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Bits, Atoms, and Information Sharing: New Opportunities for Participation

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ABSTRACT

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KEYWORDS: digital technologies, participatory culture, digital fabrication, do-it-yourself, democratization, makers, hackerspaces, open source hardware

The particular characteristics and affordances of technologies play a significant role in human experience by defining the realm of possibilities available to individuals and societies. Some technological configurations, such as the Internet, facilitate peer-to-peer communication and participatory behaviors. Others, like television broadcasting, tend to encourage centralization of creative processes and unidirectional communication. In other instances still, the affordances of technologies can be further constrained by social practices. That is the case, for example, of radio which, although technically allowing peer-to-peer communication, has effectively been converted into a broadcast medium through the legislation of the airwaves. How technologies acquire particular properties, meanings and uses, and who is involved in those decisions are the broader questions explored here.

Although a long line of thought maintains that technologies evolve according to the logic of scientific rationality, recent studies demonstrated that technologies are, in fact, primarily shaped by social forces in specific historical contexts. In this view, adopted here, there is no one best way to design a technological artifact or system; the selection between alternative designs—which determine the affordances of each technology—is made by social actors according to their particular values, assumptions and goals. Thus, the arrangement of technical elements in any technological artifact is configured to conform to the views and interests of those involved in its development. Understanding how technologies assume particular shapes, who is involved in these decisions and how, in turn, they propitiate particular behaviors and modes of organization but not others, requires understanding the contexts in which they are developed.

It is argued here that, throughout the last century, two distinct approaches to the development and dissemination of technologies have coexisted. In each of these models, based on fundamentally different ethoi, technologies are developed through different processes and by different participants—and therefore tend to assume different shapes and offer different possibilities.

In the first of these approaches, the dominant model in Western societies, technologies are typically developed by firms, manufactured in large factories, and subsequently disseminated to the rest of the population for consumption. In this centralized model, the role of users is limited to selecting from the alternatives presented by professional producers. Thus,

according to this approach, the technologies that are now so deeply woven into human experience, are primarily shaped by a relatively small number of producers.

In recent years, however, a group of three interconnected interest groups—the makers, hackerspaces, and open source hardware communities—have increasingly challenged this dominant model by enacting an alternative approach in which technologies are both individually transformed and collectively shaped. Through a in-depth analysis of these phenomena, their practices and ethos, it is argued here that the distributed approach practiced by these communities offers a practical path towards a democratization of the technosphere by: 1) demystifying technologies, 2) providing the public with the tools and knowledge necessary to understand and shape technologies, and 3) encouraging citizen participation in the development of technologies.

RESUMO

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PALAVRAS-CHAVE: tecnologias digitais, cultura participativa, fabricação digital, do-it-yourself, democratização, makers, hackerspaces, open source hardware

As características e affordances de artefactos e sistemas tecnológicos definem a esfera de possibilidades colocadas à disposição tanto de indivíduos como da sociedade e, desta forma, desempenham um papel fundamental na modelação da experiência humana. Enquanto que algumas configurações tecnológicas (por exemplo a Internet) facilitam a comunicação entre pares e estimulam práticas participativas, outras (como o sistema de transmissão televisivo) propiciam formas de comunicação unidirecionais e a centralização de processos criativos. As affordances de tecnologias podem também, por vezes, ser limitadas por práticas sociais. Esse foi o caso, por exemplo, da rádio: apesar desta tecnologia permitir, ao nível técnico, a comunicação entre pares, a regulamentação das ondas de rádio transformou-a efetivamente num meio de comunicação de massas. Por conseguinte, tendo em conta o papel fundamental desempenhado pelas tecnologias, esta tese procura interrogar os processos através dos quais estas assumem determinadas formas, significados e usos.

Apesar de uma corrente de pensamento comum alegar que o desenvolvimento tecnológico é baseado essencialmente numa lógica científico-racional, estudos recentes demonstram que as tecnologias são principalmente formadas por processos sociais ancorados em contextos históricos. Segundo este ponto de vista, aqui adoptado, a seleção entre desenhos alternativos (que determinam as affordances de cada tecnologia), é efetuada por agentes sociais de acordo com os seus valores, premissas e objetivos. Assim seja, a configuração específica dos elementos técnicos de artefactos tecnológicos obedece aos pressupostos e interesses dos indivíduos e grupos que os desenvolvem. Por esta razão, para compreender os processos de formação de tecnologias, quem neles participa e de que maneira as tecnologias resultantes propiciam determinados comportamentos e não outros, é necessário entender os contextos em que estas são desenvolvidas.

