only bring money into the space but also increase interactions within the space and the flow of people in order to grow the community.

with locks installed. At Leicester, there was a discussion about whether to insert a camera only looking at the door, so that the members can feel free from being spied upon, but at the same time safe in terms of their belongings. At this general meeting at Leicester Hackerspace, finances were the big issue because expenditure was barely met. The presentation given by the member responsible showed that the income of the community, although allowed it the space to function for the year, nevertheless was insufficient for expanding the community. It occupied not only the time allocated for the discussion of finances, but being financially insolvent came up endlessly during most of discussion on other matters too, such as bringing in more machines and materials. During the meeting, members justified their opinions, comparing the Leicester Hackerspace to those in nearby cities, but also through their understanding of the differences in development and community members. For example, the space that only recently opened in Coventry had a minimum subscription of £25 and was mainly operated by an individual rather than the community. This means that for many people who would be irregular users, such an approach would not be an appealing. It would place unnecessary strain on those who are members of multiple Hackerspaces of the region to contribute to all of them to help them grow. In addition, it could create barriers to a variety of other users; those university students who wished to spend some time in the space but were not prepared to be regular members, those who just donated a small amount just because they thought it was a good idea, and those who had considerable financial limitations. “They already have problems in their everyday lives” an elder member suggested, “we do not need to give them a hard time too”. The issue of finances is a hurdle to most spaces, where according to the structure of the space, there is an income system to sustain themselves. What works for one community might not work for another.

Nottingham Hackerspace, for example, the largest (both in members and space) Hackerspace with a ‘pay as you feel’ system in the region, was unusually successful at bringing in new members at the right time when they moved to the new facilities. Within a few months the attempts of the community to grow surpassed initial positive calculations by managing to bring in many members and financially stabilize the community. In Germany, by contrast, to solve the financial issues at Fabulous St. Pauli Niels confessed that there might be a hope that their community might obtain funding through the EU. They saw this possibility from the experiences other Fab Labs in the Netherlands. This stance seems contradictory to the idea of having no sponsors and having the freedom of the members from institutions, but the options in this case are limited. For the people of Fabulous St. Pauli, having a relationship with the EU through funding schemes is better than collaborating with the local authorities, which are seen as an immediate physical barrier, sometimes opposing and blocking their plans. Instead, the EU to them is an institution which does not appear to interfere in their everyday life, meaning they would still have some autonomy over the projects. Another option taken into consideration in the case of St. Pauli was to have a Techshop [103] as a business, with the profits generated going toward the growth of the community.

Returning to Leicester Hackerspace, by the end of the general meeting, the 'pay as you feel to use the space' model prevailed for another year, with 20 members present at the annual general meeting voting for it, 2 abstentions, and none against. The reason was that members who had second thoughts about the payment system were convinced by energetic disagreements that the space should have a sense of responsibility to the greater community and should strive to be more inclusive rather than exclusive. But there was a discussion on how to politely suggest to those who could to contribute more. "Organizations are as valuable as the member's contribution", was suggested by a member, who thought that should be a motivational way of raising more funds. Contributions are not limited to

[103] A Techshop is a workshop similar to the idea of grassroots communities, but as business service. As the name suggests, it is a shop, a space where customers can rent the space and use machines and materials for their own ends. It essentially is a commercialised workshop run for profit, just as Hackerspaces/Makerspaces/Fab Labs are not for profit. A notable reason for using a 'shop' model instead of a community, is because it does not depend on the members to run it. Thus, evidently a Techshop usually offers more machines and materials than a grassroots community, working effectively under the responsibility of the owner.

participation nor the direct influx of funds through membership; there are individuals who could donate, who could loan or give free equipment (such as servers, laptops or smaller things such as resistors, cables etc.) and other materials, or give information about the space. Some can even give their time and their skills to the Hackerspace. Rounding up all these types of contributions, one cannot help but notice that the setup fits the description that Hardt and Negri gave for the term 'commons'; 'First of all, the common wealth of the material world [and] more significantly those results of social production that are necessary for the social interaction and further production, such as knowledge, languages, codes, information, affects, and so forth' (Negri and Hardt 2009, p. viii)

Maker infrastructure II: ubiquitous and networked

The discussion on how to bring in more members rested on the importance of workshops and events, which have a double functionality. Firstly, the workshops usually entail a fee and thus are good sources for revenue for the space. The 3D printer at Leicester Hackerspace, for example, was sold by the same person to the space who was conducting the workshops for the space to pay for it. It was in a sense work for the community to be able to afford the machine. Secondly, workshops and events are important to ensure activity for a Hackerspace, which is ontologically important for a it; without the activity of people, it ceases to have a reason to exist. Thus, in order to bring people in for a variety of workshops and events, a number of factors were of strategic significance. A discussion about the new space, for example, included the need for easy access for people who walk, cycle, come by car or by bus; the new space needed to be close to the city centre. Publicity is gained through social media, such as 'Meetup'. The members know already that there are people who look for 3D printers or Hackerspaces or people who have skills in such digital infrastructure.

Even IT issues are oriented around the means of access for newcomers which could give dynamism to the community; 'Trello',[104] for example, was less favored than Google Groups because the latter was closer to the general public in terms of user-friendliness and visibility. Hence the discussion on infrastructure, what kind of access, where should the space be, or what kind of software and hardware is available is guided not only through the desires of the members, but through the idea of building on a culture that already exists and the limits such as financing entail. The whole procedure seemed like a small self-governed enterprise, with the exception that there is no product; the only objective was to set up an appropriate infrastructure for the governance of a space in which individuals could do what they liked. The decisions were informed by the opinions of the members that were present. Those who were interested enough but were not able to attend could send their opinions through the Google Mail group, but they still lacked the capacity to react in real time to other people's opinions. Limits and how to overcome them is a never-ending process in such spaces; it also adds to the fun and play of building and bonding with the community.

Most of the Hackerspaces have Google Groups accounts to use as a forum, where anyone can join and learn either news about the space, ask a question or just read the daily questions of others on the forum. The openness of such a process, means in this context being exposed in public and anyone can see and join. This also creates an informal rule about not wasting the time of the rest of the people on the group. On the Google Group it is very unlikely, for example, to find jokes or sharing of personal information. Rather, it is common to see questions about any problems or lack of resources and invitations to new projects or events. The implicit arrangement is that when someone has a good chance of knowing the answer, they help or point to the person who might. There are no specific people to answer the questions; however, it is likely to see many answers being offered by those members that are more deeply involved and committed to the space, rather than individuals who participate occasionally

[104] A web-based project management application.

in events. A factor that determines involvement is usually the type of work a person has or how busy their personal schedule is.

The connectivity of people through the Hackerspaces using technologies that can be easily portable and user-friendly is an essential part of the infrastructure. It is almost by default that a new space introduces itself by having a virtual presence and presenting some basic information; what kind of machines are available, a calendar of activities, the physical address, and some very basic introductions about the character of the space. 3D printers are usually in the list of available machines, both because it is a very attractive technology to new members, but also it can provide a source of activity for some people in order to start projects; its small size and portability make it an attractive project to start with. Building a 3D printer based on the RepRap model, for example is an exciting Hackerspace activity that might generate more projects as the members learn from each other. For this reason, there were hardly any Hackerspaces where a finished or unfinished 3D printer based on the RepRap is not present.

Figure 27 To the left is a RepRap under construction; to the right, an Ultimaker 3D printer. St. Pauli, Hamburg, Germany. Photo Credit: Leandros Savvides

When events are organized, either by local groups in collaboration with authorities, members and users of grassroots community workshops are more likely to be present than anyone else. 3D printers are some of the most resilient machines [105] a Hackerspace can have. The reason for this is because they can demonstrate their capabilities simply by being plugged into an to electrical socket. They can also be modified on site as well as being able to be fixed and made to reproduce many of its parts using its own functions (see Sun et al. 2011). It is a machine that combines an intricate combination of software and digital design, but also able to demonstrate a finished object. Being able to touch something at the end of the process gives the individual a more complete sense of matter, touch and smell included, that the digital design excludes. 'Ubiquitous computing', a concept which digital users are only able to start understanding when using cloud computing (Weiser 1991, 1993) to access their files anywhere from multiple screens and devices, is to some extent giving a boost to the concept of ubiquitous manufacturing (Foust 1975; Bi and Zhang 2013; Dubey et al. 2017). Printing (almost) anything, anywhere, anytime, is a prospect that few spectators are not keen to see. It naturally draws people's attention, which translates either to new members in the Hackerspace, more participation in workshops and/or renewed enthusiasm in craft through something which is digital but entails a sense of craft-making. Thus, 3D printing has the combination of qualities that meets the needs of all ages, digital natives and traditional craft-making enthusiasts, which is also reflected in the position 3D printers occupy in Hackerspaces, Makerspaces and Fab Labs.

Events such as Maker faires combine all the above elements which put to test the resilience of 3D printing; they combine ubiquitous computing, as many communities bring their 3D printers with them at the event, they involve some form of cloud computing or memory stick to be able to print objects on site, are open to all learning ages and provide a good starting point for communities to welcome craft-makers into a digital realm. 3D printed objects can be used to showcase the creation of objects on site, thereby not only creating physical objects but also reinforcing ideas (see previous chapter) such as ubiquitous manufacturing, and that objects can be created in the absence of a craftsperson through some basic understanding of user-

[105] See the section 'Resilience and the meaning of openness' in the next chapter.

friendly programmes. The complexity of objects available usually adds to the enthusiasm of experienced makers and newbies alike. The individual on the receiving end of the showcase sees the appearance of materializing information with the click of a few buttons, sometimes in the middle of the street.

Figure 28 A complex object printed as a single one for the purpose of showing the complexity of prints. Derby Mini Maker Faire 2015. Photo Credit: Leandros Savvides

Maker infrastructure III: Maker faires

In 24 October 2015, I went to Derby Maker Faire, a good place to see in action the infrastructure and the state of the makers' movement in the region. The preparation takes about half a year and a call for projects is open as early as April in order to give a chance for preparation and participation of individuals, civil society groups, companies, authorities and universities. A 'Maker Mini Faire' which started with a low participation level in the previous years grew considerably by 2015 to become one of the major Maker faires in the UK. Starting in 2012 as a collection of a few dozen exhibitors, the event grew each year to reach hundreds by 2015 and become an important event for making in the region, as visitors numbers grew to over 1000. By 2017, the event was able to attract over 2,500 visitors, showing an increasing development of such culture and networks of making in the region.

The growing of the Maker community in the Midlands region required an upgrade of organisational infrastructure by the local Hackerspace, which is housed in the first factory in the world, the Derby Silk Mill [106]. An upgrade of the capacity to grow from a few dozen people to hundreds of projects and thousands of people visiting means that sponsors and other stakeholders are needed. Despite the term 'Mini Maker Faire' a few illustrious institutions support the venture such as Rolls Royce, the University of Derby, *Make* magazine and Microsoft, which among other things, give legitimacy to the event as a high profile making event. The term 'Mini' in the name indicates that the event is an independent event, community-driven and not directly organised by *Make* magazine. The enlargement of the event and the more people it attracts, the more likely it will be to have more contacts and sponsors for the next year.

Figure 29 The event is organized in such a way to appeal to all ages, but there is particular focus on youngsters. Photo Credit: Leandros Savvides

Corporations aiming to showcase their products and capabilities, university projects, civil society groups, experiments by individuals – all these have a place at the Derby Mini Maker Faire. It is an event which brings

[106] The silk mill is now a museum. The Hackerspace is operating in a section of the building with permission from the authorities in partnership with Rolls Royce to operate every Wednesday for a few hours in exchange for their help in the restoration of the building as a museum. See more at: http://www.derbymuseums.org/thesilkmill/

together academics, students, workers, authorities and the corporate world. The aim of the event is manifold; the obvious purpose is the attempt of individuals and groups with vested interests to promote STEM education to children, to popularize experimentation and scientific inquiry. But there are other purposes, some which come in subtler ways and others which are more apparent. Such events reinvigorate the feeling of a community which is growing year by year. In order to grow, the event is not only a place to exhibit a project or have fun, but new experiences are created, meetings of people that might become inspired to work together in the future.

Figure 30 A Microsoft stand at Derby Mini Maker Faire 2015, advertising robotics Photo Credit: Leandros Savvides

All the different experiences and meetings at an individual level are also transferred into the virtual space for people who are not present, in real time Exhibitors usually use their website to recap of the event from their perspective. As a result, and as the slogan of the Maker Faire summarises itself (‘The biggest show on earth (and tell)’), the aim is to get the projects, networks and learning experiences into the public eye. Those who perhaps missed the even can have most of the information a person that is present can have; live videos to look around the space, images of projects and people alike, information about each space and what who can do. The event is taking place online and offline in a literal sense. The promotion of the event through a personal story gives an extra layer of multiple perspectives in which people can see such events. Sharing personal stories of the event are in fact encouraged by the event staff; “Can you please tweet something with this hashtag?”, a volunteer asked me as I was moving through the different exhibitions. This way of approaching people is friendly and polite, and thus it is difficult to reject such a request. All the tweets under the designated hashtag are streamed on a number of different screens within the event as well; the online part is therefore both for those who are physically present and those who are not. Those who are not present can see all the relevant information, but those who are present can enhance their potential of receiving interactive information. In essence, the online stream becomes a pool of interactive stories that everyone is communicating to everyone else, whether they are present or not.

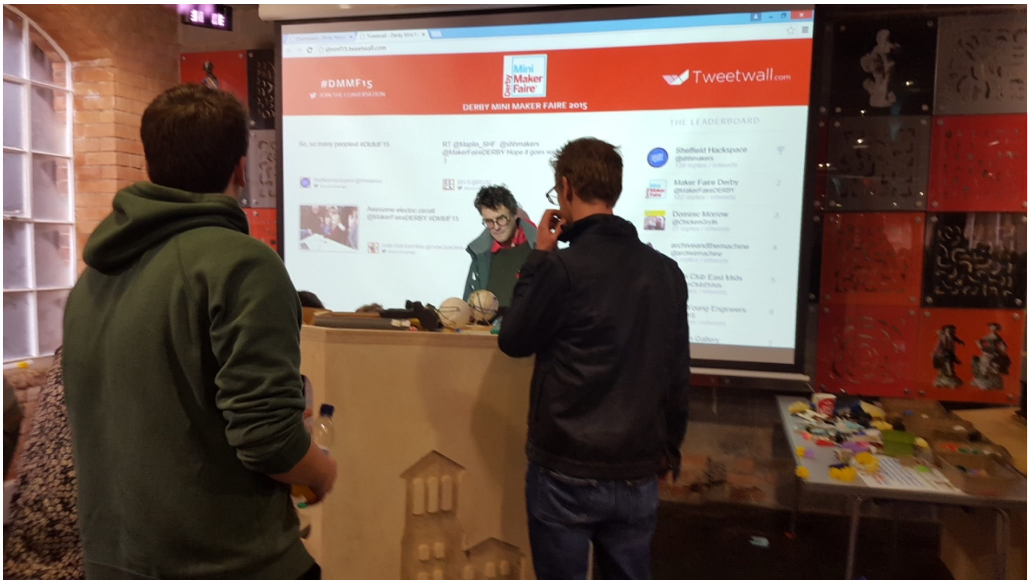

Figure 31 The twitter wall. People create a pool of personalized information stories which others can access without knowing each other in person. Everyone can learn from everyone else. Photo Credit: Leandros Savvides

The structure of Maker faires such like the one described entails many facets of maker infrastructure. The communities should be able to collaborate with a number of authorities for the venue, exhibiting their machines or projects and issues of security of the event. Moreover, such events seem to be dependent on sponsors or donors, because their expenses cannot be covered only by a minimal entrance fee. Additionally, the internal infrastructure of the communities themselves needs to be able to send the message to their own members and either organize exhibitors or visit the events. Adding another layer to it, individuals who are not participating as part of communities need to be able to find information on the event, usually through a mixture of all of the above.

But what can you do with that?

Not everyone has been happy with 3D printing's hype, presented in the futuristic images of ubiquitous manufacturing and easy personalized production. As 3D printing is presented a brand new way of thinking and public engagement with crafts, hacking and science, often the more practical individuals in the room are wondering "yes, it seems like a good idea, but what can you do with that?" Organizations or groups of people who want to skip the hype and focus on creating objects and machines come to understand that there are interesting things a 3D printer can do, but there are also many limits. Opinions on the use of 3D printing are varied according to what the goal is and how familiar different communities are with the specific technology. Amongst the various fans of 3D printing, a more practical approach brought me into contact with a non-profit organization called REMAP. As it is a nationwide network of local groups, I came into contact with the one located in Leicester. It is a group of engineers whose interest is in creating non-commercial technologies for people with specific disabilities, or "specialist aid for disabled people" (Ken, Leicestershire Remap group, Interview). REMAP is one of the cases that cannot be exactly categorized in a specific context; it seems like a charity, but it works as a community service. It is a fairly mature organization and the interaction with it can reveal a root from which Hackerspace culture sprung. Despite the differences, I also see similarities between a variety of community groups and the recently-assembled Hackerspaces of the region.

We agreed to meet with Ken at the National Space Centre, where he is currently employed. As he introduced himself he outlined that their work is run on non-commercial basis; "We do not create anything that is commercially available". Their aim is to serve the needs of those that the market cannot accommodate;

> Most people with disabilities have very unique problems. If a device is very commercially available, great, it is a problem with money not engineering. But there is a great void between products that are commercially available and are quite right. That is where Remap fits in, we design equipment to suit individual needs. (Ibid.)

The work is usually done in private garages, houses or anywhere; usually at the personal space of the person who accepts to complete the project. Once a person agrees to work on a project he or she is "expected to deliver" the project within reasonable amount of time, usually within a few weeks. However, there is no pressure to succeed, and that means there is a risk of failing to provide. The dependence on donations is the main source of financial income, which means Remap is fulfilling its role as a charity organization and this in turn limits the possibilities for expensive equipment and forces the members to reach out to their contacts whenever there is an expensive tool or an intricate technology they are not able to use. As I was told; "we raise our own money, we do not charge the end user, and we donate the equipment". Despite finding 3D printing a promising technology, for engineers such as these the technology is still without a particular function.

> It is an interesting technology we are monitoring for some time. However, there are barriers to us using it. When you look at the websites where you can see shared designs for objects, it's just full of gimmickry and toys, things of no use. The most useful thing I saw was a bracket of a fan of a computer. I have a practical

> engineer's view of 3D printing, in the extrusion world – sintering is different but it is not yet within the reach of the hobbyist market – there are barriers in using it. One is the strength of the material, second, the level of skill needed for our engineers, most of which are retired, to do the CAD designs and the slicing to use it. So, for me, 3D printing at the moment is a solution looking at a problem, rather than the opposite. We haven't got a problem for it yet. We only had one job that we needed this, a lady needed a specialist handle and we contacted Loughborough University. So, we kind of subcontracted this to specialists of 3D printing, to friends of Remap. The first object, which was created by an extruding technique, broke, the second, remodelled and created through a sintering technique, was successful. But, for us, as I said it does not seem as useful as it looks, as we need objects which can handle considerable pressure. (Ken, Leicestershire Remap group, Interview).

I ask whether he thinks what Remap is doing, end products for disabled people, can be produced in Hackerspaces,

> Hackerspaces are interesting, a relatively new phenomenon, whereas Remap has been for a long time. We do have contacts with them, in fact we had a hacker event here at the National Space Centre. But there is some difference; they develop flash and light technology, wearable, things that amuse them. Sometimes creative and artistic projects rather than end products that will actually be going to do good in society. There is nothing wrong with that of course, but

> this is what I think is the difference between the two. (Ken, Leicestershire Remap group, Interview).

Later, he talked about people who participated in Hackerspaces who asked to join Remap in parallel to their Hackerspace membership. The interconnectivity between non-profit organisations, Hackerspaces, Makerspaces, Fab Labs and individuals who move in between seems natural despite the different organisations and their aims. It is very revealing of the connections and the culture of connecting the dots between individuals and organizations when one sees that once organisations are interested in STEM subjects, creative individuals and Hackerspaces, they are tend respond to each other's calls for events. Information flowing within such spaces is not about downloading designs for the 3D printing. The mere act of meeting in events and workshops is also a good way of getting information flow from one organisation to the next, usually in the form of volunteering.

On another day, I visited 'NottingHack' interested on how 3D printing fits with the activities of the Hackerspace. At the time of my visit, there was a university student who printed components for his engineering class whilst another was building his own RepRap printer. Being in the open-plan room, where there is no heavy machinery and it is also a good and safe area for parents to spend time with their children, to print and play. But nonetheless, the viewpoint I received from Alastair, highlighted the limitations of 3D printing in the 'developed world'. The limitations mentioned were very similar to the REMAP engineer's. We met in the lounge area of the Hackerspace; as we started discussing the space and his involvement, I ask him how he found out about 3D printing. "I do not reckon knowing about 3D printing before the Hackerspace. I had used a CNC[107], but I do not think I had ever seen or heard about it before the Hackerspace days." This was around 2009 or 2010, when 3D printing was of interest to the maker community but had not still exploded into the popular media that inform the general public. He continued:

[107] CNC or computer numerical control are automation machines programmed to replace mechanical movements.

> There was a guy who was building RepRaps, who is now called RepRap Matt because of this. That was the first time I saw a 3D printer live, I think I saw one on *Make* magazine but that was my first time seeing it in front of me. I think the first thing printed was a whistle, but it did not print quite right, we had to somehow hold the sides. At the time I was looking into buying tools and a CNC machine, because I make circuit boards, seemed more useful to me. But looking back, probably I would get a laser cutter if I was to go back, this is what I use the most here at the Hackerspace. (Alastair, NottingHack, Interview)

Although the process by which 3D printing is delivering digital files into physical objects is “amazing”, he nevertheless was not very impressed in terms of practical reasons.

> I do not reckon being blown away with 3D printing when I was thinking why I might need it. I was looking at it from a point of view of my work, which would end up looking like an object that you can buy, the resolution was not good enough for business. But I was interested in their mechanics at the time. (Alastair, ‘NottingHack’, Interview)

He later voiced his own attempts with the 3D printer; first he passed through an introductory course, as it is usually the case in Hackerspaces. As it turned out, despite being impressed at the implications of printing digital into material, a number of reasons hampered his use of 3D printer,

> I wanted to build a 3D printed anemometer, so I got an induction to the 3D printer we have here. So, we downloaded the design and printed it, it was pretty impressive as a process. But the quality is not quite there yet and the design needs work in terms of how it should work but there it is, you can literally print this thing out! (Alastair, 'NottingHack', Interview)

What seems to matter more for many hackers and makers in terms of the 3D printing process is the intangible stuff. Alastair argued that he saw the technology from a new perspective, as he did not yet find a good function for the technology in a country where one can find and buy almost everything one needs. But the story changes in terms of his experience with a different culture, conception of time and value of goods can alter the functionality and thus the practicality of 3D printers.

> I think this is interesting from the perspective of my experience in the Philippines, where access is an issue. In the West, in a way, especially stuff is cheap and time is expensive. In the Philippines, stuff is very expensive and time is cheap. So, people would literally rewind speaker coils, because it's cheaper than buying new speakers. Here, none would do that. So, this is where I think 3D printing will be greatly needed. If you are in a remote place, you do not need to have stock of bits, you can print these bits out. (Ibid).

What is useful for producing in a Hackerspace is not always the cheapest way to do it, at least in the cities with mature capitalist relations, as the availability of most everyday objects in very low prices mean that there is no motive for printing them. As such, 3D printers can work better for a specific object design that is not available [108] on the market yet and other prototypes.

Figure 32 Phone cases made by 3D printing and a laser cutter as part of creating a DIY phone workshop in St. Pauli. Photo credit: Leandros Savvides

This is something I encountered across all such grassroots spaces. However, the issue of producing functional objects is addressed differently and with different rates of patience. In St. Pauli, for example, the use of 3D printing to create a suitable replacement for the kitchen sink tap knob is not as cheap “as going to the store nearby to buy a new one”, says Andreas from Fabulous St. Pauli. When an object breaks, whilst theoretically a 3D printer can allow the creation of a replacement, its creation is usually determined by the intended use of the act. If the creation of a useful 3D printed object is to show the case for other users, it is usually worth the print despite the possibility of buying a new one through a nearby shop at a cheaper price. What is of more use, though, is the opportunity to create custom parts for already existing products which may not be available.

[108] See ‘Crafting science’ section in the next chapter.

Figure 33 A printed object as a replacement for a product Photo Credit: Leandros Savvides

Figure 34 A custom-made handle for an already-existing object Photo Credit: Leandros Savvides

Aside from printing objects, perhaps one of the most appreciated features of 3D printing is the ability to personally control the pace of a project. Undoubtedly, the time given to print may take several hours for a seemingly simple object. But looking at it from another perspective, the individual or group of people working on a project are able to control within their decision making and design space, as well as what to produce; this ends up giving makers a feeling of controlling the production process of objects that was not there before. Instead of designing an object elsewhere, socializing elsewhere and delegating the responsibility for carrying out the production process elsewhere, these previously three different spaces have shrunk into one. Whilst printing is usually thought of as part of production, in the Hackerspace people can have workshops, carry out mundane everyday tasks or perform other activities, even working on other projects. The seeming loss of control of the pace of a print in which the machine has physical limits (which is indeed slow), thus remains a productive time, as users (knowing their machines and the time needed for each print) find other ways of filling this time with all sorts of activities.

Figure 35 Stacking the fridge with drinks for the community whilst waiting for a 6 hour print Photo Credit: Leandros Savvides

Entrepreneurship and Social Justice

On another day, a cold Sunday in March 2016, I visited Fabulous St. Pauli which is located near the port in Hamburg, Germany. The area is considered to be historically a working class area, which has recently been gentrified with construction projects. The area's economy depends mainly on tourism, as there is a famous red light district near a street called Reeperbahn.

Figure 36 Niels preparing a 3D printing workshop Photo Credit: Leandros Savvides

It was my second visit to the city, the first time as a researcher and I was already familiar with some locals. Sundays, I was told, are days that people traditionally are expected to spend their free time with their friends and families. This contradicted my initial idea that on Sunday Fabulous St. Pauli would be a very attractive place for makers to print their favorite objects or develop their own prototyping projects. However, on that Sunday, Niels had organized a workshop: an introduction to 3D printing. The idea seemed odd, given the fact that no-one is expected to spend their time outside the circle family and friends. I was wondering whether people would show up since the introductory course on 3D printing was run on such a day was meant to attract those without plans or the ones who were very eager to be present.

Given that in our discussions, contemporary politics and Niels' work with the 'right to the city' network were prevalent, this scene left me pondering what would be the link between teaching 3D printing and this political movement. From his explanation, I could distinguish the importance of the personal commitment towards spreading a particular kind of knowledge, demanding a critical stance on how objects are made and letting this knowledge connect individuals through technology and making. So naturally, I was expecting politics to be blended with the importance of making and how technologies such as 3D printing can be of service to making and to politics.

As I was expecting, the first thing he did was to explain the basic philosophy of the space: What is a Fab Lab? What is the goal of such a space? although people may not ask these questions, they are nevertheless an important part of every workshop done by Niels. After describing the identity of the space, he moves on to talk about Adrian Bowyer and the thinking behind open source 3D printing. The participants are rarely brought to the workshop by the stated philosophy, but for the people running the workshops, the technical part is not disconnected of why they exist in the first place. Niels is very motivated not only because of his passion for creativity but also because of his involvement in political struggles in the city as well, which as he told me solidified his perspective on both. Further to this, whenever I was present, he also mentioned who I was and what my study was about, in case somebody was interested in it; his belief was that many good things can happen with more connections. The same happened this time as well; he served as the mediator between designers and people who had ideas for social movements, either art projects or protest events. Although I do not understand German, some participants did speak English. “It is about bringing people into this thing” he told me, meaning first the space in order to use the technology and secondly the culture of political engagement.

This is an example of how the members conceived of developing the space in order to serve a bigger cause. Spending around three or four hours at the Fab Lab on Sunday is part of nurturing the space, taking step-by-step the daily routine of growing the community around it. This may or may not be an exponential task, meaning that sometimes guests can carry out minimal participation, but there are instances where guests become vibrant members who organize, take care of the space or find machines to enrich the space.

The goal is to bring people into the Fab Lab through the general rules and interaction amongst members in which the outcomes could come either directly or in kind, either serving as a host to people developing their projects or in other cases making individual or collective projects to engage in direct political action through the social movements of the city connected through a loose association called the 'Right to the City Network'. In each case, the members of the Fab Lab would be happy that the space has enabled individuals to engage in some form of action, combining practice as politics but using this type of practice to grow and nurture political movements. For Niels and likeminded members, the issue at stake is more than just 3D printing: it is about thinking the city as a home and practicing solutions to everyday problems.

Figure 37 3D printing workshop at Fabulous St. Pauli. Photo Credit: Leandros Savvides

Henry Lefebvre is a figure whose work is important to the "Right to the City Network", a network of a variety of smaller and bigger groups of citizens attempting to build a grassroots social movement in order to act on a variety of issues. The reason Lefebvre is important is because his understanding of space is as an ever-evolving production of social relations. In other words, for the members of social networks, understanding that space is both reflecting the state of power within the city and reproducing this kind of power shows them what to fight for and how people are limited by such a balance of power.

It is an understanding closer to Autonomist Marxism (Hardt and Negri 2000, 2004, 2009; Cunninghame 2013; Katsiaficas 2006) and prefigurative politics (see for example Holloway 2002; Yates 2015), with several people identifying themselves closer to anarchism rather than any other political affiliation. As Katsiaficas (2006, p.277) has it:

> Unlike Social Democracy and Leninism, the two main currents of the twentieth century Left, the Autonomen [109] are relatively unencumbered with rigid ideologies. The absence of any central organization (or even primary organizations) helps keep theory and practice in continual interplay. Indeed, actions speak for most Autonomen, not words, and the sheer volume of decentralized happenings generated by small groups acting on their own initiative prohibits systematic understanding of the totality of the movement, a first step in the dismantling of any system. No single organization can control the directions of actions undertaken from the grassroots. Although the Autonomen have no unified ideology and there has never been an Autonomen manifesto, their statements make it clear they fight 'not for ideologies, not for the proletariat, not for the people' but (in much the same sense as feminists first put it) for a 'politics of the first person.'

The influence of Lefebvre is not only evident by seeing how politicised the issue of space reproduction is, but also because the movement attempts to make widespread use of his thought. Aside from translating his work into

[109] Although 'Autonomen' is not exactly the same as 'Autonomist Marxism' or 'Italian Autonomia' which managed to attract widespread support during the 1970s, nonetheless they share the same understanding that building massive unions and a centralized party in order to seize state power is problematic and call for a different route.

German with a foreword by members of the Right to the City network [110], these influences have been further shared in a book that seeks to further the conversation on how the city could be governed in the age of smart cities (Boeing 2015). The author invites the reader to think about issues and problems of the city, for example issues of inequality and space availability in an area where the rent is increasing and areas which are left derelict are beginning to become gentrified. Understanding that authorities not only have economic power but also the law on their side, the author suggests that the bodies of those who are interested in an alternative way of living and doing this play a central political role, and doing activism involving their bodies. The author was kind enough to translate some parts for me in order to understand his basic proposal:

> In the cities, however, one side enters the match with lots of capital, demolition excavators, a tooled-up police force, and the law as a weapon. The other side has nothing but their determination, their wit, and their bodies when they take to the streets. The other side are the city dwellers that try to hold squares, save houses, defend tenants, squat infamous vacancies, protect refugees. For that they are beaten up, shot with tear gas grenades, forbidden to gather in assemblies or demonstrations. All in the name of the constitutional state, of course, in the name of the market-compliant democracy […] The right to the city manifests itself as a superior mode of rights: the right to freedom, to individualization in socialization, to housing and living. The right to works [oeuvre] (to participatory activity) and the right to appropriation (well distinguished from the right to property) are included in the right to the city. (Neils Boeing, Fabulous St. Pauli, written note)

[110] See for example Lefebvre, H. (2016) *Das Recht auf Stadt*, Hamburg: Nautilous Flugschrift

Very similar to the above description, the “Right to the City network” attempts to democratize the city through different practices that included squatting of historic buildings for the purposes of using them for those who need but cannot afford them. There is no party line or a set of specific policies that govern the network, but it is what it describes itself as: a network. This includes artists, environmentalists, designers, engineers and a wealth of others that overlap in what they are interested in but follow a set of general rules; to make the city more accessible not only for citizens but also non-citizens such as refugees. As I was told by members, there are three waves of the movement for the right to the city but as much as the next wave was influenced by the older one, it involved many new people with a set of motivations that were orientated toward the problem addressed at each particular time.

Figure 38 Launching a book on the right to the city at a squatted building at the centre of Hamburg. The place is full of activists, students, academics, artists from all over the city. Photo Credit: Leandros Savvides

In 2010, groups of citizens managed through mobilizations to stop the gentrification of the section of historic neighbourhoods near the port. The authorities would give permission to a property management company to tear the buildings down and build luxury villas in their place. This was the second attempt by the city authorities to use public space and buildings for extracting surplus value at the cost of the needs of the population; the first time, in the early 1990s, a movement emerged to oppose the plans, resulting in the squatting of several of the buildings as well as designing and implementing a park for the neighbourhood. The mobilizations managed to leave many of the poorer sections of the population of the area in their homes, as well as leaving the place protected from violent gentrification.

After opening in 2011, the Fab Lab relocated in the summer of 2015 to a new space, as the initial space was to be utilized for housing purposes. The new space was a few blocks up the road, an old factory which the owner rented cheaply because of his intention to demolish it sometime in the future. The members of the Fab Lab thought this could be a temporary solution with a bigger space, one that housed experimental artists, woodworkers, small entrepreneur artists and digital artists under one roof. The idea behind the further development of the Fab Lab from a situational event into a growing community was that of connecting people from different backgrounds and gathering support – either practical or ideological – from a diverse crowd. The skills of a designer could help a woodworker with making their own furniture. Another case might include using the skills of a software developer for identifying and fixing bugs in open source software, which could save money for individuals who are usually dependent on the company which the software is licensed from. For people like Andreas, the history of the place is important, but what attracted him to the Fab Lab was access to tools and networking, which, as he said were important parts of the region for years, since craftsmen and artisans were common in the area. In such circles, participating in political activism was not just about single issue campaigns but a whole new world; people fought for their craft, their identity and ultimately building networks within which they could find employment. Keeping up with the older generation's identity whilst developing the new one is one of the key aspects that came up when discussing how it all started, We are a diverse people so the intentions were diverse, but there was an interest in the technology or in doing things. For others, it's the topics around it, like potentials for education or for others this is a political issue. For me it was very important to find access to the tools and I found many aspects of the ideals of the community interesting. Here in Hamburg are of course our values are different than others. For example, St. Pauli was in the 1990s one of the poorest areas in the country. I would say that it still is, but it is not so visible anymore. What you should know is that there were craftsmen and small shops here throughout the years. What happened then, big companies build new hotels so the neighbourhood kids did not have anywhere alternative to go. For instance, the children in my neighbourhood used to go to the gasoline station. It was a meeting point, some of the kids' brothers were working there as well, simple jobs like cleaning cars. That was the only remaining perspective for young children here. The new buildings had receptions and the rest was closed to the kids. An example is that even car rental station was underground and nobody could see anything in there. So buildings were systematically closed. So when companies went out of St. Pauli, either because rents went higher or because companies grew and wanted to move, we started the Fab Lab against some investors who bought many houses over the area. There was an initiative against these, so the investors wanted to buy the places from them because they were not interested. For some time, it looked like the initiative could buy the space there. It was rental buildings and economic buildings. So the rental

> buildings, housing, was ok, but what could we do with 2,000 square feet of economic space, to get income from it? So we met and agreed to invite people for breakfast [and] part of that became the Fab Lab. Architectonically, it was very interesting, because it was like a shop, had special cellars, a park, next down the street was a school. It was interesting for them as well as they saw no perspective for their lives there. The problem was that the people there did not know how the economy works, so then we agreed maybe with the Fab Lab we can develop this. People can come and build their own projects and next to this you have someone who knows about this stuff, a professional who started as a cabinet maker so he could explain a lot of things. If you were from the other side of the town, it was a meeting point, a point for people to search for learning, how to learn, what can they learn. Maybe something develops from this space, and a job opportunity arises as well. (Andreas, Fabulous St. Pauli, interview)

Figure 39 The new location for Fabulous St. Pauli. Photo Credit: Leandros Savvides

Because the rents are lower in the nearby buildings, this allows people of lower economic status to afford access. The collected experience of the previous generation in such types of mobilisations was very helpful to the

“Right to the city” network. In the squatted places, migrants without papers and refugees from African countries, and more recently from Syria and other places, were housed temporarily until a better solution became available. Some of the refugees were part of the area for quite some time, others were newcomers. ‘Park Fiction’ as it was named, symbolized the resistance of the population against the neoliberalisation of their everyday lives (see Leitner, Peck, and Sheppard 2007)[111], of privatizing buildings and public spaces, thus pushing more people to the margins[112].

Figure 40 Everyday life at Park Fiction, also known as Gezi Park Photo Credit: Leandros Savvides

[111] What this means, essentially, is the continued transfer of governmental responsibilities to the private sector through public-private partnerships and the introduction of cost-benefit analysis to almost every facet of everyday life in urban environments.

[112] ‘Park Fiction’ was later renamed ‘Gezi Park’ as a sign of solidarity with the Gezi Park uprising in Istanbul, Turkey. ‘Many of our Turkish neighbours took to Hamburg’s streets in solidarity with their friends, comrades and relatives. We support them. We developed the park together in the nineties with our Turkish neighbours. The artificial tulip field was designed by a Turkish neighbour. We know from life in Hamburg how important it is to fight for free spaces that symbolise emancipatory movements, and how important these spaces are when desires congregate to take to the streets – to change the world. Taksim and Gezi are exactly that - big style. Make two, three, thousands of Gezi Parks. Let thousands of desires blossom. Park Fiction, June 16 2013.’ Retrieved from http://park-fiction.net/park-fiction-is-now-gezi-park-hamburg-16-06-2013/

This follows the understanding that, as Christoph Schäfer (leading member of the "Right to the City network") put it "It's all about the spacialization of conflicts." Neils continues in his book about the importance of such politics:

> The spacialization of conflicts: occupy areas or buildings, stop development plans, block evictions, create places where people can be active on their own terms, can gather. All this might appear like odds and sods in the face of a system that is so powerful it makes you feel helpless. Yet these activities are not fruitless. Seemingly tiny conflicts about urban spaces show, first, the context and mechanisms of neoliberal policies in the immediate vicinity. By that they mobilize, secondly, not only people who are directly affected but also other sceptical minds who had not yet found a point [at which] to join causes. Third, even tiny conflicts provide a first experience of self-empowerment that can change the thinking of the inhabitants and even give them a new dignity. Ideally they create, fourthly, spaces in which a logic beyond neoliberalism can be tried. Anne Querrien calls these spaces local micro-potentialities. (Neils Boeing, Fabulous St. Pauli, written note)

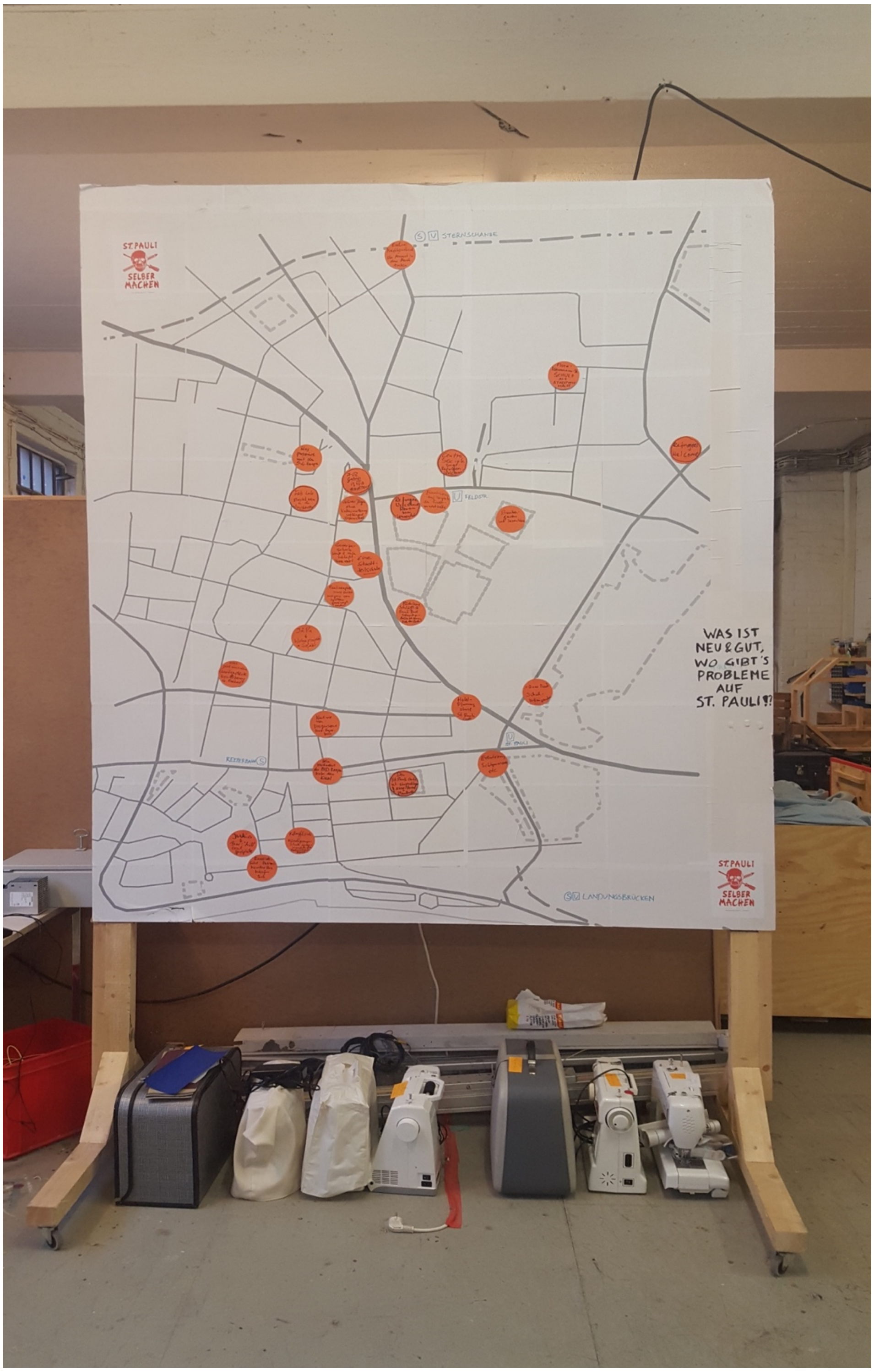

Figure 41 A mapping of the right to the city network within the area. Underneath, machines for the knitting workshop. Photo Credit: Leandros Savvides

In order to gather support for the mobilizations, Niels and a few others who were familiar with new resilient technologies and Fab Labs, invited the

Fab Lab truck from Amsterdam [113]. Their motivation was that through such occasions they could interest more parts of the population of the area to join in, especially younger people. The Fab Lab truck would be seen as a way of reading the desire of the population to create a Fab Lab in one of the squatted buildings. This was the process by which the Fab Lab in Hamburg emerged. The bodies of participants making, tinkering and hacking is thought to be transforming the city and creating such potentialities, as a first step towards transformation. As many of them are planted, these seemingly insignificant practices and spaces accumulate activity which then transforms into political leverage and power.

Figure 42 Introduction to the general idea of a Fab Lab as well as introduction to Fabulous St. Pauli. Visitors are surrounded by 3D printers, a laser cutter and a heat press machine. Photo credit: Leandros Savvides

Grassroots activism, clashes with authorities on blocking gentrification and thinking about the needs of the city and the population, whether they were citizens or not: in this way, the Right to the City network as a movement connected issues that relate to the city, with problems of inequality, shortage of space, technology and production within cities of the 21st century. Access

[113] A Fab Lab truck is a vintage truck that is equipped with basic Fab Lab machines and tools for showcasing in festivals and schools in the Netherlands and across Europe. It includes machines such as a laser cutter, a 3D printer and an electronics workshop; it is a Fab Lab in small and portable package.

to technologies such as 3D printing technology through the Fab Lab is seen as opening up of the city and its people to technology to include much of the marginalized population. It is part of an emerging inclusive debate about what it means to be living in the particular city by people with different statuses, be they refugees, citizens, migrants or visitors.

Figure 43 Helping migrants without papers and refugees is a major concern at Fabulous St. Pauli. Clothes were collected to distribute to those who need them. A laser cutter workshop takes place next to this. Photo Credit: Leandros Savvides

‘The city is our factory’ is a sign at the Fab Lab, Niels explaining that many of the members understand the city as the foreground for mobilizations of all sorts; technological availability, everyday problem-solving, socializing. People getting involved means having less faith in the local authorities which are seen as trying to exploit spaces for the purposes of extracting value, whereas the needs of the population are not met. Against the neoliberalisation of everyday life, the Fab Lab’s identity is rooted in the belief that politics within such cities with a diverse population can find a common ground of practical unity through such activities and experiences of spaces. However, beyond the starting point Niels points out that the use of such spaces far exceeds the local, immediate politics:

> [N]ine industrial centres in north America and Europe and how the number of jobs in manufacturing went down from 1970s to mid 2000s [...] we all know what is behind that. The factories were converted into cultural or start-up centres for the service industry and the manufacturing takes place in other continents. This is an important framing for me to tell people that we have a problem with that development. And the people are not aware that this is a problem, we have to explain to them. This comes down to two aspects. One comes from sustainability research which I found convincing, though there are some problems with the term. That is connecting the problem of resilience. So how resilient is a city nowadays when for example because of some natural catastrophe, factories in Asia shut down? We had this in Fukushima accident, in the floods of Thailand when the hard drive production stopped. The global production reached a point that you have maybe only ten places which can produce a certain product that is very important. (Neils, Fabulous St. Pauli, Interview)

As argued by several members of this Fab Lab, access to resilient technologies [114] such as 3D printers, laser cutters and Arduinos give the opportunity to marginalized people who cannot access big industrial centres the opportunity to work and help themselves through a community with a wealth of skills. Because there is no ideological unity, the space is used also entrepreneurially by individuals who just want to make a prototype or just work something they cannot find elsewhere, but this is seen as having the door open and gaining as much support as possible. Entrepreneurship, in the form of helping individuals with their own projects, is not considered

[114] See next chapter in the section entitled 'Resilience and the meaning of openness'.

something against the rules of the space. The space is not commercial "but people can work on prototypes that later can be commercialized if they want" said Niels. The space functions as a book, software and hardware library, a social centre and a production space at the same time. The members are not only expected to use the materials and the machines but are also obliged to participate in grassroots democratic decision-making. It is a very inclusive process but with limitations as well. One of them is that besides the conscious endeavours for creating as much horizontality as possible, the people devoting more time and having more free time to participate usually have more say in the direction of the project as a whole. Informal ways of dealing with many personalities means that sometimes it can be difficult for people who accidentally become mediators due to their well-meaning presence. At the moment, resolving these problems involves a personal approach; usually a person with good interpersonal skills who has time available for the daily care of the space.

Activating themselves through personal projects, the social environment can then help turn members and guests of the space to the bigger questions: How do we understand the flow of goods in our cities? Who has the right to develop technologies or create technologies specifically addressed to the needs of the population? In Fabulous St. Pauli, these are not theoretical questions but rather practical ones. The commercial enterprises cannot solve problems that will not deliver profit on their investment. The people that use the Fab Lab can use their own skills to address those issues that need a personal twist or the market cannot address. Inevitably, bigger questions emerge out of the congregation of such practices: Whose industrial revolution? How is work to be divided and spatially directed? why can't the people who use the facilities decide that? Whereas printing objects can solve small everyday problems, the production of objects leads to an emergence of the big questions in the form of building a social movement that articulates demands. Fabulous St. Pauli is a community that aims to introduce these questions as political problems into the public discourse. This space is not an easy way out of these questions, but rather is situated at the heart of them.

> I don't mean that a community fabrication community could ever replace an industrial production," says Niels, and continues: "if we think about the heavy industrial production, thinking about liberation, of course [this] comes to the question of ownership of the factory. So in a future structure of manufacturing in the cities we have to think about how can we get hold of the heavy means of production. This is not just playing with a 3D printer. We know that chip factories are so capital intensive. We could never for example replace them. Our task is to get hold of medium technology that is not so capital intensive because we cannot get our hands on semi-conductor factory. (Niels, Fabulous St. Pauli, interview)

"The Right to the City" network encompasses community workshops, small shops and individuals that not only participate in political interventions but try act as a community of associates who produce and distribute as much as they can between each other. It suggests an alternative form of relation that attempts to alter the dichotomy of user and producer. Individual actions, the flow of goods and special mobilizations integrating resilient technologies are understood as ways of wielding power, creating both a social situation but also leaving room for individuals to do their own projects. 3D printing in such a context is both a software for making things and a powerful symbol for action. It is understood as planting an alternative political economy terrain based on the needs of the networked teams and individuals. Such new forms of alternative economies are similar and borrow some aspects of forms of production that involve the user as an active component in the production process. The members do not attempt to integrate the user in the professional production process nor return the professional to a user mode. They try to metabolize the expertise of professionals within the user environment in order to widely distribute it into the social context. In such a context, entrepreneurship cannot be distinguished from a conception of social justice and personal stories.

Concluding this chapter, there is no denying that 3D printing owes much of its appeal on its adoption to such spaces. Organizing through Makers communities is a multifaceted process in which both the community and its actions are just as important. Politics in such organisations is a product of reflecting and integrating users' means into their stated purpose. Equal attention on the means and ends of such communities can be seen through their organising principles and schemes in relation to their goals. Their principles of networking, collaboration, and an alternative conception of the purpose of the city centre, ingrained in their everyday activities, aim to contest passive consumerism and the dichotomy of users and producers. This is evident in the building of infrastructures to support and run the communities. At the same time, some grassroots community workshops such as Fabulous St. Pauli aim to challenge the view of politics as non-negotiable parliamentary policies detached from everyday life. The next chapter of this thesis explores types of outcomes of 3D printing in such dynamic and collaborative infrastructures.

3D print in everyday life: crafting, innovation and learning

> *The main appeal of craft is its connection to the rhythms and realities of what has been called the 'everyday'* (Adamson 2010, p. 1)

What is certain, is that 3D printing and its usage, whether in homes or other grassroots spaces, has clarified the comeback of craft in the way things are done, but in a new digitally integrated way in which the practices of the new digital generations are developing into a social transformation. Unlike the faceless positioning of 3D printers in mega-projects such as the Manufacturing Technology Centre situated in Coventry (UK), a desktop 3D printer is a machine that in most cases evokes play. I stand by the word faceless, because for the professional factory setting, the positioning of the 3D printing in the space has less to do with the people who use it, than with the way management intends to utilize the machine for the extraction of value. In many instances, having the opportunity to work with one brings a diffusion of digital and hardware material that otherwise could be understood in separation. But the biggest revelation is the position of learning within an understanding about innovation that goes beyond R&D or policy making (Edquist 2011) with the emphasis put on craft, both in doing and thinking. In this context, innovation is understood less in terms of creating commercial products or even prototypes of such, but in a multifaceted way the promotion of creating or learning something by doing. Thus, the definition given by Lundvall in an attempt to link innovation theory to national systems of innovation, correctly implies interaction between users and producers.

> One of our starting points, is that innovation is a ubiquitous phenomenon in the modern economy. In practically all parts of the economy and at all times, we expect to find ongoing processes of learning, searching and exploring, which result in new products, new

> techniques, new forms of organization and new markets. In some parts of the economy, these activities might be slow gradual and incremental, but they will still be there if we take a closer look (Lundvall 1992, p. 8)

As I often found in the course of my fieldwork, it applies even without the users volunteering that their activities are directly linked to the creation of new markets. The various accidental discoveries in the field, suggest an understanding of innovation in mature capitalist economies such as the UK and Germany. Innovation, that is, as a commercial activity but also through DIY and other non-commercial activities. It cannot be claimed that innovation is an activity which takes place solely and exclusively within the boundaries of academic or commercial professional laboratories. Rather, a new approach that is gaining ground at institutional and grassroots levels is the institutional bridging that links users, creators, universities and the industry. Examples of this new approach include the the “Catapult” program in the UK (Uyarra et al 2016) or the use of European Union regional funds to help Hackerspaces to grow (Johar et al 2015). At first glance, no apparent profit motives evident. It seems all, the emphasis is placed on building the right habitat to inculcate innovation rather than trying to distill it from fixed sources. The lesson this teaches is the value of spanning the divide that separates profit and use values. Between profit motive and an evolutionary process (like that described by Nelson and Winter 1977, 1982; Nelson 1995), this approach seeks to understand technical change and innovation as generating new entities that are ‘superior’ in at least one aspect to those in existence, through market mechanisms and the like. Activities that don’t fit the market concept are also embraced in indirect ways, the expectation being that at least some will eventually find their way onto the market or create new markets themselves. There is a growing sense that Europe’s’ lack of a Silicon Valley ethos (Moritz 2016) has to be tackled not just by finding the right institutions but also by cultivating a culture that actually is already there. Hackerspaces, Makerspaces and Fab Labs co-evolve within economies where many highly educated consumers with creative capabilities earn a living as freelancers or are jobless for long periods of time. As we have seen in previous chapters, the creative power within such spaces has more than captured the interest of mainstream media and businesses. They have become directly involved in the process of transforming them. In the US, some voices go so far as to claim that these 'gadget makers' (Bradshaw and Mishkin 2013) are to a large degree responsible for bringing manufacturing back to the USA. 3D printing has made it possible for creators to produce single or small volume pieces in a fraction of the time and at a fraction of the cost than was the case before. This dynamic of crafting at the intersection of freelancing and entrepreneurship is the catalyst that drives the culture and makes it thrive. This is what Smith, Hielscher and Fressoli (2015) called 'transformative social innovation', where social aspects are incorporated within the innovation process.