Argumenta-se aqui que, ao longo dos últimos 100 anos, duas abordagens alternativas ao desenvolvimento e disseminação de tecnologias evoluíram em paralelo. Em cada um destes modelos, baseados em ethos essencialmente distintos, as tecnologias são desenvolvidas através de processos diferentes por intervenientes distintos e, por essa razão, tendencialmente assumem formas diferentes.

No modelo predominante em sociedades ocidentais, as tecnologias são tipicamente desenvolvidas por empresas, produzidas em fábricas, e subsequentemente disseminadas para consumo. Neste modelo centralizado, o papel dos utilizadores limita-se à escolha entre os

artefactos disponibilizados por produtores profissionais. Assim, neste tipo de abordagem, as tecnologias que hoje em dia estão tão profundamente entrelaçadas com a experiência humana, são essencialmente definidas por um número relativamente limitado de criadores.

No entanto, ao longo dos últimos anos, as comunidades *maker*, *hackerspaces* e *open source hardware* têm vindo a desafiar este modelo dominante através da implementação de uma abordagem alternativa na qual as tecnologias são individualmente transformadas e colectivamente formadas. Através de uma análise das suas práticas e ethos, argumenta-se aqui que este modelo distribuído oferece uma possível via prática para a democratização da esfera tecnológica através de: 1) a desmistificação das tecnologias, 2) a disponibilização das ferramentas e conhecimentos necessários para a compreensão, apropriação e transformação de tecnologias e 3) o estímulo à participação pública na modelação de alguns dos artefactos mais importantes da nossa época.

CONTENTS

INTRODUCTORY NOTE

During the six year period of research for this dissertation—in parallel and correlated with it—I was actively involved in the three communities (makers, hackerspaces and open source hardware) that are its object of study.

Research for this dissertation began in the summer of 2008. At this time, I was already an electronics hobbyist, but was not yet engaged in the maker, hackerspaces or open source hardware communities. This involvement began in early 2009, after attending a workshop at Medialab Prado in Madrid on the topic of "Citizen Science." In addition to collecting information for this dissertation and beginning to build and operate personal 3D printers, two other related projects arose from this workshop: Open Materials and AltLab.

Open Materials was originally conceived as an independent research group focused on DIY materials. The project was launched by Kirsty Boyle and myself in the Spring of 2009. It has an online presence (openmetarials.org) in which we share do-it-yourself experiments with a wide range of materials: from conductive inks and polymers to bio-materials and composites. Open Materials seeks to bring open source practices, experimentation and knowledge sharing into the realm of materials.

AltLab is Lisbon's hackerspace. It was founded by myself, Ricardo Lobo and Tiago Henriques also in the Spring of 2009. I chaired this hackerspace between 2009 and 2010 and, during this time, conducted extensive research on previously existing hacker clubs in Europe and the U.S. with the goals of establishing a solid foundation for both my academic work and the practical implementation of AltLab. AltLab still exists today and is a thriving community of approximately forty members, as well as an affiliate of the Portuguese Network of Hackerspaces (Rede de Laboratórios AZ).

In 2010, I became a visiting scholar at the Interactive Telecommunications Program at the New York University (ITP-NYU), under the supervision of Professor Tom Igoe, with the goal of advancing my academic research in a setting where the maker, hackerspaces and open source hardware communities are particularly active. That same year, I also joined the New York hackerspace NYC Resistor, in order to continue research work for both this dissertation and Open Materials.

Since 2009, several opportunities arose to present both academic and applied research—on the topics of smart materials, the maker community, hackerspaces, and open source hardware—at a variety of conferences and universities. These included two speeches at TED Global 2012 (Mota 2012a), TEDx conferences in Stockholm (Mota 2012b) and Porto (Mota 2013), Maker Faires in the Bay Area and NYC, software conferences such as LinuxCon (Mota 2012c) and EclipseCon, design conferences like Interaction South America, and a variety of master classes at the New York University, School of the Arts Institute of Chicago, Indiana University, and the School of the Arts in Aix-en-Provence. Additionally, in 2012, I taught a graduate class—focused on the combination of high and low tech materials and titled "Tech Crafts"—at the ITP-NYU master's program.

Also in 2012, academic researcher Dustyn Roberts and myself co-chaired the annual Open Hardware Summit conference and became founding members of the Open Source Hardware Association (OSHWA)—a non-profit organization launched and led by fellow academic Alicia Gibb. Later that year, I had the opportunity to join OSHWA again as Research Chair, a position I still hold today and whose functions include researching the history of open source hardware, as well as collecting and analyzing data on open source practices.