An afternoon crafting with 3D printing, might not directly result in new 'superior[115] entities' and innovation in relative or in absolute terms, but from the user's perspective it is time well spent on meaningful activities.. Certainly in the case of an increasingly digitalized British society, this is part of a bigger transformation forcing many businesses to alter the way they operate while creating new consumer and working habits. Put in different words, 'grassroots innovation' (Seyfang and Smit 2007; Seyfang and Haxeltine 2012; Hargreaves e. al 2013), is an intricate concept when it comes to the special interests of the individual and groups involved. This also may explain the interest capitalist institutions show in adopting similar strategies as, for example, aspects of 'open innovation'. (Fressoli et al 2014; Smith and Ely 2015; Smith et al 2016).

3D printing offers an alterative craft culture when it comes to the rituals of everyday reproduction as can be seen from the stories that follow but it

[115] Superior in this case means not in absolute terms but in a relative sense. Technological and innovative process is an open-ended evolutionary process, meaning that objects and practises which come into existence are a product of a more complex rather than a simpler process. I use this term from Edquist 1997 and Nelson 1987; although problematic in some sense, in the absence of another term it helps to distinguish between innovation and just technical upgrades.

also allows alternative human-object interactions (Watkins 1993; Malewitz 2014). In many respects, it sits at the intersection where craft, design and access to knowledge meet through digital technology (Radju and Prabhu 2015) and a diffusion of institutions and organizations (Edquist 2011). It has the ability to 'turn data into things and things into data' (Gershenfeld 2005) which makes it an enchanting technology (Gell 1992). To put this in perspective, enchanting technologies, as Gell suggests, can be read as technologies that cast 'a spell' on how we discern reality through technical processes - i.e. through 'enchanted forms' (Ibid, p.163). In other words, technologies that promise transformations so appealing, that perhaps hinder critical thinking of possibly problematic aspects of the transformations that take place in the present. The imaginaries which are closely associated with the use and integration of 3D printing in the new way of digitally integrated production (European Parliament 2015) and reproductive activities are one way of enchanting[116].

This chapter, focusses on activities enabled by 3D printing which foster learning, searching and exploration in everyday life through craft and innovation practices. What has become apparent through 3D printing ethnographic vignettes, among the new trends and developments introduced by the technology, is that absolute dichotomies such as bottom-up versus top-down, bureaucracy versus resilience, manufacturing vs craft making, are problematic when confronted in real life situations. Many of the users that I encountered relied at one time or another on bureaucratic norms to help complete their tasks. For example, they depended on the supply chains that bring better and faster machines onto the market and into their hands; the centralization of designs that emerged from the 3D printing infrastructure; the safety standards and quality control of materials that became synonymous with manufacturing processes. This was certainly true for those who wished to move beyond a mere acquaintance with 3D printing. However, the burden

[116] See the first chapter discussion on imaginaries closely associated with 3D printing.

of bureaucracy[117] as it stands was impossible in some instances to move beyond the idea. After all, a prime motivation for using 3D printing in a grassroots context is to develop and learn more about the process and its applications by experimenting and by collaborating with people of different skills and know-how. Being able to craft while using digital infrastructures, being ready to tackle practical problems, being resilient enough to combine all the above drawing upon users' personalized access and the time they have at their disposal, is what gives 3D printing's innovative culture its unique. character

The three vignettes presented in this chapter aim to focus on singular issues while showing the multifaceted and overlapping characteristics of current practices. The first vignette introduces a school which attempted to integrate 3D printing into the curriculum in order to shift learning to an experiential activity. The relationship between teachers and students and the role of technology in the learning environment are the primary topics of analysis. In the second, I introduce Benjamin, a radiographer at the Royal Refinery Hospital of Leicester., Using 3D printing and a Hackerspace, he was able to complete a device that enhanced the accuracy of his work results.. This raises questions about locality and craft problems of science. I also attempt to highlight the relationship between grassroots community and practices, digital infrastructure and policy. The third vignette is about Aleksander, an immigrant to the UK, who discovered the capabilities of 3D printing using social media, allowing him to build his own printer while developing his technical skills. Aleksander typifies how users can and do engage in social transformation. Far from being the popularly imagined stereotype, Aleksander's story perfectly illustrates how communities are in fact the primary means of materializing ideas, just as they also generate such practices and ideas. For the user, the development of 3D printing and its emerging infrastructure offers an ever greater opportunity for user innovation - the increasing participation of users in areas previously the exclusive

[117] As users attempt to innovate or just follow the legal path to commercialise their creations, they are befuddled with rules and regulations that make it almost impossible to fulfil. As it happens, many of them try to hack their way towards their goals.

preserve of professionals. These are the types of users which also attract institutional interest.

Democratization and user innovation

A broad interpretation of innovation as exemplified by that at the beginning of the chapter, is reason enough to suggest there is a trend towards what is being called 'democratization of technology'. The growing recognition that innovation by anyone can happen anywhere, anytime, and that it can come in many forms and shapes is what lies at the heart of the idea of democratization. Three ways of democratizing come to mind. First, provide access to and participation by marginalized populations to technology. Second, create appropriate structures for facilitating this participation. Third, shape the agenda of technological developments upstream. For users who are theoretically reflecting upon their activities in Hackerspaces and other grassroots organisations, this is the basic motto. The more people get involved with technologies, the more they come together by establishing connections, the more likely it is that their activities will yield an outcome. The relatively stress-free environment of grassroots organisations encourages creativity. Of course there are instances where users are under pressure to complete their projects, where relations between the users can be tense and things don't go smoothly. Once adopted, the fast development of technologies and the widespread adoption of the desktop 3D printer made user collaboration easier to the point where such machines became the the glue and a tool of such endeavours. Eric Von Hippel (2005) suggested more than a decade ago, that the ability of individual users to innovate or to upgrade existing software and hardware is changing. Given the right conditions, access to tools that were previously available to industrial manufacturers, now can be utilized by ordinary people.

> When I say that innovation is being democratized, I mean that users of products and services—both firms and individual consumers—are increasingly able to

> innovate for themselves. User-centered innovation processes offer great advantages over the manufacturer-centric innovation development systems that have been the mainstay of commerce for hundreds of years. Users that innovate can develop exactly what they want, rather than relying on manufacturers to act as their (often very imperfect) agents. (Ibid, p. 1)

The trick of this process is that there is no one-size-fits-all. If innovation within the manufacturing industry can be a "messy" process, innovation that results from the assorted desires and available resources of individuals and groups can be unique each time.

> The ongoing shift of innovation to users has some very attractive qualities. It is becoming progressively easier for many users to get precisely what they want by designing it for themselves. And innovation by users appears to increase social welfare. (Ibid, p. 2)

Indeed, a simple personal computer (a tablet or even a smartphone), a connection to the internet and the ability to move it to the nearby Hackerspace, are all that is needed to get started with designing and printing objects. The quality of the end product may be questionable. Several 3D printers may be time consuming if the printer is a cheap item object they can find on the market, but for custom parts, the process is on the contrary time saving. Traditionally, getting the end product from the design process meant that the user had to know either how to craft it or had to wait weeks or months for the item to be delivered by a company. Thus, the consumer becomes part of the production process. What the mature markets designate as the 'consumers', is known to the emerging digitally augmented environment as the 'users'. A look at how software and hardware “consumers” understand their role in terms of getting what they want, readily explains the emergence of the term ‘user’. Reading from Von Hippel,

> Today, in sharp contrast, user firms and increasingly even individual hobbyists have access to sophisticated design tools for fields ranging from software to electronics to musical composition. All these information-based tools can be run on a personal computer and are rapidly coming down in price. With relatively little training and practice, they enable users to design new products and services—and music and art—at a satisfyingly sophisticated level. Then, if what has been created is an information product, such as software or music, the design is the actual product—software you can use or music you can play. If one is designing a physical product, it is possible to create a design and even conduct some performance testing by computer simulation. After that, constructing a real physical prototype is still not easy. However, today users do have ready access to kits that offer basic electronic and mechanical building blocks at an affordable price, and physical product prototyping is becoming steadily easier as computer-driven 3-D parts printers continue to go up in sophistication while dropping in price. (Ibid, p.122)

3D printers are combining both software and hardware capabilities. The users of desktop 3D printers have benefitted both from the opening of hardware, open source electronics such as the Arduino but also from the already happening diversity of software programs, both for experienced but also for complete newbies in CAD design. As one might expect, there is a great variety of users whose interests are as diverse as their everyday material limitations. Access is one issue that, for the moment, is a bone of contention between the different actors and interests. For example, between those who favor a stronger patent system and those who are against. Another issue is the emerging debate on cybersecurity that could put at risk the already problematic understanding of ''free flow'' of digital objects. Then there are those who seek to limit the extent to which everyone should be able to innovate in their everyday lives. In this instance, time limitation is often cited. Assuming the issue of access is resolved and an individual does manage to get into the Hackerspace, the amount of time they are granted can determine or limit what it is they seek to create. It is unlikely that someone would go to the Hackerspace just to print a whistle, which (as mentioned in an earlier chapter) is the most common item that one can use as a template. A local store or online market platform can deliver such objects in the UK so cheaply and quickly that it would be impractical use of time and effort to redeem the printed whistle just to hang on the wall as a novelty.

Material conditions aside, culture also plays a role when it comes to enabling or restricting users. As Alessandro Delfanti (2013) argues, many users exhibit a mixture of old and new cultural habits reflected in the way they use the technology. For example, a commitment to open source materials, hardware and software cannot be justified only as a cynical excuse to save material and time. The issue has taken on an ideological flavor as some argue for open-source in preference to closed because the former works for the benefit of all society, whereas the latter serves only the interests of a few powerful corporations. Delfanti (2013, p.119) also highlights that this kind of experimental culture has at its core 'public engagement with science, open source, participation, decentralization and innovation'. As he suggests, 'hacker cultures represent an important driving force for contemporary innovation regimes and are somehow an heir of scientists' culture' (ibid, p. 49). The open way of communication, craft and gift economies, an impulse and outright rejection of authority (albeit in individualist terms most of the times) represent the values of this culture.

Despite various interpretations of the hacker culture (Levy 1984; Kelty 2008; Delfanti 2013), one vital element without which the culture could not flourish, is that it eliminates barriers for the individual to create. What happens from then on is up to the users – their creative intentions, the context of space and the social environment in which they operate (Maxigas 2012; Coleman and Golub 2008). In order to be able to create and innovate, the hacker culture exemplified in this context is all about access; not only to information (2003) but also to material and hardware. In addition, since not everyone can be skilled at everything, means recognizing that the multiplicity and heterogeneity of technologies that can be created with the same tools requires the input of a range of unique skills as well. In order to create, software hackers need to be able to find the right materials at the right time and learn to combine skills and teamwork. This is how the learning process started to shift away from a centralized knowledge given by an authority to a hive-like, research network where leading schools now focus more on the methodology and not solely fixated on final results. This is the new context in which 3D printing unlocks possibilities in everyday life for what is termed "democratization of technology". Its increasing presence in community workshops and homes alike, provides potential users with easy access. Moreover, its use in the context of community workshops provides a breeding ground for building participatory or inclusive institutions as well as shaping the technological agenda through feedback and collaborations.

The final answer is nothing, the method is everything: learning with 3D printing

The role for 3D printing as an education tool is gaining more and more recognition and attracting more attention among its adherents. Stratasys, one of the biggest 3D printing companies, went so far as to create a curriculum for in school and college use. The growing influence of 3D printing as an education tool is reflected in how more and more schools are using the technology to re-organize the way learning is conducted. For this reason, I found it helpful to visit a school where traditional teaching is transitioning towards new learning experiences. In July 2016, a newspaper article described how a small robotics team from my former school in Nicosia, Cyprus, had won the innovation prize at a competition organized by Microsoft Innovation Center in collaboration with the (privately funded) European University[118].

I contacted the head of the robotics team, who agreed to guide me through the facilities and explain the students' vision, work and projects. In addition to 3D printers, the learning space included Engino toys for robotics, 3D screens for learning, tablets and other new technologies. It is worth noting that 3D printing services made their appearance in Cyprus just recently, a start-up culture spearheading government plans to stimulate job creation and tackle youth unemployment through flexible work schemes and importantly entrepreneurship[119]. I asked how the integration of 3D printers fitted into the school's general framework and curriculum. The answer was that it is part of a wider vision "to prepare students for an unknown environment" (Maria, Head of the robotics team, Grammar School Nicosia, Interview). Entrepreneurship is key here because of the element of the unknown and a willingness to instil a culture of risk-taking and individual responsibility in the new generation.

According to Maria, "10 years ago, we did not even know that there would be professions such as web designers or graphic designers" (Ibid) on such a mass scale, or other professions that have emerged as a result of the development of technology. Its direction could not be predicted so a new curriculum was required to accommodate this elusive unknown element. Two

[118] Microsoft Innovation Center is located inside the European University, self-described "state of art technology facilities for collaboration on innovative research, technology or software solutions, involving a combination of government, academic and industry participants." Grammar School, is a private junior and high school in Nicosia with a progressive profile and reputed to be one of the best schools in the country. In trying to establish a ''competitive advantage'' in the country's education market, it regularly upgrades facilities and programs. In addition, last year the school "introduced an innovative collaboration with Microsoft to establish an IT Academy [making it] the first school to become a Microsoft Office Specialist Testing Centre in Nicosia". This meant introducing new ways of conducting classes, within existing modules and in extra-curriculum activities.

[119] For example, "Startup Weekends" is a network which seeks the creation of 54-hour events to bring entrepreneurs, designers, developers together in interdisciplinary ventures.

interdisciplinary teachers organise the school's modular courses on technology for the different age groups and classes. When a teacher opts to print objects to enhance a classroom's understanding of a particular subject, he or she arranges for the technology experts to come along and help.

The school encourages the development of new practical technologies as a form of hands-on learning that engages the students more directly than a read-out of the theoretical logic of matters. The fact that Students have been developing technologies and creating devices so they can participate in national competitions as individuals or as members of class teams seems to bear this out. Some make connections beyond the school and link up with on joint projects with university students and others who have ties with the school. Such enterprising spirit attests to the school as an innovative institution, engaged in multiple student projects using the technologies located on the premises. In one instance, students developed a device that could create frappe[120]. The eye catching display featuring the device was staged at the biggest shopping mall in Nicosia. As the director of the school robotics team related it, the frappe display had the desired impact. Shoppers and passers by stopped and stared, and its public debut featured in the local press. Public displays like this showing off the students' ingenuity also serve to raise the school's profile. But, the gain is two-fold given the amount of extra-curricular effort and after-school time the students pour into the such projects. Their commitment came as a gratifying surprise to many of their teachers, who, I was told, were unaccustomed to such shows of enthusiasm with other classes. It is part of a culture of experimentation that the school promotes. The future-orientated narrative now sweeping the country suggests that innovation is a vital component for economic growth not only through the introduction of innovative products but an innovative process where learning is the keyt (Edquist, Hommen and McKelvey 2001)

[120] Frappe is a distinct popular way of drinking cold coffee in Cyprus. The expression "does the machine create a frappe too?" is often used humorously when a complicated device is being demonstrated in public.

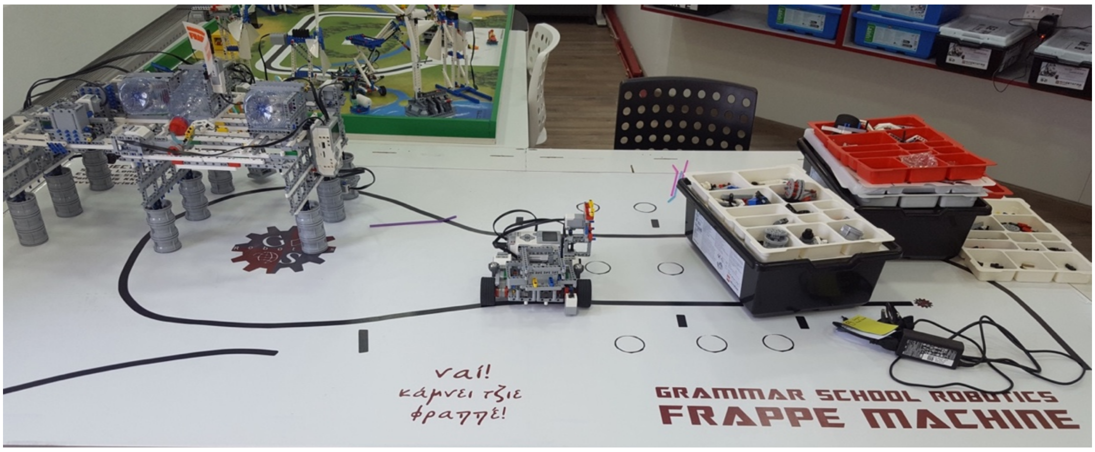

Figure 44 The Frappe machine exhibited at the shopping mall. In the center of the table is the hand-written caption citing the popular expression "yes, it can even make a frappe!" in the Cypriot Greek dialect. Photo credit: Leandros Savvides

Similar accounts can be found in the Cypriot media and among official stakeholders (government, local authorities, industry reports) extolling the innovative and experimental activities of young people using the new technologies. The same is true of EU policy papers dealing with the subject. This kind of serendipity occurs because the hackers and makers culture has yet to form specific and perhaps rigid viewpoints, thus allowing communities to pursue issues and policies that may be closer to their members' interests. There are few hacking spaces, but they are usually informal groups of professionals related to hacking and making, still trying to organize. Often, the aim of such spaces is to be able to collaborate either in EU-funded projects or with universities in order to keep growing as communities and to sustain the space financially. In these circumstances, the word "hack" probably applies more appropriately to entrepreneurial activity than to non-profit open-ended practices. This is also reflected in various events which bear the title "hackandare" organized by groups and associates more interested in promoting entrepreneurship[121].

Understandably, as enthusiastic as the teachers were about the school's newly introduced "learning space", they were cautious about what information they should share with me. From the outset, the teachers

[121] Hack Cyprus is one such annual event. It aims to link entrepreneurs, academics and businesses through making for commercial purposes. This does not mean that all work done at such events is commercialized but rather that it is the underlying intention while still allowing participants to have fun.

responsible for the learning space, were frank about what they could show and unveil to me. The school did not want to jeopardize the competitive edge it has over other private schools. This was a major difference compared to the freedom of movement that Hackerspaces give to members and guests. The school aimed to assimilate some of the practices that grassroots community workshops exhibit into the curriculum design. While it does not launch commercial products through its activities, the learning space is, nevertheless, a commercialized educational space. That being the case, my visit was supervised by the coordinators who determined what information to disclose.

The availability of 3D printers as part of the curriculum gives the school's reputation a fillip that in turn can become a revenue-boosting attraction by raising the number and quality of student applications seeking to attend the school. This was stated unequivocally when I asked to record our interviews or capture photos of the space for data gathering purposes. Once initial doubts and skepticism were put aside, the atmosphere became cordial and soon they agreed to explain the whole process and show the premises. George informed me that kids as young as 8 or 9 years old are able to use the 3D Cube (by 3D systems)[122] or the Makerbot replicator (for bigger projects). George did admit, that despite having to make an introduction in order to "explain in theory" the difference between "3D in relation to 2D", the arrival of 3D printers at the school was done in perfect timing to transformations happening in social and schooling practices. Many of the students for example, even those below age ten, own a smartphone and are familiar with 3D concepts on the screen.

"Normally, most children attending the school have seen a 3D movie, which enhances their capability in understanding the concept" George tells me as he points out the dimension that is least experienced at school depth. "So, width is something they experience on the screen, which will then help them with the software and other related activities." In order to get the best

[122] This 3D printer comes as a closed lid machine. The coordinators of the curriculum decided to provide a closed lid 3D printer as a safer choice to a 3D printer without lid.

out of the students the teachers ask them “to find practical reasons a 3D printer can help their activities. This is when they start to visualize where 3D can help - enhancing the chances of humans being in places they cannot be physically; cutting costs on training activities, to name just a few.” An essential part of understanding 3D printers is not to learn about the process in isolation which, he explains, is why the students are given “the chance to understand 3D not only as printing but also in other technologies.” He continues,

> What we have done essentially is to transform the space. When you talk to someone about a class, they imagine a series of desks in a row looking at the teacher. We changed that from a class to a learning space. The teachers can move and re-arrange the class as they want. It is not a fixed space anymore. The desks are very light in order to move them. The students can move around according to the lesson and depending on the project they are involved with. Everything is mobile in this space. There are several screens and interactive boards as well as tablets in order to help them. The school has Wi-Fi. Students have a different password than the teachers. I have even integrated their smartphones into the lesson, instead of trying to suppress their use. The goal is that the student has to have access to the internet anytime, anywhere at the school. (George, Technology teacher, Interview)

By deliberately transforming the space, George aims to shift the focus from the teacher to the student. George studied in the UK and so was clearly familiar with the new digital transformations taking place between learning, art and production. This shift in learning was part of the school strategy at the time of my visit. However, my general feeling from our discussions, was that George had much to do with this strategy. “The teacher is not the main source of information, the internet is”, George told me as he was showing the new mobile classroom arrangement. The dynamics of the class are altered. The teacher, no longer the traditional authority figure who is responsible for knowing the answer to everything the student might ask, has become a part-guide rather than an absolute source of knowledge. In this way the student assumes the role of researcher from a young age and learns how to find ways to cope with projects by through a combination of methods and technologies. The importance of 3D printing, especially for very young students, now becomes a crucial factor. “Most of the students see the 3D printer as the first technology capable of manufacturing objects. They have no other reference technology or craft as in the past. They do not know that a bottle in the factory passes through stages in the assembly line, is pressurised etc. The 3D printer is for them the reference point upon which they distinguish the rest.” Thus, in order to widen the students’ thinking possibilities, the teachers try to push their imagination even further, integrating social science fiction stories[123] by saying that “3D printers in the future will be able to print cars and even humans!”

> The teacher’s role is to guide and synchronize the students in their search, so the student becomes like an apprentice. It is ok for the teacher not to know everything and for the student to see its role differently. Some of the students take their projects to levels that we do not expect. I do not claim that this way does not have any problem but generally it works. There are even classes in which I give the answer and look to see the method of completion rather than the opposite. And you do see a variety of groups in the class having much different approaches. So we shift the focus from the

[123] see chapter on politics and imagination

> result to the method of learning through practical technologies such as 3D printing and with the effective use of the internet. (George, technology teacher, interview)

The new setting attempts to alter the focus of the learning experience. Instead of transmitting knowledge, the introduction of technologies in which the students are engaged physically aim to make learning a practical experiential activity. “The students learn how to proceed and get in the mind-set of how to arrive to an answer themselves.” The lessons become interdisciplinary, combining theory and practice in order to raise new questions and perspectives on subjects that have remained largely the same over the years. By combining “art, history, technology and modelling” a teacher took the initiative to teach about Choirokitia, one of the earliest recorded communities found in Cyprus, through the use of digital media. So, even though the primary objective of the lesson was to learn history, the students had to find ways of expressing history through projects they could choose. The teacher, although loosely trained, with the help of the teachers responsible for the learning space, was able to use enmeshed technology in order to

> give the students another perspective. In the beginning, we talked about the issue as we normally do through the textbook. Then I organized a trip there[124]. I organised the kids in groups where some of the groups would take photos, other groups paint, others create a short theatrical play. When we came back we discussed our trip. Some of the students, those who took photos, have shared them with me in one drive, or the note that we are connected through.” (Eleni, Art history teacher, Interview)

[124] The school provides tablets to the students which they are allowed to take home but must return at the end of the academic year

One of the student groups choose to scan objects of everyday use and then print them as a way of understanding the life of the community. When using 3D printing, the students asked questions that would have been impossible to think up had they just engaged with history through a textbook. For example, they asked questions “about size and shape of objects of the materials used at the time and what would that mean both for 3D printing and for those societies. I asked, what size would that object be, smaller than real or similar? What kind of material is 3D printing made of? “Because the students were very excited about the whole process, they were very engaged”, Eleni responded, and aware of the surrounding; the lesson was not a mere transmission of dates and details from the teacher to the student. The lesson was irregular to begin with as they did not remain in the room of the prints the whole time during the prints.

> They “came to look for the prints at one per cent, asking a variety of questions. Then, after a couple of hours we came to see how much completion was done.” In the classroom the questions raised had more affiliation to the historical side of the lesson “but whenever they came to see the prints, they were asking much more practical questions. They were asking how the scan works, how the technology of transmitting data from the software to the hardware proceeds. At some point, they became aware what was done wrong in the software and their digital design so that their physical object was not quite exactly how it looks on screen.” (Eleni, Art history teacher, Interview)

Along with the 3D printer, they had to use a scanning device to capture the object. Very quickly in the process they became aware that “in order for the software to scan an object well, it needs to rotate at a steady speed, somewhat slowly but smoothly. At some point, you could see them asking each other how to move at the right pace so the scanner can read, showing an understanding of the time details of the machines." It wasn't only the scanning. Every technology, however much taken for granted, was subject to questioning, because once they had their own space for creating the project, the students had to understand what to include and how to achieve it. "They were interested to see how infrared rays work in order to get the whole process of 3D scanning and printing." Then, once they had grasped the basics, said Eleni, the teachers stood aside, observing from a corner of the room,

> leaving the space to the students who were not only leading the process, but asking and answering questions by themselves. You could see that when some groups were ahead in the process, they were effectively showing the rest how to complete the tasks. What emerged from this experiment, was collaboration between students that was not mediated by any authority figure such as the teacher (Eleni, Art history, Interview).

Figure 45 Objects printed from the visit in Choirokitia archaeological site. The exhibits are stored in the art class after completion, the original are stored in a museum at the city center. Photo credit: Leandros Savvides

The process of learning without the mediation of an expert figure, stimulated familiar line of thought. Not unlike what I had encountered in Fab Labs and Hackerspaces but, being a school, in a more structured setting. Nevertheless, the core principles of collaboration and experimentation were evident not only in theory but also in the way the students reacted. What distinguishes the school from the Hackerspace is the regulated manner in which this process has to take place. Framework and basic rules are set by the teachers, but the students were free to experiment within these parameters. Of course, the school is responsible for ensuring the students' safety and that of the process including equipment maintenance. For example, one of the problems that emerged was the issue of circumventing power supply cuts[125] because of the school's location. In a Hackerspace, this would be treated as a community problem, given that the point is to utilise hacking and collaboration skills for the benefit of all. In the school, the issue is resolved by a paid professional. In Hackerspaces, depending on how they are organised, it is up to the community or the responsible committee to deal with it.

Health and safety in a learning space replete with technological tools is sufficient reason to argue for a controlled environment. The issue rarely comes up in a grassroots space. It emerges and becomes more visible as the space becomes more organised and more people become users. Solving this while giving the students the freedom to perform their projects their own way can be a challenge. Normally, a balance is negotiated. The students did ask whether the 3D printers were safe to be around and to use. In a genuine grassroots organisation such as a Hackerspace, the responsibility usually falls either on the person responsible for the specific machine, the user, or both. There is always an element of surprise and/or risk, when a user is exploring and experimenting even though the machine has been approved for consumer use. In certain spaces, such as the one in St. Pauli for example, there have been cases where potential users expressed their concerns about

[125] Located in an area where power cuts by local authorities is not an unusual occurrence, they had to take into account how machines respond to such events.

health and safety factors with 3D printers. This is because there is no substantial research yet into the possible impact on health of the fumes coming from the process of melting plastic. Rather, it is often assumed by users, that because it is traded as a product, PLA must meet safety standards.

Learning through the lens of 3D printing is an emerging trend as is evident in social spaces. The trend represents a melding of the theoretical and the practical without diluting one into the other. It is utilizing local context to create digital technologies. Ultimately, it affords users the possibility to control the process as in a craft environment. By learning practical matters such as size and types of materials, students who perhaps think themselves more inclined towards theoretical subjects, can be in touch with the materiality of objects, and find themselves raising different questions which in turn demand and yield different answers. This approach requires a nuanced view on how to manage resources, on how to think and, ultimately, on how to create as part of understanding and learning. This is possible not only because the processes *per se* but also the implicit embrace of the open software and hardware movements' core principles: that evolving technologies through community offers a a faster mechanism for development as well as giving access to a wide range of users outside the professional community.

So what does this type learning environment have to do with innovation? What is important for the creators of this learning framework, was to inspire students not only to experiment - the new mantra of individualism that comes as a valuable skill for the labour market today (see Chiapello and Boltanski 2005) - but to make the students resourceful and entrepreneurial through digitally integrated methods of creating. There is an apparent contradiction between the attempt to make the students collaborate and the individualist and even competitive culture that is fostered, as well as the independent thinking that is encouraged within the limits of the given framework. Where social problems persist, this independent thinking is harnessed to finding solutions to problems within the existing economic framework. However, despite the market economy remaining largely uncriticised, the students are encouraged to deviate from established methods to achieve their goals. Such an approach to learning fosters independent thinking and problem solving, as the user seeks ways to circumvents existing social problems using the newly available technological tools. This can be done in style through craft and personalised technologies.

"It is really just problem-solving": crafting science

During my visits to Leicester Hackerspace I met many different types of users. One whose activities I decided to follow was Benjamin. A radiographer at the local Leicester infirmary, Benjamin found the Hackerspace by "Googling". He set out to use the space, helped by several other regular users, to create a device to help with his work at the infirmary. The aim was to solve problems associated with radiographic theatre imaging that industrial manufacturers had no financial incentive to do commercially.

> Manufacturers are just interested in making lots of money, can I use the F word? They are not interested in solving these problems and yet they are problems. The doctors want them solved, the patients would like them to be solved. (Benjamin, Radiographer, Interview)

So, for Benjamin, the only way to make it happen, was by coming up with some solutions on his own. He likes to complete his own projects in his spare time, in the garage, usually working alone. He also has a website where he publishes some of his work. This project was different because it required the support of some people from the local Hackerspace. The project entailed use of various hacking technologies including Arduino, 3D printing and some programming. Because he was unfamiliar with Arduino, Benjamin asked people in the Hackerspace if they would be interested in helping him hack a small tilt meter device. Moreover, he needed advice on other micro-programmable devices that might help complete the project. As a reward, he mentioned a small charity fund he received to help him as well as providing "tea and biscuits" in return for brainstorming.

I was alerted to Benjamin's project because, other members of the Hackerspace were aware of my interest in following project that entailed use of had 3D printing elements. On contacting Benjamin with an offer of general help, he promptly let me know that he had found the members with the expertise he needed but indicated he was open to discuss the project.

> At the moment it looks like there are quite a few Hackers interested in this who have Arduino experience but we'll see who actually turns up tomorrow :) Thanks for your offer of support as long as all of those who help are committed then you can certainly help however if the group gets too big it will slow down (I'm sure there is some law of diminishing achievement with over-sized teams). (Benjamin, Radiographer, Interview)

As with some other projects I saw at the "Leicester Hackerspace", this one required very specific inputs of prospective participants with the appropriate expertise in order to proceed effectively while keeping to a carefully planned timeline. Benjamin, having politely turned down my offer of help in the first place [126], by now had agreed to meet me at the Hackerspace, where he was meeting other members to discuss the project in person. It was an open hack-night[127], so it was expected that the space would be full. As soon as I entered the Hackerspace, Benjamin was already there talking to other members, seemingly immersed in the project looking for relevant technologies that might help him create the device. He found the outmost

[126] I assume that my initial rejection had to do with my lack of the relevant expertise he was seeking.

[127] Open hack-nights are nights when the Hackerspace is open to guests. Depending on how organised the Hackerspace is, visitors are shown around by designated members, informed about its activities and why it might be a community worth joining.

attention by Rahul, a usual figure in the Hackerspace, whose interests are far ranging, from 3D printing to programming. Others joined in, advising Benjamin about the kind of technologies best suited to the device he was seeking to make, which, in essence, was no more than an idea. He wanted to 3D print the cover parts of the designs he had made but would need help with finding small enough products that could control the lasers and the wireless. At some point a member suggested that the latest small electronic component called a ‘‘light bean’’ might help him control the wireless device. The member had come across this device on Kickstarter a few months prior, as one of the early funders of the project. The meeting lasted no more than an hour, during which Benjamin seemed to absorb everything the assembled members offered by way of tips and possible routes to the project. After the brainstorming, he came to greet me in person and ask if I felt the project was something that interested me[128]. For my part, I was feeling inundated with too much information. Benjamin spoke very quickly, assuming an understanding of the many technicalities that Hackerspace aficionados are presumed to be familiar with.

I can only imagine from the way our first conversation went, that my attempt to research social aspects of the 3D printing phenomenon must have struck him as odd since it amounted to another language, one that usually remains outside hackerspace doors. My position at the Hackerspace had to be explained as "inactive user", since members would consider it an oddity that someone visited their space on several occasions yet neither created nor hacked. As Benjamin continued in full information overload, he did offer to talk about the project but he was in no mood for casual exchanges and made it clear too any interview would be conditional. "Yes no problem as long as it doesn't take too much time from the Hacking! :-)".

Me: How did it all start?

[128] Despite not knowing who I was, he recognized me because I was following the discussion that was taking place and took some notes, without being part of the project.

> Benjamin: It is really just problem-solving for me, just doing my job We are constantly trying to solve a problem t by eye. You see a patient and you try to position them perfectly into the machine. If it's a little bit awry, I mean just a little bit, a few degrees, it will not be able to record the exact image. If it is not straight if you like. And that applies to all sorts of joints and spinal parts. They are complex structures. So I see it in a geometrical way and I think I can solve this geometry problem. If the patient moves, you must measure their movement.

The conversation brought to mind Ridley Scott's movie, "Martian" (2015). The protagonist, Matt Damon, is a scientist left on Mars after space mission. His survival depends on his ability to combine the world's knowledge of almost anything and his own craft making skills. Drawing on the traits of an an earlier Hollywood craft-based character, TV series MacGyver (1985 – 1992), the Martian concludes that 'in the face of overwhelming odds, I'm left with only one option, I'm going to have to science the shit out of this' (Martian 2015). It is a masculine concept of rugged consumerism; the replacement of the adventurous spy with the indomitable scientist, an attempt to up-date cultural stereotypes but not obliterate the underlying concept. Using science and knowledge to craft ways to survive, the central theme, the movie explored the existential social theme of how humanity needs to move on in times of crisis. The protagonist was clear. Science is the way forward for humanity. But, returning to the Hackerspace meeting, Benjamin was still speaking extremely fast and, unlike the film, was too technical for an outsider to understand his project, which, in any case, was in such an experimental phase that he was trying out new things to see what might work. We agreed to talk again once the project got underway. Meantime, I was to send some information about open source metal 3D printing that might be of use.

I then lost track of the project for more than two months, a period during which things stood still since Benjamin was on a personal break. When we reconnected in late January, Benjamin confirmed he was "back and printing away". Efforts to meet at the Hackerspace and perhaps help never panned out. After a couple of months, he agreed that we meet at his home where he would arrange to show the finished device and explain it. Living a few kilometers outside Leicester city center where the Hackerspace was located, I could see why he selected this particular Hackerspace as the place to develop his project. He later confirmed,

> What I did was to web search – I have been a Googler for a long time. I would search everything on Google… I was like, I really do not know all these Arduino things, so I started looking for Arduino groups that were close to me because many of them were very distant. This is how I eventually found the Hackerspace, because they were doing some workshops on it. (Benjamin, Radiographer, Interview)

Finding a location that suits can be a real hurdle, since it depends on the potential user's particular circumstances - proximity, transport availability, free time allocation, enthusiasm about the project, availability and willingness of people to collaborate. The back-and-forth required, communication problems, misunderstandings, are part and parcel of the craftsmanship process with projects at grassroots organizations. When the collaboration is voluntary without the obligations of a business transaction or a wage relationship, creating and setting up a project and coordinating or synchronizing the the free-time availability of all the participants become a major part of the creation process too. Take too long and some members might not be interested or lose interest. Negotiating time commitments and what each participant does can be crucial in determining whether the project will be completed -- certainly as much as finding the right material and people with the relevant skills. Looking back on the experience, Benjamin acknowledged the people and the skills that are required and the exacting demands of trying to complete a project as fast as possible in order to minimize the chances of it being left in the garage incomplete:

> There are some things I do not know. Although I like to be a one-man band because I can keep control and because it's rapid if it's only me doing something. Other people tend to slow me down. That began to happen with the Hackerspace by the way because of Rahul being very busy. I appreciate his help of course, but I booked to do it with him, and it is a bit slow. In the beginning, we were quite good, doing bits every week and moving along all sorts of things with the project. But now it is slowed, because he has so much stuff going on, perhaps too much. I am not going to complain about Rahul. He is a great guy, an amazing guy, but he is too busy, there is little time for it all. So, for me, I like to do things very fast. Just because I have an instant gratification problem, I want things now (laughing)! So, it is one of my things to try and do them very fast. When I think something now, I plan so I can have them by next week. (Benjamin, Radiographer, Interview)

Benjamin did acquire the information he needed at the Hackerspace about existing parts that would provide an essential component of the device. To control the device, he needed something like an Arduino but would have preferred something simpler, even smaller.

> So, first I went on the internet to search for wireless tilt meters. I found some but they are not small, and they are not light and they are not cheap. I needed light,

> small and preferably cheap. So, I went to the Hackerspace and talked to people there. Somebody told me about this new thing that came out, ‘light blue bean’. That has been a revelation and light blue bean is very good. So, that opened that door for me, but also the electronics expertise. I am not a good solderer. I have a lot of skills, but if I am impressive at some things, my soldering is definitely not impressive. I can do it, but it’s not very good. Some people like Rahul can do these things. But I don’t have the steady hands for it. (Benjamin, Radiographer, Interview)

As he repeatedly stated during our discussions, Benjamin has an “instant gratification problem”, by which he means he has an almost obsessive need for the satisfaction that comes from completing short-term projects successfully like finishing a project with a workable object. It doesn’t matter how many times it will be used. What counts is the feeling of accomplishment. This is where speed comes into play for Benjamin. His crafts are a way of having fun. When projects take a long drawn-out time to complete he loses that sense of satisfaction and excitement that comes with completion, so much so he may even end up leaving the project unfinished. Speed was cited by many I encountered as a limiting factor of 3D printing. Yet, for practitioners like Benjamin who cannot easily find what they want at the local stores, it seems a very fast solution. Although it may take up to 20 hours to print a part, it is available and very cheap and is, comparatively speaking, a very fast way of bringing an idea to life. Certainly, it is much faster than waiting for parts that are either imported individually or involve laying out a lot of money to have injection molds made for a specific shape that does not exist. This is where experimentation, essentially a gamble, allows the user to try several parts without much hesitation. Assuming the user knows the machine and has a basic knowledge of designs, the printed objects can be printed with relative consistency. In the case of Benjamin, this is where craft and science merged. Once he can craft this device, as he told me later, he will be able to change how his job as a radiographer is conducted.

> When I first saw a 3D printed object I thought 'hmm this is a punt, but it is only going to cost me nineteen pounds! I will just put the camera into this thing and see what happens.' And it worked about 28 times, so this thing seems to be working.
>
> […]
>
> 3D printing really changed my life, because there was not other technology that could help me arrive at a finished product as fast as this. To arrive to something that looks like a finished product. I only thought how to make it in January and now, four months later, I have been using it for a month and it is practically a finished product. I have been doing some other stuff as well. If I wanted to focus only on one item and go all the way, it would take years and layers of bureaucracy to make it into an approved final product than the actual prototyping. (Benjamin, Radiographer, Interview)

Benjamin's story shows how the mix of handcrafting, communication skills and various new technologies helped him develop a device that would otherwise have remained no more than a thought. Not only a DIY device, the tilt meter he developed gives him the right to claim that he actually advanced radiography, practices that had been entrenched for some time. By using digital craft methods, he aims at lifting the methodology of measuring x-rays from a craft status to a science status. The new method, makes his field "more scientific", he claims.

This changes radiography from a craft, to a science! So, it is a mathematical geometric correction, combining a a wireless monitored patient and geometric correction" he said, explaining,

"There is this book, like a bible for radiography, written by two women, Kitty and Clark, or Kitty Clark as it is called. It is several volumes actually with specific positions and angles for patients to get into. You have to remember the whole thing. But actual patients, it turns out do not behave like the figures do in the book. They are drugged or unconscious or broken, so you have to adapt the position around the person and try and capture that moment. The doctor will say unable to examine the patient, would not cooperate. I am thinking, how am I going to get these incredibly accurate X-rays when the patient won't even let you touch them! Nobody has done anything since Kitty Clark in a way. It is like radiography stood still for 60 years. In fact, it has gone backward, because other modalities have been eroding away in the plain film world." (Benjamin, Radiographer, Interview)

I asked why companies in the field had not created the device before him or why other radiographers had not thought about doing so. Craft, Benjamin suggests, is an essential part of the identity of radiographers. It is not just the way the profession has been conducted for so many years, but also how people identified themselves upon joining the profession. Being able to identify by eye how the angle of the patient would seem on the X-rays, is essentially all that separates a professional radiographer and the calculations of an amateur. Understandably, radiographers would feel powerless if a new, more accurate DYI methodology were to appear possibly rendering them redundant. Therefore, according to Benjamin, since professionals neither request nor demand tools, the manufacturing companies are unwilling to produce new types of device or to make the profession more scientific.

> I think it is a lot about money, because there is not a lot of money in these tools that I am talking about. Those who do the job, also have to want them in the first place. So, radiographers themselves are involved in the purchase of what I call radiographic accessories, tools to help you do your job, that depend on their skill and craft. If you make a tool that negates personal skill and craft, they might not like it. They lose the status that goes with their job, which is, partly, to be able to position people by eye, skill and craft. So if you want to make the images perfect every time, and with some of the knee images especially that is not easily done first time around, so you have to try a second time, make corrections and get the perfect image. This is where I am going with that. (Benjamin, Radiographer, Interview)

I try to understand this distinction about the skill that radiographers are required to have as part of the job. Benjamin appears sympathetic to his colleagues about pride in their profession and their skill of angle vision. But he is not afraid to try and alter the method by altering the way of thinking. The professionals may think of angles as a personal skill. Benjamin thinks of it as a geometric problem, a mathematical problem, solvable with the use of lasers and equations rather than feeling and experience. Until now, professionals relied on the the diagrams and recommended positions from the books as well as on their experience of previous x-rays to guide the patients through the process. Now a device would be available that could measure the angles simply and accurately so that they would no longer have to proceed by trial and error, realignment and adjustments. Not that the profession should lose any of its importance from this though. Patient care, calming their anxieties, as they sit, stand or lie down for the X-ray are still very much essential parts of the job and require empathy, sensitivity and experience.

> I am trying to solve positioning image problems. Because the angle which the X-ray beam goes through the patient is the viewpoint. If I take my camera and move it a little bit, the image will be spoiled. So, we do that by eye. It is a craft. So I am just trying to make it perfect, really. I think of it as a geometric and technological problem, whereas other people think of it as a craft and skill. So they are using their skill and craft to manipulate patients mostly, so that the patient is facing forward for instance. When you try to position them in a way but their pain does not allow them to lean forward. Sometimes the cases are complicated because the patient may have dementia or Alzheimer's, they may be very ill, semi- conscious. I am not talking about a patient like that once a month. More like 20 a day. And as patients get ill, they usually are impatient with the imaging. And that is just the simpler X-rays. Then we come to the other more complex X-rays such as facial wounds that require an exact perfect position. As soon as you rotate the cheek fractionally, the zygomatic arch will be overlapped by another part of your face. They need to be at a varied 2% degree when they are up against a big board by eye. This is a skill, a craft that you learn as part of the job (Benjamin, Radiographer, Interview)

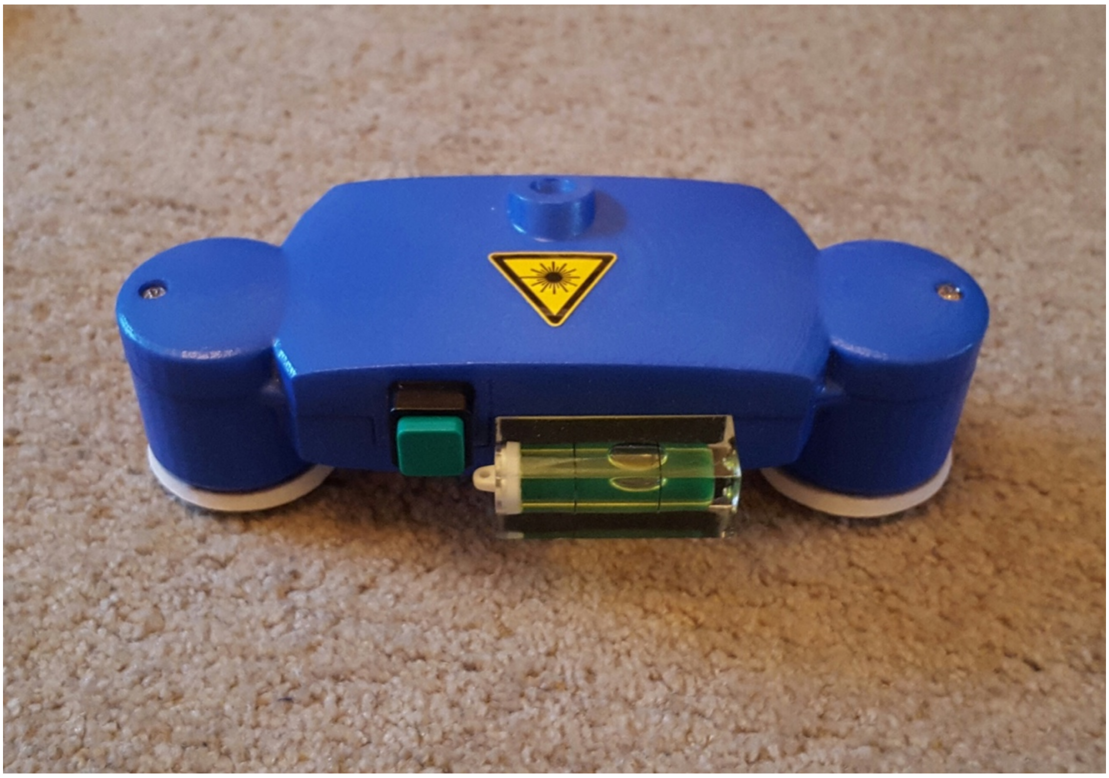

Figure 46 Benjamin's Tilt-meter device. Photo Credit: Leandros Savvides

The device is simple, yet indeed it seems that in its simplicity and craftiness, it does upgrade a specific task from the status of craft to something more scientific. The cover as shown in the picture is SLS (Selective Laser Sintering) 3D printed, whilst other parts where ordered through internet platforms. The device bottom is usually placed at the chest of the patient where they have to hold it steady, in order for the laser to show the correct angle.

The enthusiasm of creation in this case was evident, not only because Benjamin was able to complete his project, but as he joyfully said

> I created a multi-steerable X-ray machine in theatre that you can actually guide during the surgery. So I made essentially a 3D navigation system in essence with a few pieces of plastic and magnets and lasers (Benjamin, Radiographer, Interview)

His enthusiasm was part satisfaction at what the device can actually achieve but was also about the possibilities for new projects might come up. The completion of a project using not only technologies such as 3D printing, but also institutions and collaborating with the local Hackerspace, show in practice how he managed to conduct science through crafting and collaboration. The allegiance to what craft played its part in this case. Throughout our discussions, my impression is that for Benjamin, what interested him in crafting was not fulfilled on the job, but rather on advancing his surroundings and everyday activities. That part feels far more enjoyable and fulfilling for him, the sense of mystique of the professional craft is removed and is replaced by an intrigue to discover the scientific basis of his actions. It's a contradictory statement, but in this case it worked. Craft is there, science is there too. Benjamin's is a characteristic story of someone who enters the playful environment of makers, tries to figure out through frugal means and craft how to achieve workable but also aesthetic devices and objects. He is in a position to understand how institutions work so that he can have available funds, is informed about new technologies but also knows where to look for things he does not know. Simply put, Benjamin managed to use the full extent of the blend between grassroots organizations, institutions and new technologies such as 3D printing. The craft thinking exhibited here is about how to balance between social actors not only how to work objects.

Frugality and craft thinking

We already showed in the previous chapters some of the objects that can be created through 3D printers. Here we expand on the concept of frugality. This is the idea that imperfect objects can also be useful, that you don't need perfect prototypes or the best design in products. I already have images of mobile phone cases and other objects to help us explore this concept and overcome a 'tired dichotomy' as Rafael Cardoso (2008) says of craft vs design. These are all examples of 'good-enough' products that meet basic needs at low cost and provide high value. Products like these are examples of Christensen's (1997) concept of low-end disruptive innovation.

They have also been dubbed ‘resource-constrained innovations’ (Ray and Ray 2010), ‘cost innovations’ (Williams and van Triest 2009; Williamson 2010), and ‘frugal innovation’ (Economist 2010). User-friendliness and design are important to users of electronics. There is nothing new in this. Throughout the twentieth century, people have been involved in fixing and creating custom objects and devices for themselves at home. The emergence of this maker culture attracted mainstream innovation theorists because these actions can be integrated within the economic system. Here I want to make clear that frugality in countries with mature economies, the field of my ethnographic work, does not refer to the idea of scarcity (as in past literature) but with the idea of abundance. In essence it means is that users are encouraged to be creative and to be able to create anything they want using frugal means while being fully aware that the materials and technologies they can find and create are abundant. Therefore, being resourceful equates with being able to decide what is best. Resourceful is a fundamental word here.

3D printing users, at least those who started to experiment with 3D printing in the early development stages, have learned as they address practical problems to become masters of slow technology (see Hallnäs and Redström 2001)[129]. They see beauty in their devices through imperfection. Thinking through craft suggests integrating makers and hackers’ values into the objects and machines they create. The 3D printing culture aims to show a wider public that craft and thinking through craft are not about very complex activities attainable only by the few. On another level, the aim is overcome the perception that craft is low tech and means little more than working with one’s hands. 3D printing user projects are indeed hands on but those who are machine-averse or techno-awkward can learn a lot more by starting to think about and through craft. The two concepts of frugality and craft thinking are crucial in the process of grassroots innovation.

---

[129] As technology becomes pervasive in everyday life and at faster than ever speeds, some would argue that the emphasis on speed has not deflected attention from how technology shapes society. Slow technology is a philosophical concept. Proponents advocate that designing slower technology takes greater account of its long-term impact. Getting users to create their potential useful technology is one of such steps.

Simple as a device may look, it must function and serve its purpose, as Benjamin attests repeatedly. To avoid having to deal with time consuming government and commercial regulatory red tape, he was forced to look for grant funding in the world of philanthropy and charities. In the UK, such funding often makes the difference that enables the user to complete his or her project. In Benjamin's case, the help was critical. Admittedly "extremely frugal with money", a grant of 10,000 pounds was to prove more than enough to let him experiment with a variety of 3D print designs before deciding, spending a few hundred pounds on parts he might as well print. His approach, emphasizing minimal tools, zero bureaucracy, and moving ahead as fast as possible, showed how frugality was fundamental to his thinking as much as it was a matter of necessity.

Frugality is a concept that sets out to use resources carefully, perhaps not with the best devices and materials, and not necessarily in a commercial environment. The field of study emerged partly due the inability of the more resource-constrained to find objects and devices that met their needs (Stiglitz 2007), especially in areas where purchasing power was a factor that limited creation (Prahalad and Hart 2002). The phenomenon can be observed in places where frugality is not just an option, but actually impacts on the availability of products. This has been described and cited in Niel Gershenfeld's (2006) book on fabbing, where, recounting the early days of his MIT class on how to make almost anything, he details the problems faced by populations in rural India. Bhati and Ventressa (2013, p. 3) in an attempt to theorize this emerging field of innovation studies, suggest that frugal innovation is 'in essence a label that capture a range of heterogeneous activities which cut across different sectors.'

Focusing on commercial uses of products arising from this process, they acknowledge that 'there is ton of activity which isn't even labeled as frugal innovation, but equally has components of frugal innovation, without consciously being aware of in practice' (Ibid, p. 3). Instead of having abundance as part of the core thinking around creating objects, frugality, as a philosophy, embodies 'doing more with less' with the aim of serving as many people as possible. As I mentioned earlier, despite frugality being closely associated with scarcity in theory, my field observations showed that this is not entirely true. Where resources are finite and limited, does not mean that they are scarce. Scarcity is the outcome of entering resources in the market and profiting by making only some of them available. Scarcity exists because resources are enclosed within a framework of professional commercial activities in which companies compete for profit. As such, an alternative framework of producing and distributing suggests that frugality is not the opposite of abundance, but rather the result of alternative decisions on the choice of materials and technologies. Such an alternative system of resource management could be the commons[130] (see Frischmann 2004; Bauwens 2005; Berges 2006; Bauwens and Kostakis 2014; Ostrom 2015), in which organizations with motives other than profit can co-operate and utilize. As a result, creating simple objects and devices, either for cost cutting or out of an ecological awareness on the user's part, requires complex calculations and choosing the right combination of resources. In other words, my observations showed a closer association of frugality to entrepreneurship and inclusive development rather than with scarcity (for example in Pansera and Sarkar 2016).

> I am an open source guy. I would like patents to drop dead personally. I want to share stuff. Because what patents want to do is to stop you from doing things. (Discussions about patents and companies waiting 20 years for expirations). A lot of what I am doing, the problem is the money is not in the market because it costs so much money to get something to the market and to get all these patents - thousands of pounds for a thing that costs just about twenty quid. But this is because they pay all this money into the bureaucracy in

[130] There are a range of interpretations and attitudes on the concept of commons, but a common denominator is the access of individual and collective users for their mutual or shared benefit and for the larger society.

> order to get the appropriate papers and certificates and safety marks. Now, regarding the one I am working with, I don't know if any companies or institutions will be interested. There is one company that I have been working with that sells X-ray accessories. They made a couple things I designed in the past, so I might be able to work with them for this. (Benjamin, Radiographer, Interview)

Frugal innovation is the mindset often associated with what constitutes innovation. Bhati, Khilji and Basu (2013, p. 131), claim that regulatory regimes in the developed economies in the West 'may actually hinder frugal innovation while the lack of elongated regulatory procedures in South Asia could offer ground for creativity'. Rather than an attempt to stifle and harness individual creativity within existing structures, entrepreneurship acts as a guiding force to channel the individual towards public visibility and markets. Frugal innovation thrives in an institutional void, an intuitively ingenious and inevitable fallback (or way forward) for determined users doggedly pursuing their creations, working outside the structured strictures of more conventional and/or commercial environs. of Hackerspaces with their emphasis on skill transfer, informality and a less than rigid application of health and safety regulations (in the case of Fabulous St. Pauli, where no health and safety code applies) provide just such an accommodating environment.