As part of my work, I also had the opportunity to author, or otherwise contribute to, a series of articles for periodicals and books, including: "A Strategist's Guide to Digital Fabrication" (Igoe and Mota 2011) published in the magazine *Strategy and Business*; "The Rise of Personal Fabrication" (Mota 2011) in *Proceedings of the 8th ACM Conference on Creativity and Cognition*; "Open Sourcing Materials" in *The Open Book* (Braybrooke and Nissila 2013); an in-depth interview in *Makers at Work: Folks Reinventing the World One Object or Idea at a Time* (Osborn 2013); and a chapter titled "The History of the Open Source Hardware Movement" in the upcoming book *Building Open Source Hardware: Manufacturing for the DIY Maker Movement* (Gibb 2014).

On a personal note, during this period I also developed friendship ties with some of the participants and leaders of the maker, hackerspaces and open source hardware communities, both as a result of academic research (through interviews for this dissertation) and the more applied work on Open Materials and hackerspaces. And in December 2013, I married Marcin Jakubowski, executive director of the Open Source Ecology project.

Thus, throughout these six years of research, my involvement with the topic of this dissertation was simultaneously academic, professional and personal. I believe this insider approach provided me with a deeper understanding of the dynamics underlying the themes and questions in discussion here.

INTRODUCTION

The relevance of technologies[1] for contemporary societies can hardly be overstated. Technologies now permeate virtually all aspects of life, from communication and transportation to work and leisure. Even those mundane objects around us that are not themselves electromechanical devices are the product of manufacturing technologies: tools with which furniture, objects and houses are created, appliances to prepare food and keep it fresh, a vast array of machinery that turns raw materials into the artifacts of everyday life.

It is also widely understood that the technologies a society creates and adopts greatly influence its social practices. With each new technology that is introduced and adopted some courses of action become easier to pursue—or harder to prevent—and others more difficult to follow. The adoption of mass manufacturing technologies, for example, made it easier and cheaper to produce and disseminate large batches of a single design, but in the process relegated small-scale, artisanal production to the periphery of the industrial system.

Thus, the affordances[2] of technologies—the possibilities and opportunities they offer or deny—play a fundamental role in determining the range of behaviors available to individuals. Today, this is perhaps most visible in the communications arena. The technological system of television broadcasting, for example, effectively establishes a one-way communication process—although receivers can use the telephone or other media to send messages to the broadcaster, the television medium itself does not allow it—and therefore stimulates listening rather than speaking, receiving rather than emitting, consuming rather than producing. Conversely, the technical architecture of the Internet not only allows but positively encourages one-to-one and many-to-many communication—and has, therefore, enabled the emergence of what became known in recent years as a participatory culture.

This power of technologies to shape the realms of work, play, communication, production, and consumption, is experienced first hand by citizens of industrialized societies.

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[1] In the specific context of this dissertation, the terms "technology" (singular) and "technologies" (plural) refer to discrete types of electromechanical artifacts—such as automobiles or computers. See "Terms" section below.

[2] The term "affordance" is used here in the sense in which it was introduced by James Gibson (2013): the possibilities for action available to individuals (independently of whether they are perceived or not).

However, given that most individuals are not directly involved in the creation, development, production and dissemination of technological artifacts, from their point of view, technologies often appear to emerge out of nowhere—like some *deus ex machina* (Marx and Smith 1994)—unilaterally imposing their demands on individuals and societies. For this reason, in popular accounts, technologies are often portrayed as asocial forces evolving according to an internal logic of their own and guided only by the technical pursuit of efficiency (MacKenzie and Wajcman 1999; Smith and Marx 1994; Bimber 1994). In this view, mass production technologies, for example, were simply the next stage on the technical evolution of manufacturing systems—rather than the product of human choices—and the reorganization of society they enabled the unavoidable cost of progress. This standpoint is commonly designated by scholars as technological determinism.

Contrary to this view, a growing body of work[3] in social sciences has suggested that the emergence, development and adoption of technologies is highly dependent on historical and social factors. In *The Second Industrial Divide*, for example, Piore and Sabel (1984) contend that the transition to an industrial society based on mass manufacturing was not an unavoidable development, but the product of historical and political forces—under different social conditions, other technological alternatives might have succeeded. Adopting a similar position, Susan Douglas (1987) demonstrated that radio, rather than emerging fully formed as a broadcast medium, was primarily shaped by a series of struggles over the meanings and uses of the technology. In the same way, Paul Josephson (1991), through a comparative analysis of the technologies of totalitarian and democratic regimes, has shown that the technical apparatus a society generates tends to reflect its political system.