In the case of solving a practical issue such as the above with radiography, being frugal also means 'open source', the key to time saving and to saving materials. It goes well beyond saving materials. There is a common pool of hardware and software which all users can access and work with, ensuring the compatibility of the various machines and applications created as well as providing access to community involvement and support through a common language. According to Benjamin, what is considered to be an innovation and what is a mere technique is apparently dictated by national bodies controlled by the government. Where an innovation is concerned, it has to have a commercial application.

> There are some things that I have done already that are open source and I put them on my website. So, my primary project was in laser guided surgery which was quite successful. But they told me what I have done there was a super technique rather than an invention. The difference is that when an object is something nobody else has used, it can get a patent. However, if it is just technique based, you cannot patent the technique, no matter how clever it is. (In the US they patent everything 20-50) In the UK there is a difference between copyright and patenting. There is some overlap, but they are two separate things. They are very strict about it. The stronger the intellectual protection you get the more difficult it becomes for individuals to create. Somebody would say that what I am doing is designing alignment tools that are in principle similar to other alignment tools used for other purposes. (Benjamin, Radiographer, Interview)

According to Bhatti, Khilji and Basu (2013, p. 129), the concept of frugal innovation has two meanings. The frugal part is the attempt to work within and despite the limitations of material supplies. The second is about maneuvering institutional complexities and being able to reach people who are not the primary target of markets – i.e. the need for products which are not delivered through commercial activities. This is what Benjamin aimed to provide. By maneuvering around institutions and getting access to technology, he managed to provide a device that was produced outside the commercial realm (see also Maric, Rodhain and Barlette 2006). The innovative part in such technologies is being able to advance practical or thinking technologies and institutions with an eye towards a social end. 'Often technology is not designed for underserviced users and neglects critical institutional and social aspects. So, conceptually, frugal innovation involves overcoming the market or technology failures to create inclusive markets' (Bhatti, Khilji and Basu 2013; p.130). Inclusivity here is the framework component which substitutes this inability or lack of markets to reach to the individual needs in which case users can step in and fill the void.

At a grassroots level, frugality is about nurturing the creativity of users to solve their own problems and create their own objects and technologies, creating an alternative arsenal of resources. As a policy framework, it is a set of institutional changes that aim to bring the individual to the market instead of the opposite. Understandably, some of the objects and technologies are not finding their way into commercialization, but act as additions to the whole cultural and ideological narrative. In some instances, there isn't even a commercial motive, but rather a desire to solve a specific problem or need, or simply to create for the simple pleasure of of developing personal relations. This was true for example of Remap[131], the charitable organization that also operates locally in Leicester. It focusses on solving engineering problems for disabled people using technology that the markets have yet to or fail to offer.
Mainstream innovation thinking revolves around the impression that technological breakthroughs are created and advanced by wealthy and sophisticated early adopters (Geroski 2003), thus requiring expensive input resources (people, technology and material as investments) and aimed specifically at people who can afford them (Prahaland and Mashelkar 2010). Other, less affluent users can harness the trickle down effects once the market makes them cheaper and more reliable. Bhatti, Khilji and Basu (2013) argue that this 'top-down' approach that favors the affluent is not only unsustainable because it uses material based on a perception of abundance rather than scarcity, but also because the austerity policies of recent years have shrunk the potential market (se also Bhatti and Ventresca 2013). This I could see from the spaces, conferences and Maker faires I have visited, but

[131] See previous chapter section "But what can you do with it?"

very few believed that products, materials and skills would eventually be distributed any better or faster through the mediation of the markets. Most hackers and makers I encountered believe this can be best achieved through free and self-organized ICTs. Frugal innovation is useful to hacker and maker communities where it reverses the “top-down” idea and attempts to focus on the consumers at the bottom and allows the majority of consumers gain access to the latest science and technology innovations (Bhatti, 2012, 2013; p.128). Being forced to adopt a frugal innovation strategy can even be the outcome of being denied access to or the services of certain technologies because of the control measures imposed by regulatory bodies.

The intricacies of the current governmental legal system are such that only enterprises with great resources can afford to negotiate a way forward. As the system stands, it is an impediment to new technologies that might be of benefit to people at the bottom. Benjamin was very open about not wanting to steer his tilt meter through the commercial process (with its extensive legal complexities). His reasoning, was that getting the device approved and passed as required by all the regulations would require considerable expenditure on details and paperwork. The downside of this was that a device cannot be classified as an innovation or recognized as a technical upgrade without being tested within the existing institutional framework. Benjamin, as he mentioned, wanted neither the hassle nor the of the time constraints. He was informed that the device could be treated as a research project, resulting in financing and publication of the results. He preferred to cut to the chase, create and put the result on his website. He showed little interest in making a profit *per se*. Nor did he want to lose valuable time dealing with the demands of different actors who might demand some say and interfere with his control over how to make the device.

> I got a professor who is telling me that I can play with all this stuff, and try to solve the problem as I see it, but unless it becomes a viable product, it will never change the world in any way. So he suggests to get research

> approval, the ethics etc. But the way they want to show it into the whole mill of research is too much for something as simple as I want to do. All I am doing, is making a very simple measurement principle. Let's not make it have to pass through regulations like new drugs pass through. (Benjamin, Radiographer, Interview)

He was right. Much of the device was simple to build. It had very few components but worked. His frustration was with the institutional commercial framework in place for dealing with all newly created devices. This could explain why he had little interest in making the device an academic research project. Why would he do that, if, excluding possible profits, he could find academic help and knowledge outside the official bureaucratic structures.

> It is a little light bulb – it's not going to explode in someone's face or something. The way they to tackle issues, Is with a hammer. You have a laser in the device, so there is regulation for that. Touching a patient (hohoho careful). Other regulations. The regulations are racking up. What I can do is just make the information open source and then somebody can pick that up and do their work properly. There are probably companies who do this kind of stuff. Eventually, if they decide there's not enough money to produce the item, then I cannot help them. My mission is just to get it out there. If I patent it, it will just stop people from using this. So if you care to get this thing out there, it might be better just forgetting about it, because as soon as you get the patent you stop other people from doing it. Let's not mention that it will take you a minimum of 5 grand to get a patent, and that is

not a really good way to patent anyway. (Benjamin, Radiographer, Interview)

Assuming that one did take the grant and all the necessary steps to patent and go the commercial route, profit is not always guaranteed. There are many factors as to how and why creating such a product might fail to reach the markets in the regulated way. Unless a company or organization with resources comes along, it is difficult to even predict how such an endeavor would result. So, to to satisfy his own curiosity and solve his own problem, Benjamin proceeded to create the device bypassing the need for paperwork. The only paperwork he did, was apply for a grant through a charity. He opted for frugality for the purposes of being fast and active.

> If you are not going to make a lot of money out of the item, do not patent it. It will cost you thousands in order to patent it. The first person you have to go to in order to patent, is a patent agent. Have you ever met a patent agent? Do you know what it is? A patent agent is actually a high paid lawyer and they write legal documents in technical language and make sure that everything is covered so people cannot just pass by and use stuff. (Benjamin, Radiographer, Interview)

Still, there is a growing awareness that the bottom of the pyramid markets could be untapped ground for the inclusion of the poorest sections of consumers (Hart and Christensen 2002) and that this could provide what Bhatti (2013, p.132) calls fertile ground for disruptive innovation[132] and

[132] Disruptive innovation involves the development of new practises, services or products that happen at the bottom or even sometimes outside the market, but which eventually move up and displace existing ones. In this process, new companies can develop into giants or be taken over by established ones that wish to acquire what is new. Sometimes, when new practises and products are the result of a cultural trend rather than a commercial endeavour, established markets can alter their behaviour to suit the new realities. Perhaps one of the most visible effects the Makers movement has had on markets, was the latter, when companies from many different markets tried to utilise its dynamic cultural impact.

creative destruction (Schumpeter 1942). That is being able to disrupt existing practices, value chains and business networks or create new ones, as Makerbot did with the desktop 3D printers. However, because these networks and practices are not solidified, there is shortage of materials, people and other resources, there is a creative way to curb traditional innovation routes (Nakata 2012). This is true for the poorer sections of the populations, as it is for people like Benjamin who would consider themselves in the middle strata, having high educational capital, a relatively permanent job and enough resources to start new projects for a hobby. Rigid-type of innovation needs a lot of capital and does not diffuse between practices, people and institutions; thus it loses the advantage of reaching increasing numbers of possible consumers/users. What seems to gain in respect even by proponents of market economy, is this inclusion through frugal innovation[133].

To a large context, it does not matter whether some of the innovations that happen as a result of frugal approaches find a commercial application or not. At this stage, policy makers, business leaders and grassroots innovators are in agreed that the more innovations there are the better for all. The artisanal or craft process gains because of its appeal to authenticity, individual control over the activity and the fact that the task not being monotonous. Users like to include stories of how they found the place to work with, the community which helped them, the possibly shared identities or values, when it comes to describing the process of crafting. The spread of such thinking is often aligned with the rise of “tech-shops” or shared machine shops in the US, a way, it seems, to steer this process into commercial channels. However, in the UK, the spaces that allow such creativity to happen are grassroots organizations like those mentioned in previous chapters, Hackerspaces/Fab Labs and Makerspaces. This cultural imaginary is deliberately merging entrepreneurship, learning of skills and risk taking with individual interests and the drive for creativity.

---

[133] As Geoff Mulgan (2012), NESTA’s director suggests, there is trend to innovate, creating tools that support frugality as well as a frugal way of innovating.

Skills, individualized 3D printers and building robots at home

In Leicester Hackerspace, one open hack night Jenny introduced me to Aleksander, a 25-year-old engineer. For a while, we discussed our mutual interests in 3D printing. Aleksander tells me that he wanted to build his own 3D printer in order to develop prototypes, and that he thought the Hackerspace would be a good place to start out. In the end, the Leicester Hackerspace did not prove large enough to host his project. We kept in touch by email over several months consisting of exchanging information about science and technology, sharing observations about Elon Musk and his space exploration visions, and general remarks on industry 4.0.

What began as a chat at the Leicester Hackerspace, later developed into quite an open dialogue. Originally from Poland, Aleksander is one of those young people whose personal interests can collide with his work interests. This is often the case with grassroots innovators who seek to develop their entrepreneurial skills as much as their technical and communication abilities. Aleksander came to the UK in his early twenties seeking work that would enable him to remain while looking to find opportunities for future studies. He became disillusioned with studying psychology in Poland, so dropped out in search of something closer to his interests. Now in his mid-twenties, he is determined to withstand the future uncertainties and anti-immigrant sentiment resulting from the Brexit vote, by making friends and having a permanent job in the UK. He has already switched a few jobs, sometimes voluntarily, looking for openings in the field of engineering. However, when I met him, engineering was a completely unknown field for him before coming to the UK. I was surprised to hear that, since in our discussions he displayed a wide grasp of related issues, robotics, automation, 3D printing, solar energy, space technologies and the like. As he explained, he tried to get information and understand technical issues through interaction with people and colleagues at job.

After a trip we made to a professional exhibition, he revealed to me that he is not interested in traditional institutions like universities had little appeal for him. In his view, they don't give the kind of information you can put to direct use. Moreover, you can find the requisite information elsewhere, cheaper, especially in the professions that interested him. Technical schools and colleges offer knowledge that he can use directly to make his own things and gain a competitive advantage in the labour market. Aleksander suggested that he needed such technical knowledge to combine with broad knowledge of political, social and economic transformations, which he had learned through reading books and following the news. This was the kind of thinking that brought him to 3D printing. Upon arrival in the UK, he had come across a social network, that put him in touch with people with similar interests.

> To be honest I was looking for people who shared my interest in the same new technologies and development. I found them on the internet, through social media, I think it was the one called 'meetup'. I had an account there. There are groups of people with the same interests. I have been at a couple of meetings through that as well. One about designing, business innovation and Hackerspace. My impression is that it is a Google development for such purposes (Aleksander, Leicester Hackerspace, Interview)

As a digital exponent, Aleksander is curious and likes to dig out the details of whatever he chooses to explore. He concluded business-type projects were a non-starter given his situation and status. Yet, hobbyist groups activities were too slow for taking his time-sensitive schedule into account. So he started looking for interactions that would have a sense of informality but that might lead to something worth learning. He concluded that 'meetup' as an application which provides a platform bringing individuals into groups whose objective is to bring people intersecting between "hackers, business and civil society". For this matter, he thought to try and find groups that suited his interests.[134]

After joining a couple of groups, finding out more about their members and their interests, 3D printing came up as a possibly interesting technology. Aleksander was looking for technologies that offered a combination of several traits of the digital economy so he could build up his skills portfolio while having fun, exploring specific shapes and forms he could access easily. Thanks to "meetup", he acquired sufficient information about 3D printing to realize that he could actually create his own. Enjoyment aside, setting out to build his own 3D printer was about gaining more skills.

> The main reason I did this was for experience, to gain skills, understanding of the 3D printing technology and what it can actually do. Also I can print the parts for experiments with engineering. I can print parts for robots or any other of my experiments. In the past I printed parts for what was called 'Mars curiosity', a robot car idea [about 7-8 inches in size]. Basically I printed the framework and used similar components like servomotors to control the system to make it work. (Aleksander, Leicester Hackerspace, Interview)

Experimenting with lasers and Arduinos, integrating software and hardware through Wi-Fi and being able to learn basic code skills, all included play but also opened the way for learning as much as possible, always having in mind the potential for collaboration. Such acquired general knowledge might not be of direct use right away but Aleksander believed that with the right team and right idea he might be in a position to apply for available European Union funding at some point. Aleksander's story is similar

---

[134] According to its website "meetup" is, "organized around one simple idea: when we get together and do the things that matter to us, we're at our best. And that's what meetup does. It brings people together to do, explore, teach and learn the things that help them come alive."

to others I have heard before – the growth in confidence and the creative additions that result when a determined mindset and alert mentality set out to to create a replicating machine. This focused mentality can then be applied to other parts of daily activities when having side projects. Networking for information and know how and making good use of freely available pooled knowledge are essential to thinking through practice and collaboration, always with an eye to personal development. In order to create his 3D printer, Aleksander made good use of the local Hackerspace, finding out more about what it was he was looking for and at the same time learning more about what to look for.

Upon deciding to build a 3D printer, Aleksander searched through the internet for more information on where to find the different parts. Already a big part of the everyday culture, the internet serves as a source of verification and filtering for all the information one gets from the various users and individuals encountered in the Hackerspace. Eventually, Aleksander wanted to look for a cheaper and, if feasible, faster way to do the job he had in mind than building a 3D printer from parts he could get through an engineering magazine.

> I started by doing some research over the internet, because when I first heard about a 3D printer I popped into a magazine store where I had seen a magazine with a 3D printer on the cover. The magazine, a monthly, offered parts of the 3D printer with each issue. Every month, another part. The final goal was to collect all the parts, put them together and build your own 3D printer, in about one or two years. So, I went on to calculate the price each month, how much would I spend on this magazine in order to build this 3d printer. It was about seven hundred pounds, altogether. Initially, I was thinking to buy this magazine, to take time and learn how to do it. But I was curious about the

> actual price of a 3D printer on the internet. So as I looked through the internet, the price was much cheaper than the price of the magazine, without having to wait each month for each part. I found the RepRap and I thought it was an interesting case to have a look at it. I was thinking to order it online. (Aleksander, Leicester Hackerspace, Interview)

The RepRap model offers more than just open source hardware models to build your own printer. Granted, having access to the open design of various 3D printers from which to build your own is just what a user requires when attempting to create their own machine. But the RepRap comes with a whole community or fan base that can help and advise in helping members realize their goals. In short, information is from everyone to everyone, peer-to-peer. It gives the potential user time to validate information about what kind 3D printer to build, without the user feeling that they must take everything on board. After all, the process of building your own 3D printer should leave you with a feeling that you have put something of your own identity into the machine, or at least that you have catered to your own specific needs. This sense of design ownership is often accompanied with some distrust towards the big corporations who prefer closed systems, reflecting corporate greed and an unwillingness to allow the general public access to everyday reproduction technologies. The ease with which users can find information about the RepRap makes it an irresistible package, one most users praise and look out for.

> I think it was pretty easy, I just typed on Google '3D printing' and I followed the links that eventually brought me to the RepRap. So, then I started investigating the RepRap and I considered that since someone has been able to do it, I can do it and contribute to someone else's work too. It would be nice to contribute instead of

> a big corporation getting all the benefits. So when I asked myself ‘if someone has done it, why not do it myself?’, I thought maybe I should give it a go, buy the parts and make it work. Then, I started investigating how people do it, on forums, like the RepRap forum somewhere, you know, the official one. I was able to find much of the information I needed there. You have to work out what kind of 3D printing you want and then what you want to print, so that they can advise you. You can find all sorts of things there. Once I found that out, I tried to look into 3D printer models, and there were a couple of RepRap 3D printers that I found most suitable for me. The model I found had aluminum rods. The RepRap is a model whose idea is that you replicate the model you have there, to make another printer. So, people are printing some of the construction for another one. To make it work in a cheap way, they just print and put the parts together. But the plastic parts are not very stable. So, I was thinking my own printer has to have a good, solid construction in order to be stable. If it’s not stable, when it’s printing, the vibration affects your printing and might damage the object you are trying to print. (Aleksander, Leicester Hackerspace, Interview)

There is a variety of different models one can consider according to taste, space and what the user wants to do with their own machine. The fact that both hardware and software are open, means that Aleksander could consider several options when building his own 3D printer. Some communities build both around hardware and software. Committed users accept it is common sense to exchange free advice with others. 3D printers are everything a user committed to open technology stands for. They can use generic hardware and software to achieve variety, although most are specific to the FDM process used by the vast majority of desktop 3D printers at the moment.

> You can say the hard part of the 3D printer is control systems. You need software, you need hardware. The biggest advantage is that the software is open source, so that people are able to share freely. The RepRap for example started as open software and shared with other people in order to develop it further. This is the good thing about it - people working on the mistakes together. If someone struggles with problems, they try to share these problems and others try to improve it. So, the software is open source and it's based on a microcontroller. The one I use is called Arduino. Others might use some other controllers, but very similar concepts and hardware. There are quite a lot of microcontrollers on the market right now and they are all pretty similar, so it is up to you which one you want to use. The only thing you have to think about, is that it must be powerful enough to process the information required when you are 3D printing. So, the best is the one which does not stick and has no issues when printing. Microprocessors, rods, motors and the extruder are the mechanical side. I think of 3D printers as consisting of control systems and the mechanical side, both of which are quite easy to find. (Aleksander, Leicester Hackerspace, Interview)

Much of the material Aleksander used to create the 3D printer, can also be applied to building the small robots he is keen on creating. Building a 3D printer is a good exercise in learning about the materials, how they work and set up a functioning relationship with the open hardware and software communities. The relationships are not rigid. They are more akin to what it was like building your own desktop computer two decades ago. Once you found all the functioning material and set up the operating system, adding to the computer hardware or software was fairly easy. In this case the 3D printer set up is similar; a qualitative difference being that once the 3D printer is functioning, parts of later physical creations are worked through it.

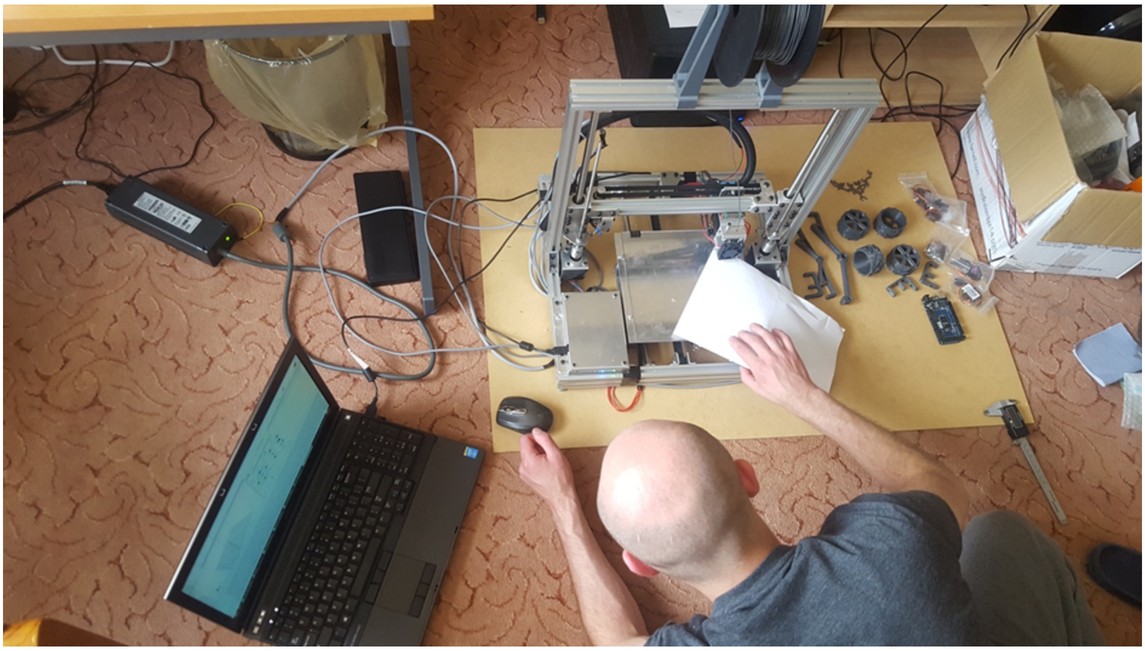

Figure 47 Aleksander is trying to calibrate his 3D printer to show me how it works Photo Credit: Leandros Savvides

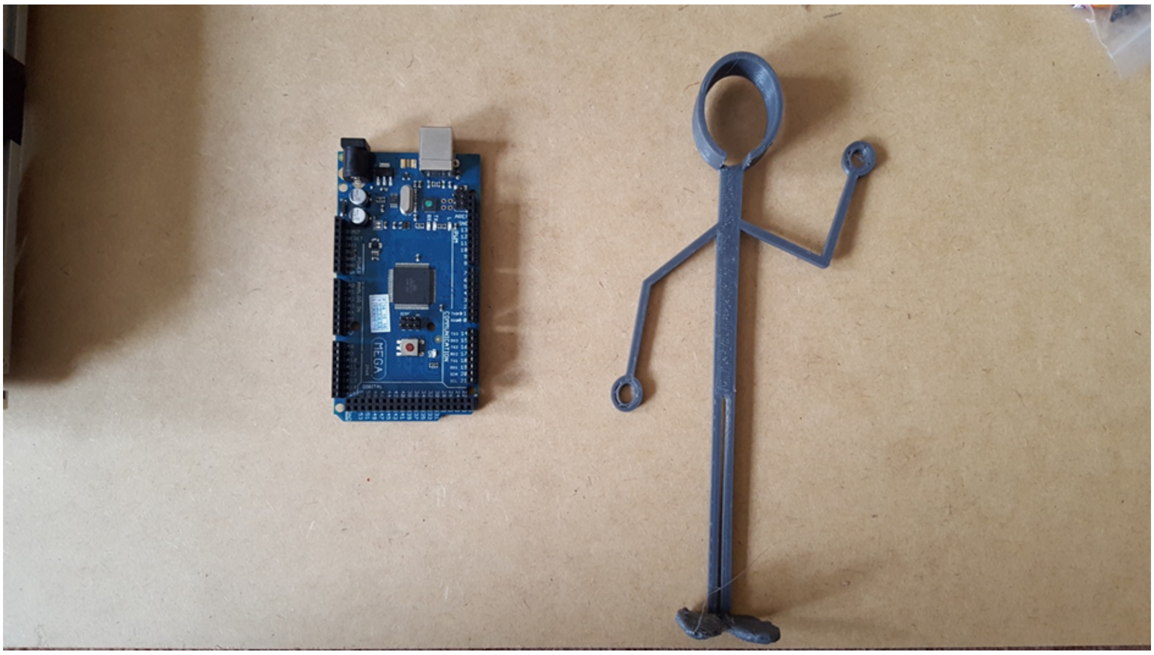

Figure 48 Printed part and hardware for creating gift robots

As happens in everyday life, many users who try to create their own 3D printers, have their own motives but such is the setting that they are not in total control of their environments. In the course of creating his own 3D printer, Aleksander found himself working in a tolerant like-minded community at a time when Polish immigrants to the UK were increasingly becoming subject to intolerant attitudes and behavior. Moreover, his creation enabled him to learn new skills through a set of resources, news media, people and events. In this section I would suggest that not all 3D printer creators are as committed as Aleksander was to the idea or need to innovate as fast as possible. Others, take it slowly, create a cozy environment and learn a new ecosystem of making and digital technologies, that may or may not lead to commercial opportunities.

For Aleksander, wanting as he did to experiment with a variety of different small devices, grassroots community workshops offered the easiest way to have additional projects on the side that could lead to an invention. As a grassroots innovator, an individual is usually enmeshed within the narrative of the grassroots entrepreneur. Aleksander's is only one of many cases encountered through grassroots organizations, social media and 3D printing. Individuals who constantly expand their skills, learn new technologies and, should they find an opportunity, are ready to use their hobbies and take risks in pursuing entrepreneurial activities. Yet, despite the strong flavor of individual preference and customization, this type of culture is based on collective effort with communities playing a big part.

Resilience and the meaning of openness

What does open and closed software and hardware mean in practice? Simply put, without the openness of both, much of what I am describing in the field would not be possible. What would I find for example if both software and hardware were proprietary, sealed and not accessible to the wider public but were solely the preserve of the professional community? My first guess would be that people who are professionals, would find way to circumvent some of the access problems, but would face an extremely difficult task finding resources. They most probably would resist sharing any information about their projects with a researcher lest they be accused of 'illegalities' for revealing confidential activities. File sharing, the sharing and development of software, the availability and development of 3D printers would be an incredibly hard task to circumvent.

Throughout my fieldwork, the stories of users who interacted with each other revealed that 3D printing embodies resilience and the appeal of open innovation to users. As they attempt to use 3D printing in grassroots community workshops, the users are immersed in an environment where resilience becomes the norm, the way to create. Using digital and non-digital tools, having a variety of software which they should be aware of according to their needs, playing with a variety of hardware too, there are many practicalities to familiarize with.

> What I personally do not like about this, is when I do something and I have to use materials or tools that I will do only for this process. For example, when I build the milling machine, I made a fix for the motor and I had just a piece of wood and a saw. So, when I want to do it

> the next time, or to improve it, I have to find the same piece of wood that I had accidentally and need another tool and do it again. I would like to be able to design a mould for the motor and share with others or build on others work. That is what is what you can see when you go to a place like Maker faire, people build up on other projects. But, there is no ideology behind this, it is indirect.
>
> […]
>
> A couple of years ago, I had the impression that people were developing skills for the labour market, especially those in the UK who take care of their CVs and careers. But now you can see many that refuse to do this. Instead, they like that they can have the freedom to do other things. We had a lot of people here in the fab lab. When I ask them what they are doing, a lot of people have quit agencies and big firms to do their own things. I think their work situation and circumstances, much of what they do whether its products or campaigns, offers them no satisfaction and is not sustainable. In the past it was really hard if you wanted to refuse this system, but now there may be another way to do other things. It would have been hard 10 years ago doing such things.
> (Andreas, Fabulous St. Pauli, Interview)

As Andreas suggests, some users find 3D printing impractical at the moment. But, this is just the start of a new line of machines where resilience is ingrained in their build up. Not only in the machines, but infrastructures that give access to such technology and material are resilient, meaning that parts can be altered and fixed at will by users anywhere, any time. Resilience in this context also means to utilize interdisciplinary and mass experimentation by anyone that can make contributions, offer practical solutions or situated knowledge (see Nygren, 1999; Haraway, 2004) to aspects that concern everyday reproduction.

Considering the innovative mind-set that I was describing at the school, having software and hardware as closed source would lead to practical problems that would make the space unworkable. “I use open source programs in order to manipulate and print the designs” as George admits. The school, which invested a significant amount of capital into this venture would find it unsustainable to use in an everyday context. He tells me that the issue of access for many people is important;

> I prefer to use open source programs because of the students; I have over 20 and it would be more difficult to use programs that need payment to install them. Even with Windows, 3D software comes as open source. (George, Technology teacher, Grammar School Nicosia, Interview)

Because the programs are directed from the community of users towards a mass audience, they are simplified to accommodate the level of intricacy the user seeks. This is very important for newbie users who do not wish to learn a programming language or a professional program in order to create, once they have solved the problem of access. But it also seems like an opportunity for large companies as well to exchange freeware for brand loyalty. In the case of the school, the use of Microsoft’s open source program

> 3D builder program for example is embedded as starting program in Windows operating system. Usually the open source is simple and students can learn very easily. You use simple designs in order to create a shape, for example you can take a circle in a rounded surface and create a doughnut. (George, Grammar School Nicosia, interview)

But aside from the school environment, the resilience of open source hardware and software can be found in the online communities. At some point, I dare to say all of the users are stuck and need help. Getting stuck is more of a ritual activity than a barrier to progress. It is expected to happen. Those who know this beforehand can be said to be insiders of the culture, acknowledging that getting stuck is a crucial factor when it comes to forming the community. As in the case of Aleksander, many find the communities first before embarking on a journey to learn a new technology. Whether building your own 3D printer or using one, the new user will always benefit from a perk or tip about how to proceed. Having communities around ensures the individual users can refer to a familiar place for help, finding someone who understands practical or theoretical problems associated with 3D printing.

> I have included a trucking for the cables so that they do not hang out. They have to follow the axis as it moves, as the bed slides the cables have to follow so this is why I included this. I saw this somewhere on the internet but it also comes from my own experience with machine building. (Aleksander, Leicester Hackerspace, Interview)

The sense of belonging to the community is not complete unless the user is able to produce something, or solve a particular issue with their project that can either inspire or be of use to others. However basic, there is an intrinsic satisfaction gained by the user who is able to show something to the community which was not done before. Aside from the fact that they might be able to fix their own project, adding to the community not only increases the inventory of designs, but brings a dimension of gratitude by the user whom the community helped, either directly by someone answering to questions or indirectly through browsing the chats.

> I added some things but I would not say I contributed with my own. I found the idea of the holder on the internet, from Thingingverse which has many designs for free, so I do not struggle with the filament anymore. So, you might say that I contributed by merging two designs I found on the internet (Aleksander, Leicester Hackerspace, Interview)

said Aleksander, while nodding and acknowledging that this is not such a crucial innovation product. Still, the community functions as an alternative to the model of a bright innovator able to do everything or is capable of taking a very big step forward on their own. Usually this idea of the star innovator fails to acknowledge all the small steps and incremental changes carried out by thousands of users on different problems. But the sense of community in this case transcends national backgrounds, to a large extent because it is online. Help for a Polish RepRap model might come from the USA, or vice versa. To a large extent, users do have a common ground and language which reflects on how they identify themselves as part of the 3D printing community. Aside from the practical and technical help, belonging to the 3D printing community means having access to information and being networked across the globe as well as producing surplus meaning and cultural value. This seems familiar since it was also true of earlier media culture processes.

What the endeavour to ''liberate'' software from a wage relation and into creating sites of collective meanings and identities, is what replicating as both play and productive/reproductive practice means for the new communities that sprang up through Hackerspaces, Makerspaces and Fab Labs. Just as Lindtner and Dourish (2011) understand 'gamers' productivity' not only as creating economic and social value but also of meaning and producers of meaning and identities, replication of 3D printing is also an activity which engages in a global public culture[135], which can also produce economic value. Indeed, in the years that I have spent researching 3D

[135] Which is based on the 'promise of innovation' through craft and leisure.

printing, I have seen what has been called a “rapid increase in the number of citizen science initiatives” (Dickinson et al 2012, p. 9). Having the ability to intervene in the reproduction of everyday life[136] through practical technologies, gives, aside from a sense of empowerment, the ability of what has been called the social sphere to question and participate in ‘boundary-spanning processes’ (Hoffmann 2017) as in the case of the radiographer described above.

In the absence of commercially available materials and machines, the users are expected to maneuver between professionals and hobbyists in order to create their projects. Whilst much research on new ways of printing, and the availability of new materials is mostly carried in universities,[137]users are increasingly taking technology into their own hands to shape both the technology and infrastructure that is built around them. This is not to say that the community is safe from conflicts in terms of patenting and closing either software or hardware in the future. But a culture that promotes a DIY attitude (with a digital twist) and frugality for innovation, creates leverage power. Such power of practices and infrastructures, shape not only the communities that ascribe to this culture, but also the commercial environment. Such new types of consumers are themselves creating their markets whilst at the same time helping propagate a culture that is not necessarily in favor of consumerist values. This is a contradiction that exists. It remains to be seen how it unfolds in future developments.

[136] More on this in the previous chapter

[137] See for example the work of Joshua Pearce (2013)

Conclusion: 3D printing as a message

> *All media work us over completely. They are so pervasive in their personal, political, economic, aesthetic, psychological, moral, ethical, and social consequences that they leave no part of us untouched, unaffected, unaltered. The medium is the massage*[138]*. Any understanding of social and cultural change is impossible without a knowledge of the way media work as environments. All media are extensions of some human faculty— psychic or physical* (McLuhan and Gordon 2005, p. 26)

It may seem evident at this point to argue that 3D printing is different than additive manufacturing. While both terms may describe the development of machines capable of creating objects through adding layers, the former has achieved a wide following as a cultural icon whereas the latter refers primarily to a machine. This study has been a mental and physical journey in search of a new cultural movement in the age of 3D printing, in hopes perhaps that it might give rise to or help shape a new social economic order. The phenomenal impact of the Makers movement on the public agenda has to be viewed in terms of its potential and in terms of its relation to social, economic and political developments. Corporations and governments may have tried to utilise the dynamism of this movement to promote their own agendas, but the movement has not been swayed to the point where it sold out to corporate interest. The emphasis of this study was to articulate aspects of the spread of 3D printing in relation to developments of the Makers movement which played such a vital role in popularizing the technology. For this reason, the thesis followed the political narratives and cultural imaginaries that surrounded 3D printing mainly in grassroots community workshops. Through personal and collective stories, these spaces provided an everyday

[138] Initially a typographic mistake, McLuhan insisted this should remain as it is. In this way, it can be read as message, mess age, massage and mass age.

understanding of social transformations and types of engagement involving 3D printing that lay behind the buzzwords often seen in newspapers, policy papers and cultural media.

Evidently, 3D printing is not a phenomenon that began at the time this field study got underway. Tracking the history and development of machines that can create objects in additive manner indicated a time gap between initial conception and eventual adoption of the technology, not just in industry but, more importantly, by users in an everyday context. In effect, the technological development was spread over a 30-year span, three phases starting with the experimentation and initial conceptualization of the early 1960s. During this period DuPont attempted to create polymer material that could be solidified when targeted by laser beams. This process was strikingly similar to initial attempts to develop the first commercial machines using the stereolithography method. From 1984 to 2009, a plethora of additive manufacturing methods emerged. The real breakthrough in terms of the public sphere came once key patents expired and the Makers movement adopted and opted developing 3D printers as part of making.

The result was increased sales of consumer or user-friendly 3D printers, signaling the emergence of a consumer market. Additive manufacturing or "solid freeform fabrication", the terms used to describe the technology within industry circles, were increasingly replaced by the term 3D printing, the descriptive term of choice within grassroots maker communities. The initial phase of development was conducted within the frame of the military industrial complex. The second phase was notable for a surge of interest among academic researchers. Then came the third phase, when 3D printing became popular as the Makers movement and like-minded organizations diffused 3D printers with desktop manufacturing, opening the way for non-professionals to play a part in its development. This is when 3D printing began to acquire significance in political narratives and feature in cultural imaginaries.

In enmeshing ideology, political narratives and cultural imaginaries, I explored why 3D printing was seen to be part of the coming future, capable of empowering individuals on the everyday level, using non- or semi-industrial infrastructure to create and communicate between each other. In communication strategies such as the "4th industrial revolution", 3D printing is presented as a technology leading to a more automated future where production is increasingly networked and transformed into a hybrid of a cyber-physical system. The proliferation of desktop or social manufacturing offered a basis for politico-economic narratives that on one hand embraced the Makers movement, while on the other, proposed a restructuring of the capitalist economy by mimicking or utilizing characteristics of the movement. If not directly utilizing the power of makers, economic news media advocated using 3D printers while drawing on the sharing principles of the movement as a way of disrupting old industries and creating new ones. The technology was hailed as the savior of lone entrepreneur craft people and of small-to-medium businesses linked in a decentralized network. It was also seen to provide a way to re-shore manufacturing back to the US and UK from China and other countries with cheap labor.

Linking 3D printers to Star Trek "replicators" and appearing as it did in TV series, films and cultural publications, it was evident by 2013 that the technology was becoming a popular phenomenon. The cultural imaginaries were co-opted by commercial enterprises such as Makerbot in order to promote their own merchandise. At the same time, NASA and other state agencies used the cultural imaginary of printing cities in space to promote STEM subjects in education. However, for grassroots communities, these imaginaries meant much more than the mere production and distribution of goods through sharing platforms or a dystopian scenario where building cities in space would ensure the future survival of the human species. Stories of everyday inspirations derived from science fiction proved that users and communities contributed to the culture through their own visions and ideals. One example, was that of Johnny, a 13-year-old from Hamburg, who sought to 3D print an exoskeleton inspired by the movie "Elysium". The intervention of Daniel and Moreshin with their "3D additivist manifesto" was an attempt to highlight positive aspects of 3D printing like sharing while also taking a critical look at the extensive use of oil and plastic in industry.

Perhaps the most comprehensive imaginary that comes with a political narrative is equating a 3D printing environment with a social structure, an autopoietic organism. This entails understanding the 3D printing environment as a hybrid of biological and non-biological entities linked within a system, where feedback and replication are vital characteristics of a closed circular system. Waste would become an obsolete concept, since what is regarded as waste material would become the raw material for other functions in the same way waste plastic can be recycled as raw material for new prints. In this respect, an open source social system would enable materials through a circular process, with professionals and non-professionals alike making contributions to knowledge, production and everyday life freely.

Hackerspaces, Makerspaces and Fab Labs constitute the organizing forms chosen by the majority of makers' communities. These are the spaces where professionals and non-professionals, experts and newbies to technology are housed, usually within city centers. However, despite their self-organized management style, they also rely on institutional help, mainly from local authorities and the European Union. While similar workshops exist in the form of small shops, for purposes of this study, the fieldwork focused on autonomous and member-organized sites. Although such spaces can now be found all over the world, most seem to be concentrated in European and US cities. These communities adopted the 3D printers and spread the word of how makers can use the technology for their own ends. In their efforts to self-organize and make, they also produced alternative forms of politics. Specifically, they became centers of political consumerism where making constituted both a practice serving the individual and/or the collective while challenging institutional and market practices opposed to hacking, repairing, fixing or upcycling These market practices include the production of devices that makers and hackers cannot open to repair and/or knowledge under seal of patents that cannot be shared. Meanwhile, where making and hacking is involved, these communities alter the concept of the city as a space of passive consumption and transform it to a cyber-physical, networked organism which connects individuals, hardware, software and spaces.

The positioning of 3D printing in a Hackerspace, Makerspace or a Fab Lab seems to be linked with the internal narrative of the community. Some communities display their 3D printers in a prominent place alongside other consumer electronics within their space in order to attract new members. Others place the 3D printer alongside other semi-industrial machines to foster entrepreneurial making. Decisions such as what machines should be made available and where it should be placed, are made by the community. As self-organized micro-societies, they also decide on how and by whom the space should be managed in terms of its economic resources and infrastructure. Despite the risk of becoming too embroiled in internal issues, these communities should not be seen as isolated communes but rather as part of a ubiquitous networked infrastructure that extends beyond city and country level. Many have ties to communities in close proximity to them but they also draw lessons from other countries. A Maker faire can reveal how this network of multiple micro-societies operates on a larger scale. Individual users, spectators, communities, academics, corporations, governmental and local authorities are integrated with one another. Each benefits from this symbiosis, but on rather different levels. Encounters in the field suggest that the effect of 3D printing as a medium to proselytize new makers seems disproportionate to the functions it offers. Many users expressed their concern that material seems to be of lower quality than expected at the moment. Others suggested that the availability of a great variety of material and machines within cities, make 3D printers seem like a luxury device producing tinkered objects.

In “Fabulous St. Pauli”, a Fab Lab located in Hamburg, Germany, 3D printers are part of a distinctive political movement. The Fab Lab was founded as part of anti-gentrification interventions by local activists opposed to transformations local authorities sought to bring to the area. This was a site where 3D printers were situated in spaces alongside laser cutters and other basic makers’ tools in direct political confrontation. The Fab Lab and making in this space were part of the "Right to the city network" that was set up in the area to help oppose gentrification. Members inspired by the Fab Lab ideals pursued an agenda to create a space that not only promoted making, but also created conditions for criticizing the existing socio-economic order. Moreover, the community challenges the notion of big factories making most of the worlds' products by attempting to introduce its members to technical ideals of resilience and design for people rather than profit. The "right to the city network" is comprised of individuals, collectives and small shops that collaborate on the same ideals, creating a networked political formation through making and entrepreneurship.

In the final chapter, I explore several stories on everyday uses of 3D printing. While political narratives and cultural imaginaries undoubtedly assist in making 3D printers an enchanting technology, its ability to print material objects through digital files is a concrete proposition that invites makers to use it. The chapter follows three ethnographic vignettes and reveals how craft, design and access to knowledge through the internet constitute three fundamental aspects of the 3D printing environment. In the case of my former high school in Nicosia, Cyprus, I describe its attempt to introduce 3D printers as part of the curriculum for a wide variety of purposes. There, I discover that learning practises of the Makers movement are utilised to create personalized education. The basic premise of technologically mediated learning seems to suggest that learning should not be about answers given to the student by the teacher. Rather, the objective of democratic education should be about creating an environment and giving tools to students where they are guided on how to find answers on their own. This method instils an entrepreneurial attitude whilst attempting to reverse the unbalanced power relation between the traditional teacher - student dichotomy.

Perhaps the most characteristic example of the use of 3D printing environment to achieve grassroots innovation, was the case of Benjamin's tilt-meter. A radiographer by profession, Benjamin tried to advance his professional practise through the crafted creation of a device that could measure accurate angles for x-rays on patients. Disillusioned with manufacturers of radiography tools, governmental and commercial bureaucracy, he called on “Leicester Hackerspace” members to help him create his own device. Utilising 3D printing, sharing platforms and local Hackerspace infrastructure, he was able to create one such device as a finished product within a matter of months. He was able to create his device at low cost, close to the price a prospective buyer might acquire it through a manufacturing system. This case revealed that traditionally viewed dichotomies such as bottom-up versus top-down, bureaucracy versus resilience, manufacturing versus craft making, can be challenged in this new making paradigm. Moreover, the case raised issues such as frugality in creating for everyday problem solving as well as the ability of the user to design his or her own devices as a form of scientific inquiry through craft thinking.

The chapter ends with the story of Aleksander, a young Polish engineer who wished to learn how to create and build his own machines. Learning about 3D printing through a social media named “meetup”, he decided to visit “Leicester Hackerspace” to learn more about the technology. After a few visits, Aleksander was able to build his 3D printer at his home with the help of a friend. While building his own machine, he learned more about how to create his own robots and to print their parts using the machine he built. His story illustrates how an enthusiast can engage with curiosity on recent technological developments. It also shows one way of having the patience experimenting in slow computing but also exploring imaginaries about the future of manufacturing and emergence of personal robots in everyday life. Resilience, the ability to create different machines and devices with the same components, replicate machines using their own functions and the openness of this environment for sharing between users emerge as key characteristics of the 3D printer culture.

Looking back at this study, the contribution of my research lies in providing unique stories on the emergence of 3D printing culture and practise. The political narratives and cultural imaginaries do not carry fixed meaning; as of course Hackerspaces and communities presented can change direction given time. One of the most difficult aspects of this project was the constant chase between narratives and physical spaces. In the years from the start of the study until its completion, such narratives and imaginaries have matured while others have changed direction. The growth of Makers' communities meant that there was always the chance that such workshops within cities might have changed some of the practises, locations or even have turned in other directions. My attempt to conduct this type of research in multiple sites as the culture became more and more visible in the public eye was one of the most difficult tasks I encountered. The reason was because I was in a continuous process of reflecting and analysing all the while I was seeking to gain access and explain my position to a diverse crowd.

The thesis contains a number of directions in which this project could be developed for future research. One direction might be to follow transformations in cities in relation to the concept of social manufacturing either through ethnographic inquiry such as this thesis or using other types of research methods. The 3D printing environment, for example the networked machines, sharing platforms, the emergence of grassroots community workshops and the makers' attitude, constitute a potential basis for alternative economic, social and political experimentation. How might trends such as prosumption, circular economy, democratization of technology and resilience develop in the future? Will 3D printing meet expectations set by users and manufacturers alike? What direction will the phenomenon take in the future? Will it be desktop manufacturing for the masses or will industrial uses of 3D printing prevail?

Finally, as I conclude this thesis, let us consider the various aspects of 3D printing culture as characteristics and part of a digital environment that emerge from the increased capabilities of desktop technologies and social transformations in cities. The work of Marshal McLuhan (2005, p. 9) seems an echo from past technological advancements and their impact on social transformations. The medium, or process, of our time—digital technology—is reshaping and restructuring patterns of social interdependence and every aspect of our personal life. It is forcing us to reconsider and reevaluate practically every thought, every action, and every institution formerly taken for granted. Everything is changing—you, your family, your neighborhood, your education, your job, your government, your relation to ‘the others’. And they're changing dramatically. Societies have always been shaped more by the nature of the media by which men communicate than by the content of the communication.

What type of message is 3D printing, for our present state and where does it point towards the future? I argue that 3D printing is to hardware and manufacturing what YouTube has been to television and films. Namely a different way of conceiving production and consumption. That its importance and what exactly it brings to the world is yet to be fully understood. If, as Marshal McLuhan (1964) put it, the radio is a hot technology and television a cold one, then I would argue that 3D printing is a ‘cold media’ technology that aims to bring participation, multiple sources manipulating data and a qualitatively different environment to making than its predecessor technologies. Thus, 3D printing environment, the machine and infrastructure build around the technology, seems an example of a productive and social paradigm. By analogy, ‘hot media’ technology would not allow multiple human and non-human elements to collaborate or to reflect and co-develop the medium.

After the printing of so many whistles and other miniscule gadgets, it seems that the effect of such printed objects is not just their functionality. Of greater importance is the message of how they were made. They are part of a process, of the technology and its environment to mature along with the imagination of the users and the socio-economic system within which they act. The way people design, the environment in which they print and test their ideas, the people and interactions within the spaces where they take place, are an important part of developing this new way of perceiving making and even industrial production. This is a similar path to when Soderberg (2008) argued about the free and open source software movement a decade ago, in which similar hype of social transformations were perplexed by the development of the internet and the software industry

> During the 1990s, for instance; it was proposed that a 'big cottage industry' would blossom in connection to the information highway. Garage firms and freelancers were said to be ganging up in a network that could tilt old monopolies and reinstate truly free markets. Though hype was temporarily cooled down with the burst of the dot.com bubble, a distant echo of that promise can still be heard in the computer underground. The free marketeer spirit is here blended with opposition to intellectual property law. Monopolies built up around proprietary software are believed to be axed soon by FOSS start-ups. (Ibid, p. 139)

The spread of the Makers movement presents a new crossroads to these new social transformations influenced by the development of technologies such as 3D printing. The movement is fully aware of the dot.com bubble. Perhaps the most important aspect of the new movement is the plethora of new forms of organizing, many of them licensed as registered charities with purpose to advance hacking and making within cities. Although popular media has presented Makers as the new entrepreneurial movement reforming capitalism, Hackerspaces, Makerspaces or Fab Labs are grassroots organizations which do not have a for-profit character. They usually manage their economic responsibilities collectively and the purpose is to sustain the space whilst bringing in more people and machines. Unlike the 1990s, the free market has come under considerable pressure. As the economic crisis that intensified since 2008 made visible the problems of unrestricted capitalism, individuals and groups are more suspicious about for-profit organizations. Perhaps the strangest contradiction of this movement is that it indeed does maintain an entrepreneurial attitude while at the same time it organizes in a non-profit way. The new movement is less about building other forms of business and more about new sets of values. This is the context that allowed 3D printing to flourish.

The development of 3D printing as a production technology, reflects the increasing socialization of technology and the changing patterns in everyday technology integration. At the moment, proponents of free market as well as anti-capitalists can claim that this is a technology that can help them build the future. The antagonistic relationship between the various actors is sometimes hidden. My interlocutors sometimes did manage their resources and were forced to use materials, spaces and skills according to their limitations and power position. But, ultimately, the prospect of an ever increasing 3D printing manufacturing process in the hands of the vast majority of the population, seems to create a social, political and economic environment where these antagonistic relations may alter form and become much more overt and direct in the future.

Appendix - *List of featured Interviews*

Aleksander, *Leicester Hackerspace*

Andreas, *Designer, Fabulous St. Pauli*

Angus, *Leicester Hackerspace*

Alastair, *NottingHack*

Benjamin, *Radiographer, Leicester Hackerspace*

Daniel, *Artist, London*

Dave, *Leicester Hackerspace*

Duncan, *Engineer, Leicester Hackerspace*

Eleni, *Art history teacher, The Grammar School*

George, *Technology teacher, The Grammar School*

Harvey, *Leicester Hackerspace*

Ken, *Leicestershire Remap group*

Lewis, *Interact Labs*

Maria, *Head of Robotics Team, The Grammar School*

Mario, *Philosopher, Cambridge Makerspace*

Niels, *Technology writer, Fabulous St. Pauli*

Tony, *Leicester Hackerspace*

Bibliography

Albo, G., Gindin, S. and Panitch, L., 2010. In and out of crisis: The global financial meltdown and left alternatives. PM Press.

Albus, J.S., 1976. Peoples' capitalism: the economics of the robot revolution. New world books.

Anderson, C., 2012. Makers: The new industrial revolution. New York: Crown Business.

Antonelli, C., 2008. Pecuniary knowledge externalities: The convergence of directed technological change and the emergence of innovation systems. *Industrial and Corporate Change*, *17*(5), pp.1049-1070.

Antonelli, C., 2009. The economics of innovation: from the classical legacies to the economics of complexity. *Economics of Innovation and New Technology*, *18*(7), pp.611-646.

Anzalone, G.C., Zhang, C., Wijnen, B., Sanders, P.G. and Pearce, J.M., 2013. A low-cost open-source metal 3-D printer. *IEEE Access*, *1*, pp.803-810.

Arditti, R., Brennan, P. and Cavrak, S. eds., 1980. *Science and liberation* (Vol. 54). Black Rose Books Ltd.

Avent, R., 2014. The third great wave, The Economist [online] https://www.economist.com/news/special-report/21621156-first-two-industrial-revolutions-inflicted-plenty-pain-ultimately-benefited [Accessed 10 November 2014]

Avrich, P., 2005. *The Russian Anarchists,* AK Press

Bacon-Smith, C., 2000. *Science fiction culture*. University of Pennsylvania Press.

Badiru, A.B., Valencia, V.V. and Liu, D. eds., 2017. *Additive Manufacturing Handbook: Product Development for the Defense Industry*. CRC Press.

Balc, N.O. and Campbell, R.I., 2004. From CAD and RP to innovative manufacturing. Computing and Solutions in Manufacturing Engineering , Ivan, N.V., Lancea, C., Filip, A., Chicos, L., Mihali, M. and Simon, A.E. (eds), Transylvania University of Brasov, Romania

Barrett, R., 2004. *Management, Labour Process and Software Development: Reality Bites*. London: Routledge.

Baudrillard, J., 1970. 1998. *The consumer society: Myths and structures*. London: Sage

Baumberger, N. and Baulcombe, D.C., 2005. Arabidopsis ARGONAUTE1 is an RNA Slicer that selectively recruits microRNAs and short interfering RNAs. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(33), pp.11928-11933.

Bauwens, M. and Kostakis, V., 2014. From the communism of capital to capital for the commons: Towards an open co-operativism. *tripleC: Communication, Capitalism & Critique. Open Access Journal for a Global Sustainable Information Society*, *12*(1), pp.356-361.

Bauwens, M., 2005. The political economy of peer production. *CTheory*, pp.12-1.

Beach, D., 2008. Ethnography and representation: About representations for criticism and change through ethnography in Walford, G. [ed], How to do Educational Ethnography, London: Tufnell Press

Beckwith, J., 1986. The radical science movement in the United States. *Monthly Review*, *38*, pp.118-129.

Benkler, Y., 2006. *The wealth of networks: How social production transforms markets and freedom*. Yale University Press.

Berkes, F., 2006. From community-based resource management to complex systems: the scale issue and marine commons. *Ecology and Society*, *11*(1).

Bhatti, Y. 2012. What is Frugal? What is Innovation? Towards a Theory of Frugal Innovation. SSRN Working Paper Series.

Bhatti, Y. A., & Ventresca, M., 2013. *How can 'Frugal Innovation' be conceptualized?* Available at SSRN. Retrieved from http://ssrn.com/abstract=2203552

Bhatti, Y., 2013. Jugaad innovation: Think frugal, be flexible, generate breakthrough growth. *South Asian Journal of Global Business Research*, *2*(2), pp.279-282.

Bhatti, Y., Khilji, S.E. and Basu, R., 2013. Frugal innovation. In *Globalization, change and learning in South Asia* (pp. 123-145).

Bi, Z.M. and Wang, L., 2013. Manufacturing paradigm shift towards better sustainability. In *Cloud manufacturing* (pp. 99-119). Springer, London.

Birtchnell, T. and Hoyle, W., 2014. *3D printing for development in the global south: The 3D4D challenge*. Springer.

Birtchnell, T. and Urry, J., 2013. 3D, SF and the future. *Futures*, *50*, pp.25-34.

BLS (Bureau of Labor Statistics). 2014 Job Openings and Labor Turnover Survey Highlights March 2014, Chart 1. Number of Unemployed Persons Per Job Opening.

Boeing, N., 2015. *Von Wegen: Überlegungen zur freien Stadt der Zukunft, Nautilus Flugschrift*. Edition Nautilus.

Böhm, S. and Land, C., 2012. The new 'hidden abode': reflections on value and labour in the new economy. *The Sociological Review*, *60*(2), pp.217-240.

Böhm, S., Dinerstein, A.C. and Spicer, A., 2010. (Im) possibilities of Autonomy: Social Movements in and beyond Capital, the State and Development. *Social Movement Studies*, *9*(1), pp.17-32.

Böhm, S., Dinerstein, A.C. and Spicer, A., 2010. (Im) possibilities of Autonomy: Social Movements in and beyond Capital, the State and Development. *Social Movement Studies*, *9*(1), pp.17-32.

Bourell, D.L., Beaman, J.J., Leu, M.C. and Rosen, D.W., 2009. A brief history of additive manufacturing and the 2009 roadmap for additive manufacturing: looking back and looking ahead. *Proceedings of RapidTech*, pp.24-25.

Bowyer, A., 2007. The self-replicating rapid prototyper-manufacturing for the masses. In *8th National Conference on Rapid Design, Prototyping & Manufacturing*. University of Bath.

Bowyer, A., and Sells, E., 2006. Directly incorporating electronics into conventional rapid prototypes. In *Proceedings of the 7th National Conference on Rapid Design, Prototyping and Manufacturing*.

Bradshaw, S., Bowyer, A. and Haufe, P., 2010. *The intellectual property implications of low-cost 3D printing*. ScriptEd, 7 (1), pp. 5-31.

Bradshaw, T. and Mishkin, S., 2013. *Gadget makers drive US manufacture return.* [online] Available at https://www.ft.com/content/1445bab6-96b0-11e2-a77c-00144feabdc0 [Accessed 28 March 2013]

Bretthauer, D. 2002. Open Source Software: A History, *Information Technology and Libraries* Vol. 21, No.1: 3–10.

Brugger, T. 2014. *The Dark Side of 3D Printing. Retrieved from*, AOL news [online] http://www. aol.com/article/2014/02/05/the-moral-dilemma-of-3d-printing/20823680/ [Accessed 10 February 2015]

Bruns, A., 2008. *Blogs, Wikipedia, Second Life, and beyond: From production to produsage*. New York: Peter Lang.

Burawoy, M., 2005. For public sociology. *American sociological review*, *70*(1), pp.4-28.

Burton, M., 2005. *Design for rapid manufacture: The impact of direct additive manufacturing on the industrial design process*, Doctoral dissertation, Ph. D. dissertation, Loughborough University.

Bybee, R.W., 2010. Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), pp.30-35.

Campbell, R.I., De Beer, D.J., Barnard, L.J., Booysen, G.J., Truscott, M., Cain, R., Burton, M.J., Gyi, D.E. and Hague, R., 2007. Design evolution through customer interaction with functional prototypes. *Journal of Engineering Design*, *18*(6), pp.617-635.

Capra, E., Francalanci, C. and Merlo, F., 2010. The economics of community open source software projects: an empirical analysis of maintenance effort. *Advances in Software Engineering*, *2010*.

Carayannis, E.G., Meissner, D. and Edelkina, A., 2017. Targeted innovation policy and practice intelligence (TIP2E): concepts and implications for theory, policy and practice. *The Journal of Technology Transfer*, *42*(3), pp.460-484.

Carbon3D, 2015. Carbon 3D introduces CLIP, breakthrough technology for layerless 3D printing, Carbon3D press release [online] https://www.carbon3d.com/news/carbon3d-introduces-clip-breakthrough-technology-for-layerless-3d-printing/ [Accessed 17 April 2015]

Cardoso, R., 2010. *Craft versus design: Moving beyond a tired dichotomy*. In The Craft Reader, eds by Glenn Adamson, 2010. 321–332. Oxford: Berg

Carson, K., 2010. The Homebrew Industrial Revolution. *United States: BookSurge*.

Carspecken, P.F., 1996. *Critical ethnography in educational research: A theoretical and practical guide*. New York: Routledge

Castells, M., 2000. *The Information Age: end of millennium*. Cambridge: Blackwell Publishing.

Castillo, G., 2010. *Cold War on the Home Front: The Soft Power of Midcentury Design*. U of Minnesota Press.

Caulking, S. 2015. *Management column: why it is time we rethink the nature of work*, Financial Times [online] https://www.ft.com/content/aa1c3d22-4ce7-11e5-b558-8a9722977189 [Accessed 14 October 2015]

Cendrowski, M., 2013. *The Cooper/Kripke Inversion,* The Big Bang Theory, USA: CBS

Chandler, A., 1977. The visible hand Cambridge. *MA: Harvard Univer*sity

Charmaz, K., 2006. *Constructing grounded theory: A practical guide through qualitative analysis,* Thousand OAKS, CA: Sage.

Chen, K.K., 2016. "Plan your burn, burn your plan": How decentralization, storytelling, and communification can support participatory practices. *The Sociological Quarterly*, *57*(1), pp.71-97.

Chiapello, E. and Boltanski, L., 2005. *The new spirit of capitalism* London: Verso

Chin, R., 2005. How mass customization changes the design process: MIT Media Lab's Concept Car Project. In *Proceedings of the Third World Congress on Mass customization and Personalization*.

Christensen, C.M. and Overdorf, M., 2000. Meeting the challenge of disruptive change. *Harvard business review*, *78*(2), pp.66-77.

Christensen, C.M., 1997. The Innovator's Dilemma. *Boston, MA*: Harvard Business School Press.

Chua, C.K., Leong, K.F. and Lim, C.S., 2003. *Rapid prototyping: principles and applications* (Vol. 1). World Scientific.

Cohen, L., 2003. A Consumers' Republic: The Politics of Mass Consumption on Postwar America, New York: Vintage Books

Colbert Report, 8 June 2011. *Makerbot Industries CEO Bre Pettis,* Comedy Central [online] http://www.cc.com/video-clips/yvz8wj/the-colbert-report-bre-pettis [Accessed 12 April 2014]

Coleman, E.G. and Golub, A., 2008. Hacker practice: Moral genres and the cultural articulation of liberalism. *Anthropological Theory*, *8*(3), pp.255-277.

Condlife, J. 2013. *The future of fabrication is a touch picture to paint*, New Scientist [online] https://www.newscientist.com/article/mg21929301-100-the-future-of-fabrication-is-a-tough-picture-to-paint/ [Accessed 07 March 2014]

Cooper, R., 2006. Making present: Autopoiesis as human production. *Organization*, *13*(1), pp.59-81.

Copeland, M., 2013. *Why 3-D Printing Won't Turn Your Home Into a Factory*, Wired Magazine [online] https://www.wired.com/2013/03/ideas-not-dinner-plates-are-the-future-of-3-d-printing/ [Accessed 25 March 2014]

Cresswell, J. & Clark, V., 2010. *Designing and conducting mixed methods research,* Thousand Oaks, CA: Sage

Crew, B., 2015. This new device recycles plastic bottles into 3D printing material, science alert [online] https://www.sciencealert.com/this-new-device-recycles-plastic-bottles-into-3d-printing-material [Accessed 20 March 2015]

Cruickshank, M. 2017. *3D printed guns continue to proliferate*, The manufacturer [online] https://www.themanufacturer.com/articles/3d-printed-guns-continue-to-proliferate/ [Accessed 06 March 2017]

Cuninghame, P., 2013. Autonomia in the 1970s: The refusal of work, the party and power. *Cultural Studies Review*, *11*(2), pp.77-94.

Das, V., 2007. *Life and Words: Violence and the Descent into the Ordinary*. Berkeley: University of California Press.

Davis, S. J., Faberman, R. J. and Haltiwanger, J. C. 2012. Recruiting Intensity during and after the Great Recession: National and Industry Evidence. *American Economic Review Papers and Proceedings*, 102(3), pp. 584-588.

De Cock, C., Fitchett, J. and Volkmann, C., 2005. Constructing the new economy: A discursive perspective. *British Journal of Management*, *16*(1), pp.37-49.

De Cock, C.J.L., Fitchett, J.A. and Farr, M., 2001. Myths of a near future: Advertising the new economy. *ephemera theory & politics in organization*, *1*(3), pp.201-228.

Dean, J., 2005. Communicative capitalism: Circulation and the foreclosure of politics. *Cultural Politics*, *1*(1), pp.51-74.

Debord, G., 2002. *Guy Debord and the Situationist International: Texts and Documents*. Mit Press.

Delfanti, A., 2013. *Biohackers. The politics of open science.* London: Pluto Press

Deloitte. 2011. *Boiling Point? The Skills Gap in U.S. Manufacturing.* Manufacturing Institute. [online] http://www.themanufacturinginstitute.org/~/media/A07730B2A798437D98501E798C2E 13AA.ashx [Accessed 27 October 2013]

Denison, R., 2011. Anime fandom and the liminal spaces between fan creativity and piracy. *International Journal of Cultural Studies*, *14*(5), pp.449-466.

Denzin, N., 2009. *Qualitative inquiry under fire: Toward a new paradigm dialogue* Walnut Creek, CA: Left Coast Press

Department for Business, Innovation & Skills, 2015. *UK's vision for the European Union's digital economy*, [online] https://www.gov.uk/government/publications/the-uks-vision-for-the-european-unions-digital-economy [accessed 25 February 2015]

Dickel, S., Ferdinand, J.P. and Petschow, U., 2014. Shared machine shops as real-life laboratories. *Journal of Peer Production*, *5*, pp.1-9.

Dickinson, J.L., Shirk, J., Bonter, D., Bonney, R., Crain, R.L., Martin, J., Phillips, T. and Purcell, K., 2012. The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*(6), pp.291-297.

Doctorow, C., 2009. *Makers*. London: HarperVoyager

Douglas, J., 2000. Bizspace, Workshop to Rent [online] https://www.bizspace.co.uk/spaces/nottingham-roden [Accessed 27 March 2014]

Dubey, R., Gunasekaran, A. and Chakrabarty, A., 2017. Ubiquitous manufacturing: overview, framework and further research directions. *International Journal of Computer Integrated Manufacturing*, *30*(4-5), pp.381-394.

Dyer-Witheford, N., 2015. *Cyber-proletariat: Global labour in the digital vortex*. Between the Lines.

E.H 2015. *Why trade unions are declining*, The Economist [online] https://www.economist.com/blogs/economist-explains/2015/09/economist-explains-19 [Accessed 10 November 2015]

Ebrahim, T.Y., 2016. 3D Printing: Digital Infringement & Digital Regulation. *Nw. J. Tech. & Intell. Prop.*, *14*, p.37.

Economist, 1014. *The third great wave*, The Economist, Special Report on the World Economy [online] https://www.economist.com/news/special-report/21621156-first-two-industrial-revolutions-inflicted-plenty-pain-ultimately-benefited [Accessed 27 October 2014]

Economist, 2011. *More than just digital quilting* Technology Quarterly section, [online] https://www.economist.com/node/21540392 [Accessed 27 October 2014]

Economist, 2012. *A third industrial revolution*, Special report: Manufacturing and innovation [online] https://www.economist.com/node/21552901 [Accessed 27 October 2014]

Edquist, C. ed., 1997. *Systems of innovation: technologies, institutions, and organizations*. Psychology Press.

Edquist, C., 2011. Design of innovation policy through diagnostic analysis: identification of systemic problems (or failures). *Industrial and Corporate Change*, *20*(6), pp.1725-1753.

Edquist, C., Hommen, L. and McKelvey, M.D., 2001. *Innovation and employment: Process versus product innovation*. Edward Elgar Publishing.

Emerson. R, M., Fretz R.I, and Shaw L., 1995. *Writing ethnographic fieldnotes.* Chicago and London: University of Chicago

Engels, F., 1993. *The condition of the working class in England*. New York: Oxford University Press

Engels, Friedrich (1978 [1892]) "Socialism: Utopian and scientific," in Tucker, R. C. (ed.) *The Marx-Engels Reader*. 2d ed. New York: Norton: 683–717.

Etherington, D., 2013. *Stratasys Acquiring Makerbot in $403m deal, combined company will likely dominate 3D printing industry*, TechCrunch [online] https://techcrunch.com/2013/06/19/stratasys-acquiring-makerbot-combined-company-will-likely-dominate-3d-printing-industry/ [Accessed 18 October 2014]

European Commission, 2014. Towards a circular economy: A zero waste programme for Europe, Communication Paper [online] http://eur-lex.europa.eu/resource.html?uri=cellar:aa88c66d-4553-11e4-a0cb-01aa75ed71a1.0022.03/DOC_1&format=PDF [Acessed 19 April 2015]

European Commission, 2015. *Digitizing European Industry*, Digital Single Market Policy [online] https://ec.europa.eu/digital-single-market/en/policies/digitising-european-industry [Accessed 27 March 2016]

European Parliament, 2015. *Open innovation in industry, including 3D printing, Industry Research and Energy,* Policy Department A: Deconomic and Scientific Policy

Faris, S., 2015 *How 3D Printing is saving the Italian Artisan*, Bloomberg Newsweek [online] https://www.bloomberg.com/news/features/2015-05-05/how-3-d-printing-is-saving-the-italian-artisan [Accessed 19 May 2015]

Fassin, D., 2013. Why ethnography matters: on anthropology and its publics. *Cultural Anthropology*, *28*(4), pp.621-646.

Featherstone, M., 1987. Lifestyle and consumer culture. *Theory, Culture & Society*, *4*(1), pp.55-70.

Feenberg, A., 2010. *Between Reason and Experience: Essays in Technology and Modernity*, MIT Press

Feinberg, J. (2016). *Winners of the future engineers' STAR TREK™ Replicator challenge visit Makerbot*, Makerbot [online] https://www.makerbot.com/media-center/2016/08/15/star-trek-replicator-challenge-winners-visit-makerbot [Accessed 18, August 2016]

Feld, B., 2011. *Foundry Group invests in Makerbot Industries*, Business Insider [online] http://www.businessinsider.com/foundry-group-invests-in-makerbot-industries-2011-8 [Accessed 18 October 2014]

Flowers, S., 2010. Perspectives on User Innovation, London: Imperial College Press

Foust, J. B. 1975. Ubiquitous Manufacturing, *Annals of the Association of American Geographers* 65 (1): 13–17

Fressoli, M., Arond, E., Abrol, D., Smith, A., Ely, A. and Dias, R., 2014. When grassroots innovation movements encounter mainstream institutions:

implications for models of inclusive innovation. *Innovation and Development*, *4*(2), pp.277-292.

Frischmann, B.M., 2004. An economic theory of infrastructure and commons management. *Minn. L. Rev.*, *89*, p.917.

Fukuyama, F., 1992. *The End of History and the Last man.* New York: Free Press

Fuller, R.B., 2008. *Operating manual for spaceship earth*. Estate of R. Buckminster Fuller.

Gadamer, HG., 1999. *Truth and Method* NY: Continuum

Gebler, M., Uiterkamp, A.J.S. and Visser, C., 2014. A global sustainability perspective on 3D printing technologies. *Energy Policy*, *74*, pp.158-167.

Gelber, S.M., 1999. Hobbies: Leisure and the Culture of Work in America. New York: Columbia University Press

Gell, A., 1992. The technology of enchantment and the enchantment of technology. *Anthropology, art and aesthetics*, pp.40-63.

Geroski, P., 2003. *The evolution of new markets*. Oxford University Press on Demand.

Gershenfeld, N., 2006. *Fab: the coming revolution on your desktop--from personal computers to personal fabrication*. Basic Books.

Gill, R. and Pratt, A., 2008. In the social factory? Immaterial labour, precariousness and cultural work. *Theory, culture & society*, *25*(7-8), pp.1-30.

Glaser. B. G., 1978. *Theoretical sensitivity: Advances in the methodology of grounded theory*, Mill Valley, CA: Sociology Press

Goldman, R. and Gabriel, R.P., 2005. *Innovation happens elsewhere: Open source as business strategy*. Morgan Kaufmann.

Gonzalez-Rodriguez, D. and Kostakis, V., 2015. Information literacy and peer-to-peer infrastructures: An autopoietic perspective. *Telematics and Informatics*, *32*(4), pp.586-593.

Goulding, C., 2002. *Grounded theory: A practical guide for management, business, and market researchers,* London: Sage.

Graeber, D., 2012. Of flying cars and the declining rate of profit. *The baffler*, (19), pp.66-84.

Grenzfurthner,J & Schneider, F.A.,2009. *Hacking the Spaces: A critical acclaim of what was, is and could be a Hackerspace (or hacklab, for that matter)* [online] http://www.monochrom.at/hacking-the-spaces/ [accessed 02/07/2014]

Grint, K. and Woolgar, S., 1997. The theories of technology. *The Machine at Work: Technology, Work and Organization*, *630*.

Guston, D.H., 2001. Boundary organizations in environmental policy and science: an introduction. Science, Society, & Human Values, Vol.26, No.4, pp. 399- 408

Haenfler, R., Johnson, B. and Jones, E., 2012. Lifestyle movements: Exploring the intersection of lifestyle and social movements. *Social Movement Studies*, *11*(1), pp.1-20.

Hague, R., Campbell, I. and Dickens, P., 2003. Implications on design of rapid manufacturing. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *217*(1), pp.25-30.

Hallnäs, L. and Redström, J., 2001. Slow technology–designing for reflection. *Personal and ubiquitous computing*, *5*(3), pp.201-212.

Hamilton, J.F., 2014. Historical forms of user production. *Media, Culture & Society*, *36*(4), pp.491-507.

Han, C., 2012. *Life in debt: Times of care and violence in neoliberal Chile*. Univ of California Press.

Haraway, D., 2004. Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. *Turning Points In Qualitative Research: Tying Knots in a Handkerchief*, *2*, p.21.

Hardt, M. and Negri, A., 2000. *Empire*. Harvard University Press.

Hardt, M. and Negri, A., 2004. *Multitude* (Vol. 13). New York: Penguin.

Hardt, M. and Negri, A., 2009. Commonwealth. Harvard.

Hargreaves, T., Hielscher, S., Seyfang, G. and Smith, A., 2013. Grassroots innovations in community energy: The role of intermediaries in niche development. *Global environmental change*, *23*(5), pp.868-880.

Hart, S.L. and Christensen, C.M., 2002. The great leap: Driving innovation from the base of the pyramid. *MIT Sloan management review*, *44*(1), p.51.

Harvey, D., 2005. *A Brief History of Neoliberalism.* Oxford: Oxford University Press

Harvey, D., 2010. *A companion to Marx's Capital* (Vol. 1). Verso Books.

Harvey, D., 2010. The enigma of capital. *New York: Oxford*.

Hatch, M., 2013. *The maker movement manifesto: rules for innovation in the new world of crafters, hackers, and tinkerers*. McGraw Hill Professional.

Hazeltine, B. and Bull, C., 1999. *Appropriate Technology: Tools, Choices, and Implications*. New York: Academic Press

Hess, C. and Ostrom, E., 2007. *Understanding knowledge as a commons*. The MIT Press.

Hess, D., Breyman, S., Campbell, N. and Martin, B., 2008. 20 Science, Technology, and Social Movements. *The handbook of science and technology studies*, p.473.

Hetherington, K., 1997. *The badlands of modernity: Heterotopia and social ordering*. Psychology Press.

Hill, A. 2016. *Technology is making collaboration easier than ever*, Financial Times [online] https://www.ft.com/content/7c30ae7e-d0eb-11e5-831d-09f7778e7377 [Accessed 23 March 2016]

Hixson, W.L., 1998. *Parting the curtain: Propaganda, culture, and the Cold War, 1945-1961*. Macmillan.

Hoffmann, E., 2017. *User integration in sustainable product development: Organisational learning through boundary-spanning processes*. Routledge.

Holloway, J., 2002. " Change the World Without Taking Power": How Ridiculous! Or Is It?. *New Politics*, *9*(1), p.175.

Hopkinson, N., Hague, R. and Dickens, P. eds., 2006. *Rapid manufacturing: an industrial revolution for the digital age*. Chichester: John Wiley & Sons.

Hornick, J. and Roland, D., 2013. 3D printing and intellectual property: initial thoughts. *The Licensing Journal*, *33*(7), p.12.

Hsu, J. 2013. *3D printing: What a 3D printer is and how it works*, LiveScience [online] https://www.livescience.com/34551-3d-printing.html [Accessed 17 October 2014]

Iannotta, M. and Gatti, M., 2016. Manufacturing and work organization: occurrences and recurrences in industrial evolution. *Sinergie Italian Journal of Management*., pp. 105 – 124

Jacobs, J.A. and Sax, L.J., 2014. STEM majors, the liberal arts and the great recession. In *American Educational Research Association (AERA) annual meeting. Philadelphia*.

Jacobs, P.F., 1992. *Rapid prototyping & manufacturing: fundamentals of stereolithography*. Society of Manufacturing Engineers.

Jamison, A., 2001. Science and Social Movements, in N. Smelser & P. Bates (eds.) *International Encyclopedia of the Social and Behavioral Sciences Amsterdam*, New York: Elsevier 20: 13625–28 (Avent, 2014)

Johar, I., Lipparini, F. and Addarii, F., 2015. Making Good our Future Exploring the New boundaries of Open & Social Innovation in Manufacturing. *Social Innovation Europe, (policy paper)*.

Johnson, B., 2011. *2020 Vision: Eat a printed dinner in your printed home*, New Scientist [online] https://www.newscientist.com/article/mg21028121-700-2020-vision-eat-a-printed-dinner-in-your-printed-home/ [Accessed 4 March 2014]

Jones, R., Haufe, P., Sells, E., Iravani, P., Olliver, V., Palmer, C. and Bowyer, A., 2011. RepRap–the replicating rapid prototyper. *Robotica*, *29*(1), pp.177-191.

Katsiaficas, G., 2006. In defense of the dialectic: A response to Antonio Negri. *Socialism and Democracy*, *20*(1), pp.45-56.

Katz, C.J., 1993. Karl Marx on the transition from feudalism to capitalism. *Theory and Society*, *22*(3), pp.363-389.

Kelly, K., 2009. The new socialism: Global collectivist society is coming online. *Wired Magazine*, *17*(6), pp.17-06.

Kelty, C.M., 2008. *Two bits: The cultural significance of free software*. Durham: Duke University Press.

Klaus, S., 2016. The fourth industrial revolution. In *World Economic Forum*.

Kline, S.J. and Rosenberg, N., 2010. An overview of innovation. In *Studies On Science And The Innovation Process: Selected Works of Nathan Rosenberg* (pp. 173-203).

Knill, O. and Slavkovsky, E., 2013. Thinking like Archimedes with a 3D printer. *arXiv preprint arXiv:1301.5027*.

Koren, Y. and Barhak, J., 2007, October. Automobile interior personalization—Trends and analysis. In *Proceedings of the MCPC 2007 World Conference on Mass Customization & Personalization* (pp. 7-9).

Korotayev, A.V. and Tsirel, S.V., 2010. A spectral analysis of world GDP dynamics: Kondratieff waves, Kuznets swings, Juglar and Kitchin cycles in global economic development, and the 2008–2009 economic crisis. *Structure and Dynamics*, *4*(1).

Kostakis, V. and Bauwens, M., 2014. *Network society and future scenarios for a collaborative economy*. Springer.

Kostakis, V., 2013. At the turning point of the current techno-economic paradigm: commons-based peer production, desktop manufacturing and the role of civil society in the Perezian framework. *tripleC: Communication, Capitalism & Critique. Open Access Journal for a Global Sustainable Information Society*, *11*(1), pp.173-190.

Kurman, M. and Lipson, H., 2013. *Fabricated: The New World of 3D Printing*. Indianapolis: Wiley.

Laaksonen, P., Laaksonen, M. and Huuhka, A., 2008. City center as a context of consumption. In *Nordic Retail and Wholesale Conference, Norrtälje*.

Laclau, E., 1996. Why do empty signifiers matter to politics. *Emancipation (s)*, *36*, p.46.

Lapavitsas, C., 2013. The financialization of capitalism: 'Profiting without producing'. *City*, *17*(6), pp.792-805.

Latour, B., 1988. The politics of explanation: An alternative. *Knowledge and reflexivity: New frontiers in the sociology of knowledge*, *10*, pp.155-176.

Latour, B., 1991. Technology is society made durable. *The Sociological Review*, *38*(1_suppl), pp.103-131.

Latour, B., 2007. Can we get our materialism back, please?. *Isis*, *98*(1), pp.138-142.

Lazear, E.P. and Spletzer, J.R., 2012. *The United States labor market: Status quo or a new normal?* (No. w18386). National Bureau of Economic Research.

Lazonick, W. and Mazzucato, M., 2013. The risk-reward nexus in the innovation-inequality relationship: who takes the risks? Who gets the rewards?. *Industrial and Corporate Change*, *22*(4), pp.1093-1128.

Lefebvre, H. and Nicholson-Smith, D., 1991. *The production of space* (Vol. 142). Blackwell: Oxford.

Lefebvre, H., 2016. *Das Recht auf Stadt: Nautilus Flugschrift*. Edition Nautilus.

Leitner, H., Peck, J. and Sheppard, E.S. eds., 2007. *Contesting neoliberalism: Urban frontiers*. Guilford Press.

Levy, S., 1984. *Hackers: Heroes of the computer revolution* (Vol. 14). Garden City, NY: Anchor Press/Doubleday.

Li, M., 2009. The pirate party and the pirate bay: How the pirate bay influences Sweden and international copyright relations. *Pace Int'l L. Rev.*, *21*, p.281.

Lilley, S. and Papadopoulos, D., 2014. Material returns: Cultures of valuation, biofinancialisation and the autonomy of politics. *Sociology*, *48*(5), pp.972-988.

Lindstrom, A., 2012. *Selective Laser Sintering, Birth of an Industry*, Mechanical Engineering, University of Texas, [online] http://www.me.utexas.edu/news/news/selective-laser-sintering-birth-of-an-industry [Accessed 22 May 2014]

Lindtner, S. and Dourish, P., 2011. The promise of play: a new approach to productive play. *Games and Culture*, *6*(5), pp.453-478.

Lipson, H. 2011 3D printing: The technology that changes everything, New Scientist [online] https://www.newscientist.com/article/mg21128236-100-3d-printing-the-technology-that-changes-everything/ [Accessed 4 March 2014]

Lipson, H. and Kurman, M., 2013. *Fabricated: The new world of 3D printing*. Indianapolis: John Wiley & Sons.

Lipson, H., 2013. New world of 3-D printing offers" completely new ways of thinking": Q&A with author, engineer, and 3-D printing expert Hod Lipson. *IEEE pulse*, *4*(6), pp.12-14.

Loy, J., 2014. eLearning and eMaking: 3D Printing Blurring the Digital and the Physical. *Education Sciences*, *4*(1), pp.108-121.

Ludwig, T., Stickel, O., Boden, A. and Pipek, V., 2014, June. Towards sociable technologies: an empirical study on designing appropriation infrastructures for 3D printing. In *Proceedings of the 2014 conference on Designing interactive systems* (pp. 835-844). ACM.

Lundvall, B.A., 1992. National systems of innovation: An analytical framework. *London: Pinter*.

MacGyver, 1985 - 1992. Created by Lee David Zlotoff [TV Series] CBS Television

Malewitz, R., 2014. *The Practice of Misuse: Rugged Consumerism in Contemporary American Culture*. Stanford University Press.

Malkki, L.H. and Cerwonka, A., 2007. Improvising Theory: Process and Temporality in Ethnographic Fieldwork. Chicago: University of Chicago Press.

Maric, J., Rodhain, F. and Barlette, Y., 2016. Frugal innovations and 3D printing: insights from the field. *Journal of Innovation Economics & Management*, (3), pp.57-76.

Martian, 2015. directed by Ridley Scott [Film] Budabest, Hungary: Korda Studios, 20th Century Fox

Marx, Karl. [1867] 1990. Capital. Volume 1. New York: Penguin Books.

Mason, P., 2016. *Postcapitalism: A guide to our future*. London: Penguin

Maturana, H., Varela, F., 1980. *Autopoiesis and cognition: the realization of the living.* Boston: Reidel

Maxigas, P., 2012. Hacklabs and Hackerspaces: Tracing two genealogies. *Journal of Peer Production*, (2).

Mazzucato, M., 2011. *The Entrepreneurial State. London*, UK: Demos

Mazzucato, M., 2013. *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*, London: Anthem Press

McCue, T., 2012. *3D Printing Industry Will Reach $3.1 Billion Worldwide by 2016* [online] https://www.forbes.com/sites/tjmccue/2012/03/27/3d-printing-industry-will-reach-3-1-billion-worldwide-by-2016/#228f00e55869 [Accessed June 2014]

McHugh, M., 2011. *iTunes Match may be a compromise for the music industry and P2P file sharing,* Digital Trends [online] https://www.digitaltrends.com/apple/itunes-match-may-be-a-compromise-for-the-music-industry-and-p2p-file-sharing/ [Accessed 17 January 2016]

McIlroy, J., 2014. Marxism and the Trade Unions: The Bureaucracy versus the Rank and File Debate Revisited, *Critique, Journal of Socialist Theory*, 42:4, 497-526

McLuhan, M., 1964. *Understanding Media,* New York: McGrew Hill.

McLuhan, M. and Gordon, W.T., 2005. *Marshall McLuhan: The relation of environment to anti-environment (Vol. 4)*. Ginko Press.

Mendis, D., 2013. "The clone wars": episode 1: the rise of 3D printing and its implications for intellectual property law - learning lessons from the past*? European intellectual property review* 35.3 155 – 169

Michaels, D., 2017. Europe leads as Industrial 3D printing takes shape, Wall Street Journal [Online] https://www.wsj.com/articles/europe-leads-as-industrial-3-d-printing-takes-shape-1493976603 [Accessed 5 May 2017]

Micheletti, M., 2003. Shopping with and for Virtues. In *Political virtue and shopping* (pp. 149-168). Palgrave Macmillan, New York.

Micheletti, M., Follesdal, A. and Stolle, D. 2006. Politics, Products, and Markets: *Exploring political Consumerism Past and Present.* Rutgers NJ: Transaction Publishers

Microfabricator, 2016. Deloitte Poland preducts rosy outlook for Desktop 3D printing, Microfabricator [online] http://microfabricator.com/articles/view/id/58377372313944c4168b4567/deloitte-poland-predicts-rosy-outlook-for-desktop-3d-printing [Accessed 28 November 2016]

Millman, R., 2013. *Scientists develop low cost open source 3D metal printer: paves the way for Star Trek-like replicators*, ITPro analysis [online] http://www.itpro.co.uk/printers/21193/scientists-develop-low-cost-open-source-3d-metal-printer [Accessed 19 October 2014]

Mitchell, L., 2013. *Internet Revolution 2.0: 3D printing*, Forbes [online] https://www.forbes.com/sites/kauffman/2013/03/05/internet-revolution-2-0-3d-printing/#6e018061672f [Accessed 9 November 2015]

Moody, G., 2002 Rebel Code: *Linux and the Open Source Revolution*, New York: Perseus Books.

Mooney, P., Samanta, S. and Zadeh, A.H., 2010. Napster and its effects on the music industry: an empirical analysis. *Journal of Social Sciences*, *6*(3), p.303.

Moore, K., 1996. Organizing integrity: American science and the creation of public interest organizations, 1955-1975. *American Journal of Sociology*, *101*(6), pp.1592-1627.

Moore, K., 2006. Doing Good While Doing Science: *Social movements and institutional change in American Science, 1945 -1975,* Princeton, NJ: Princeton University Press

Moritz, M., 2016. *Europe should forget Google and investigate its own shortcomings.* [online] Available at https://www.ft.com/content/6425979e-07b0-11e6-9b51-0fb5e65703ce [Accessed 23 April 2016]

Morton-Clark, S., and Garrahan, D., 2012. *3D printing 'bigger than the internet'*, Financial Times, [online] https://www.ft.com/video/614779df-b5c2-3d76-9a3a-c6e62a6f2ef9 [Accessed 17 September 2013]

Morton, S. F.M. and Podolny, J.M., 2002. Love or money? The effects of owner motivation in the California wine industry. *The Journal of Industrial Economics*, *50*(4), pp.431-456.

Mulgan, G., 2012. The theoretical foundations of social innovation. In *Social innovation* (pp. 33-65). Palgrave Macmillan, London.

Mumford, L., 2010. *Technics and civilization*. University of Chicago Press.

Murray, R., Caulier-Grice, J. and Mulgan, G., 2010. *The open book of social innovation* (p. 2). London: National endowment for science, technology and the art.

Nascimento, S., 2014. Critical notions of technology and the promises of empowerment in shared machine shops. *Journal of Peer Production*, *5*.

Neal, M., 2014. *Our best bet for colonizing space may be printing humans on other planets*, Motherboard [online] https://motherboard.vice.com/en_us/article/ypwwpy/our-best-bet-for-colonizing-space-may-be-printing-humans-on-other-planets [Accessed 8 October 2014]

Nelson, H., 1985. Policy innovation in the Australian states. *Politics*, *20*(2), pp.77-88.

Nelson, R.R. and Winter, S.G., 1977. In search of useful theory of innovation. *Research policy*, *6*(1), pp.36-76.

Nelson, R.R. and Winter, S.G., 1982. The Schumpeterian tradeoff revisited. *The American Economic Review*, *72*(1), pp.114-132.

Nelson, R.R., 1987. Innovation and Economic Development Theoretical Reprospect and Prospect. In *Technology generation in Latin American manufacturing industries* (pp. 78-93). Palgrave Macmillan, London.

Nelson, R.R., 1990. Capitalism as an engine of progress. *Research policy*, *19*(3), pp.193-214.

Newson, A. 2013. *The Future is here,* Exhibition, Design Museum and RMIT Design Hub, London and Melbourne

Noble, D.F., 1977. *America by Design.* New York: Alfred A.

Noble, D.F., 1984. *Forces of production*. Transaction Publishers.

Nygren, A., 1999. Local knowledge in the environment–development discourse: From dichotomies to situated knowledges. *Critique of anthropology*, *19*(3), pp.267-288.

O'Brien, T., 2011. *More brain-powered science: Teaching and learning with discrepant events*. NSTA Press.

O'Keeffe, G.S. and Clarke-Pearson, K., 2011. The impact of social media on children, adolescents, and families. *Pediatrics*, *127*(4), pp.800-804.

O'Mahony, S. and Bechky, B.A., 2008. Boundary organizations: Enabling collaboration among unexpected allies. *Administrative science quarterly*, *53*(3), pp.422-459.

O'Reilly, T., 2011. Government as a Platform. *Innovations: Technology, Governance, Globalization*, *6*(1), pp.13-40.

Osterman, P. and Weaver, A., 2014. Skills and skill gaps in manufacturing. *Production in the innovation economy*, pp.17-50.

Ostrom, E., 2015. *Governing the commons*. Cambridge university press.

Pansera, M. and Sarkar, S., 2016. Crafting sustainable development solutions: frugal innovations of grassroots entrepreneurs. *Sustainability*, *8*(1), p.51.

Peacock, S.R., 2014. Why manufacturing matters: 3D printing, computer-aided designs, and the rise of end-user patent infringement. *Wm. & Mary L. Rev.*, *55*, p.1933.

Pearce, J.M., Anzalone, G.C., Zhang, C., Wijnen, B., and Sanders, P.G. 2013. A low-cost open-source metal 3-D printer. *IEEE Access*, *1*, pp.803-810.

Pedler, A., 2011. Going to the People. The Russian Narodniki in 1874–5. *The Slavonic Review* 6.16 (1927): 130–141

Pels, D., Hetherington, K. and Vandenberghe, F., 2002. The status of the object. *Theory, Culture & Society*, *19*(5-6), pp.1-21.

Perez, C., 2003. *Technological revolutions and financial capital*. Edward Elgar Publishing.

Pescovitz, D., 2010. White House's Tom Kalil on maker culture, Boing Boing [online] https://boingboing.net/2010/10/05/white-houses-tom-kal.html [Accessed 18 Ocober 2014]

Petryna, A., 2009. *When experiments travel: clinical trials and the global search for human subjects*. NJ: Princeton University Press.

Pettis, B., 2014. *New offerings from Makerbot and the future of democratized production*, Talks at Google

Pierson, M., 1999. CGI effects in Hollywood science-fiction cinema 1989–95: the wonder years. *Screen*, *40*(2), pp.158-176.

Postill, J., 2014. Freedom technologists and the new protest movements: A theory of protest formulas. *Convergence*, *20*(4), pp.402-418.

Powell, A., 2012. Democratizing production through open source knowledge: from open software to open hardware. *Media, Culture & Society*, *34*(6), pp.691-708.

Powell, W., 2013. I wrote the Anarchist Cookbook in 1969. Now I see its premise as flawed, Guardian [online] https://www.theguardian.com/commentisfree/2013/dec/19/anarchist-cookbook-author-william-powell-out-of-print [Accessed 23 April 2014]

Prahalad, C.K. and Hart, S.L., 2002. Strategy+ Business. *The Fortune at the Bottom of the Pyramid*, *26*, pp.2-14.

Prahalad, C.K. and Mashelkar, R.A., 2010. Innovation's holy grail. *Harvard Business Review*, *88*(7/8), pp.132-141.

Pursell, C., 1993. The rise and fall of the appropriate technology movement in the United States, 1965-1985. *Technology and Culture*, *34*(3), pp.629-637.

Quet, M. (2013) Science to the people! (and experimental politics): Searching for the roots of participatory discourse in science and technology in the 1970s in France, *Public Understanding of Science* , Vol 23, Issue 6, pp. 628 - 645

Radjou, N. and Prabhu, J., 2015. *Frugal Innovation: How to do more with less*. NY: The Economist and Public Affairs.

Randall, A. 1990. New Languages or Old? Labour, Capital and Discourse in the Industrial Revolution. *Social History, 15*(2), 195-216

Ratto, M. and Ree, R., 2012. Materializing information: 3D printing and social change. *First Monday*, *17*(7).

Ray, P.K. and Ray, S., 2010. Resource-constrained innovation for emerging economies: The case of the Indian telecommunications industry. *IEEE Transactions on Engineering Management*, *57*(1), pp.144-156.

Raymond, E., 1999. The cathedral and the bazaar. *Knowledge, Technology & Policy*, *12*(3), pp.23-49.

Razeto-Barry, P., 2012. Autopoiesis 40 years later. A review and a reformulation. *Origins of Life and Evolution of Biospheres*, *42*(6), pp.543-567.

Record, I., Coons, G., Southwick, D. and Ratto, M., 2015. Regulating the Liberator: Prospects for the Regulation of 3D Printing. *Journal of Peer Production*, *6*, pp.1-12.

Reeves, P., Tuck, C. and Hague, R., 2011. Additive manufacturing for mass customization. In *Mass Customization* (pp. 275-289). Springer, London.

Reilly, M., 2013 4D printing will mean the future makes itself, New Scientist [online] https://www.newscientist.com/article/mg22029420-400-4d-printing-will-mean-the-future-makes-itself/ [Accessed 4 March 2014]

Reynolds, L. and Szerszynski, B., 2012. Neoliberalism and technology: Perpetual innovation or perpetual crisis. *Neoliberalism and Technoscience: Critical Assessments*, pp.27-46.

Rifkin, J., 1999. *The biotech century: How genetic commerce will change the world*. London: Phoenix.

Ritzer, G. and Jurgenson, N., 2010. Production, consumption, prosumption: The nature of capitalism in the age of the digital 'prosumer'. *Journal of consumer culture*, *10*(1), pp.13-36.

Ritzer, G., Zhao, S. and Murphy, J., 2001. Metatheorizing in sociology: The basic parameters and the potential contributions of postmodernism. In *Handbook of sociological theory* (pp. 113-131). Springer, Boston, MA

Rogers, E. M. (2003). Diffusion of Innovations. (5th edition) NY: Free Press

Rogers, E.M. (1962). Diffusion of Innovations. Glencoe: Free Press

Rose, H. and Rose, S., 1979. Radical science and its enemies. *Socialist Register*, *16*(16).

Rose, H. and Rose, S.(1972) The radicalization of Science, The Socialist Register p. 106

Rosegger, G. (1996) The Economics of Production and Innovation, 3rd ed., Butter- worth Heinemann.

Rosenberg, N., 1982. *Inside the black box: technology and economics*. Cambridge University Press.

Ross, A., 2008. The new geography of work: Power to the precarious? *Theory, Culture & Society*, *25*(7-8), pp.31-49.

Rothstein, J., 2012. *The Labor Market Four Years Into the Crisis: Assessing Structural Explanations.* NBER Working Paper #17966.

RT, March 17, 2015. *25-100 times faster: Revolutionary 3D-printing technology announced* [online] https://www.rt.com/usa/241453-liquid-printing-system-faster/ [Accessed 10 April 2015]

Ruckenstein, M., 2011. Children in creationist capitalism: The corporate value of sociality. *Information, Communication & Society*, *14*(7), pp.1060-1076.

Rundle, G., 2014. *A Revolution in the Making*: Robots, 3D printing and the future, Affirm Press

Ruttan, V. W., 2001. Technology, Growth and Development, New York: Oxford University Press.

Saad Filho, A. and Fine, B., 2004. *Marx's capital*. Pluto Press.

Schumacher, E.F., 1973. *Small is beautiful: a study of ecomonics as if people mattered*. Vintage.

Schumpeter, J. A. (1934). The theory of economic development. New Brunswick, NP Transaction Publishers

Schumpeter, J.A., 1935. The analysis of economic change. *The Review of Economics and Statistics*, *17*(4), pp.2-10.

Schumpeter, J.A., 1942. *Socialism, capitalism and democracy*. Harper and Brothers.

Sculpteo., 2017. *The state of 3D printing*, Sculpteo report [online] https://www.sculpteo.com/media/ebook/State%20of%203DP%202017_1.pdf [Accessed 29 March 2017]

Sells, E. and Bowyer, A., 2006, June. Directly incorporating electronics into conventional rapid prototypes. In *Proceedings of the 7th National Conference on Rapid Design, Prototyping and Manufacturing*.

Sells, E., Bailard, S., Smith, Z., Bowyer, A. and Olliver, V., 2010. RepRap: the replicating rapid prototyper: maximizing customizability by breeding the means of production. In *Handbook of Research in Mass Customization and Personalization: (In 2 Volumes)* (pp. 568-580).

Seyfang, G. and Haxeltine, A., 2012. Growing grassroots innovations: exploring the role of community-based initiatives in governing sustainable energy transitions.

Seyfang, G. and Smith, A., 2007. Grassroots innovations for sustainable development: Towards a new research and policy agenda. *Environmental politics*, *16*(4), pp.584-603.

Shah, S.K. and Tripsas, M., 2007. The accidental entrepreneur: The emergent and collective process of user entrepreneurship. *Strategic Entrepreneurship Journal*, *1*(1-2), pp.123-140.

Sharma, R., 2013. *The Real reason Stratasys bought Makerbot*, Forbes [online] https://www.forbes.com/sites/rakeshsharma/2013/09/24/stratasys-bold-moves-a-conversation-with-company-chairman-scott-crump/#32e746a31ce7 [Accessed 28 September 2015]

Shukaitis, S., and Graeber, D., 2007. "Introduction." In *Constituent Imagination: Militant Investigations, Collective Theorization*, edited by S. Shukaitis and D.Graeber, 11–34. Edinburgh: AK Press.

Simpson, T.W., Siddique, Z. and Jiao, R.J. eds., 2006. *Product platform and product family design: methods and applications*. Springer Science & Business Media.

Sinclair, A., 1984. *A Guide to Appropriate Technology Institutions* CA: University of California

Sissons, A. and Thompson, S., 2012. *Three Dimensional Policy: Why Britain needs a policy framework for 3D printing.* London, The Big Innovation Centre.

Smith, A, Ely, A., 2015. Green transformations from below? The politics of grassroots innovation. In: Scoones, I, Leach, M, Newell, P (eds) The Politics of Green Transformations, London: Earthscan Routledge, pp. 102–118.

Smith, A., Fressoli, M., Abrol, D., Arond, E. and Ely, A., 2016. *Grassroots innovation movements*. London: Taylor & Francis.

Smith, A., Hielscher, S., Fressoli, M., 2015. *Transformative Social Innovation Narrative: Hackerspaces.* TRANSIT: EU

Snow, D.A. 2004. *Framing processes, ideology, and discursive fields. The Blackwell companion to social movements*. Oxford: Blackwell.

Söderberg, J. and Delfanti, A., 2015. Hacking hacked! The life cycles of digital innovation. *Science, Technology, & Human Values*, *40*(5), pp.793-798.

Söderberg, J., 2008. *Hacking capitalism: The free and open source software movement.* Routledge

Söderberg, J., 2013. Automating amateurs in the 3D printing community: connecting the dots between 'deskilling'and 'user-friendliness'. *Work Organisation, Labour and Globalisation*, *7*(1), pp.124-139.

Söderberg, J., 2013. How open hardware drives digital fabrication tools such as the 3D printer. *Internet Policy Review*.

Söderberg, J., 2014. Reproducing wealth without money, one 3D printer at a time: the cunning of instrumental reason. *Journal of Peer Production (4)*.

Srnicek, N., 2017. *Platform capitalism*. Cambridge: Polity Press

Staggenborg, S. and Taylor, V., 2005. Whatever happened to the women's movement?. *Mobilization: An International Quarterly*, *10*(1), pp.37-52.

Stephenson, B., 2015. *How collaboration drives the curcular economy,* WEF [Online] https://www.weforum.org/agenda/2015/01/collaboration-drives-circular-economy/ [Accessed 25 January 2015]

Sterling, B., 2005. *Shaping Things,* Cambridge, Massachusetts: The MIT Press.

Stiglitz, J.E., 2007. *Making globalization work*. WW Norton & Company.

Sun, Z., Yang. G.S., Zhang, B., Zhang, W. 2011. On the concept of the resilient machine. *Proceedings of the 2011 6th IEEE Conference on Industrial Electronics and Applications*, ICIEA.

Sutherland, N., Land, C. and Böhm, S., 2014. Anti-leaders (hip) in Social Movement Organizations: The case of autonomous grassroots groups. *Organization*, *21*(6), pp.759-781.

Tamburini, D., 2014. *3D Printing Growth: Unstoppable even if "Moore's Law doesn't apply"*, Redshift by Autodesk [online] https://www.autodesk.com/redshift/3d-printing-growth/ [Accessed 6 November 2014]

Tanenbaum, J.G., Williams, A.M., Desjardins, A. and Tanenbaum, K., 2013, April. Democratizing technology: pleasure, utility and expressiveness in DIY and maker practice. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2603-2612). ACM.

Tarrow, S., 2013. *Contentious politics*. Blackwell Publishing Ltd.

Tassey, G., 2008. Globalization of technology-based growth: The policy imperative. *The Journal of Technology Transfer*, *33*(6), pp.560-578.

Tassey, G., 2010. Rationales and mechanisms for revitalising the U.S Manufacturing R&D strategies. *Journal of Technology Transfer*. 35; 283-333

Tatnall, A. and Gilding, A., 1999. *Actor-Network Theory in Information Systems Research*, 10th Australasian Conference on Information Systems (ACIS), Wellington

Taylor, V. and Van Dyke, N., 2004. 'Get up, stand up': Tactical repertoires of social movements. *The Blackwell companion to social movements*, pp. 262-293.

The Economist, April 30, 2016. *A printed smile: 3D printing is coming of age as a manufacturing technique* [online] https://www.economist.com/news/science-and-technology/21697802-3d-printing-coming-age-manufacturing-technique-printed-smile [Accessed 5 May 2016]

Thoburn, N., 2003. *Deleuze, Marx and politics*. London: Routledge.

Thomas, D., 2013. Economics of the us additive manufacturing industry. *NIST Special Publication*, *1163*.

Thompson, P., 2010. The capitalist labour process: Concepts and connections. *Capital & Class*, *34*(1), pp.7-14.

Thopmspn, P., 1989. *The nature of work: An introduction to debates on the labour process*. Macmillan.

Thornhill, J. 2015. *Ft lunch with Marianna Mazzucato* [Online] https://www.ft.com/content/f4109fae-40df-11e5-b98b-87c7270955cf [Accessed 10 August 2015]

Torres, M.N. and Reyes, L.V., 2011. *Research as praxis: Democratizing education epistemologies*. New York: PeterLang.

Tsing, A. L., 2005. *Friction: An Ethnography of Global Connection*, New Jersey: Princeton University Press

Tuomi, I., 2003. *Networks of innovation*. Oxford: Oxford University Press.

Turner, F., 2010. *From counterculture to cyberculture: Stewart Brand, the Whole Earth Network, and the rise of digital utopianism*. University of Chicago Press.

Unruh, G. (2015, Demeber 08). *3D printing has the potential to alter how we use — and reuse — materials*, MIT Sloan Review: https://sloanreview.mit.edu/article/the-killer-app-for-3d-printing-the-circular-economy/ [Accessed 10 December 2015]

Uyarra, E., Shapira, P. and Harding, A., 2016. Low carbon innovation and enterprise growth in the UK: Challenges of a place-blind policy mix. *Technological Forecasting and Social Change*, *103*, pp.264-272.

Van den Berg, B., Van der Hof, S. and Kosta, E. eds., 2015. *3D Printing: Legal, Philosophical and Economic Dimensions*(Vol. 26). Springer.

Van Oost, E., Verhaegh, S. and Oudshoorn, N., 2009. From innovation community to community innovation: User-initiated innovation in wireless Leiden. *Science, Technology, & Human Values*, *34*(2), pp.182-205.

Voida, A., Grinter, R.E., Ducheneaut, N., Edwards, W.K. and Newman, M.W., 2005, April. Listening in: practices surrounding iTunes music sharing. In *Proceedings of the SIGCHI conference on Human factors in computing systems*(pp. 191-200). ACM.

Von Hippel, E., 2005. *Democratizing innovation*. Cambridge, Massachusetts: MIT press.

Von Laue, T. H., 2011.The Fate of Capitalism in Russia: The Narodnik Version. *American Slavic and East European Review* 13.1 (1954): 11–28.

Wajcman, J. & MacKenzie,D., 1999. *The Social Shaping of Technology*, Milton Keynes, UK: Open University Press

Watkins, E., 1993. *Throwaways: Work culture and consumer education*. Stanford University Press.

Weber, C., Peña, V., Micali, M., Yglesias, E., Rood, S., Scott, J.A. and Lal, B., 2013. The role of the national science foundation in the origin and evolution of additive manufacturing in the united states. *Science & Technology Policy Institute*, *1*.

Weber, S., 2004. *The success of open source*. Harvard University Press.

WEF, 2016. *The future of jobs. Employment, skills and workforce strategy for the fourth industrial revolution.* World economic forum [online] http://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf. [Accessed 21 January 2016]

WEF, 2017. *The Inclusive Growth and Development Report,* World Economic Forum [online] http://www3.weforum.org/docs/WEF_Forum_IncGrwth_2017.pdf [Accessed 3 March 2017]

Weinberg, M., 2010. It will be awesome if they don't screw it up. *Public Knowledge*.

Weiner, N., 1948. *Cybernetics Or Control and Communication* **in** *the Animal and the Machine,* New York: Wiley.

Weiser, M., 1991. The Computer for the 21 st Century. *Scientific american*, *265*(3), pp.94-105.

Weiser, M., 1993. Some computer science issues in ubiquitous computing. *Communications of the ACM*, *36*(7), pp.75-84.

West, J. and Lakhani, K.R., 2008. Getting clear about communities in open innovation. *Industry and Innovation*, *15*(2), pp.223-231.

Wilkof, N., 2016. IP and 3D printing: do not ignore the patent aspects. *Virtual and Physical Prototyping*, *11*(2), pp.143-147.

Wilkof, N., 2016. IP and 3D printing: do not ignore the patent aspects, *Virtual and Physical Prototyping*, 11:2, 143-147

Williams, A. and Srnicek, N., 2014. # Accelerate: Manifesto for an accelerationist politics.

Williams, C. and van Triest, S., 2009. The impact of corporate and national cultures on decentralization in multinational corporations. *International Business Review*, *18*(2), pp.156-167.

Williamson, P.J., 2010. Cost innovation: preparing for a ‘value-for-money’revolution. *Long Range Planning*, *43*(2-3), pp.343-353.

Wilson, W. J., & Chaddha, A. 2009. The role of theory in ethnographic research. *Ethnography*, *10*(4), 549-564.

Winner, L., 1977. Autonomous technology: techniques-out-of-control as a theme in political thought. *Cambridge: Massachusetts institute of technology*, p.10.

Wohlers, T., 2012. *Wohlers report 2012: Additive Manufacturing and 3D Printing State of the Industry.* Wohlers Associates, Inc.

Wohlers, T., 2014. *Wohlers report 2014: Additive Manufacturing and 3D Printing State of the Industry.* Wohlers Associates, Inc.

Wohlers, T., 2017. *Wohlers Report 2017: Additive Manufacturing and 3D Printing State of the Industry.* Wohlers Associates, Inc.

Wood, L., 2007. *3D home printers could change the economy*, LiveScience [online] https://www.livescience.com/1924-3-home-printers-change-economy.html [Accessed 19 October 2014]

World Economic Forum (WEF)., 2016. *The Future of Jobs: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*, [online] http://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf [Accessed 13 March 2016]

Wozniak, S. 1984. Homebrew and How the Apple Came to Be in Steve Ditlea, ed., (*Digital Deli, The Comprehensive, User-Lovable Menu of Computer Lore, Culture, Lifestyles and Fancy* NY: Workman Publishing Company

Wright, S., 2007. Back to the future: Italian Workerists reflect upon the Operaista project. *Ephemera: Theory & Politics in Organization*, *7*, pp.270-281.

Wu, D., Rosen, D.W., Wang, L. and Schaefer, D., 2015. Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation. *Computer-Aided Design*, *59*, pp.1-14.

Yates, L., 2015. Rethinking Prefiguration: Alternatives, Micropolitics and Goals in Social Movements, *Social Movement Studies*, 14:1, 1-21

Zald, M., 2000. Ideologically structured action: An enlarged agenda for social movement research. *Mobilization: An International Quarterly*, *5*(1), pp.1-16.

Zeschky, M., Widenmayer, B. and Gassmann, O., 2011. Frugal innovation in emerging markets. *Research-Technology Management*, *54*(4), pp.38-4

Patents List

Edward T. J., 1919. *Photographic-printing process,* US1408314A

Feygin, M., 1988. *Apparatus and method for forming an integral object from laminations*, US4752352A

Frank, D., 1954. *Making models in relief in gelatine by photographic processes*, US2694634A

Holser W. T., 1952 *Radio echo system for mapping contours,* US2616077A

Munz, O., 1956. *Method and apparatus for fabricating three dimensional objects from photoformed precursor sheets*, US2775758A

Munz, O., 1968. *Method for three-dimensional imprinting a thermoplastic object,* US3405213A