Thus, on the one hand, the affordances of each technology facilitate some courses of action but hinder others, and in this way shape social and individual practices by defining the realm of possibilities available to individuals. On the other hand, these affordances are themselves shaped by the wider cultural contexts in which the development of technologies takes place. This can be understood as the dialectic process of the social shaping of technologies and the technological shaping of societies.

[3] See, for example, Pinch and Bijker (1984), MacKenzie and Wajcman (1999), Josephson (1991), Piore and Sabel (1984), Feenberg (2002), Katz, Light and Thompson (2003), Winner (1986), and Noble (1979).

Given the profound ways in which the possibilities opened or closed by technologies influence the emergence, establishment and reproduction of both old and new practices, the question of *how and by whom technologies are shaped* becomes fundamental to understanding their trajectories and the practices that flourish or perish around them.

Since the particular shape of each technology—its characteristics, affordances and uses—is related to its social context, the question of how and by whom technologies are shaped can only be understood in light of the cultural settings in which they emerge and prosper. In this sense, it is argued here that throughout the last century two distinct approaches to the development and dissemination of technologies have coexisted. In each of these models, based on fundamentally different ethoi, technologies are developed through different processes and by different participants—and therefore tend to assume different shapes and have different affordances. These two models are not only related to but also share fundamental characteristics with the two types of media represented by the examples of the television and the Internet mentioned above: one centralized and unidirectional, the other distributed and multidirectional. For this reason they will be allegorically designated here as the broadcast approach and the distributed approach.

The Broadcast Approach

The broadcast approach is the dominant method of development and production of physical and digital technologies in Western societies. In this approach, hardware and software are centrally developed and produced—primarily by firms, but also by academic institutions and governmental agencies—and then "broadcast" to the rest of the population for consumption/use. In this model, the creation and development of technologies takes place within the confines of each originating organization and users are not directly involved in this process. In addition to not participating in development processes, users are also discouraged from tinkering with or transforming the devices they acquire or use. Thus, broadcast approach technologies, although used by a large number of individuals and groups, are primarily shaped by a comparatively small number of producers. This model is based on three fundamental assumptions:

1) *Technological innovation and development are complex processes requiring large investments in equipment and expertise.* Therefore, they are best left to professional organizations with sophisticated laboratories and teams of formally-trained experts.

2) *Exclusive intellectual property rights are essential for the survival of firms and, therefore, for the technological advancement they provide.* Given the large investments required by technological innovation and manufacturing, firms must assure future revenues in the form of monopolies over the distribution, production and commercialization of the technologies they create, as well as the knowledge behind them.

3) *Users of technologies cannot, need not and want not to know how technologies work*. The complexity of contemporary technologies means that the knowledge about the makeup and functioning of devices, even those used by millions of people every day—from computational devices of various sizes and shapes to appliances and automobiles—is today considered to be largely the purview of professionals. In light of this, the professional producer seeks to design devices which can be easily used with no knowledge of their inner workings. This perspective is typically materialized in devices in which mechanisms are concealed inside sealed, opaque cases and which are operated through user interfaces.

In this context, the relationship between most individuals and contemporary technologies has been defined primarily by an obfuscation of the process of technological development, a monopolization of technical knowledge by producers, and an overall centralization of the shaping of technologies. Consequently, although technological artifacts are now more widely distributed than ever before, from the point of view of users, they have increasingly become *black boxes*: opaque objects, simultaneously familiar and unknown. Technological devices, Claude Fischer suggests, are the "instruments *with* which and the conditions *within* which we enact some of the most profound conducts of our lives" (C.S. Fischer 1992, 140). Despite this, most users of technologies neither shape nor understand them.

The corollary of these assumptions and practices is a polarized society, with a comparatively small number of producers on one side, and a large number of consumers on the other. In this model, the role of producers is to design, manufacture and disseminate technologies. The role of users, in turn, is confined to the market: competing producers bring alternative technological artifacts to market; consumers select which to acquire and use. In economics this is termed "consumer sovereignty," a process often described in American popular culture as "voting with one's wallet." Here, the concepts of "voting" and "sovereignty" equate the functioning of the market with democratic processes. Such an analogy, in which democracy is reduced to aggregate sales and purchases, links consumption with civic participation in the institutions of industrialized society.

In the last two decades, an understanding of the power of technologies to affect human affairs through the constraints and freedoms they enable, coupled with an awareness of how poor the broadcast approach's notion of "democracy" is, has led some concerned analysts to advocate for a more participatory approach to the development of technologies. Most notably amongst them, Langdon Winner has suggested the application of a "decentralized democratic politics" to the technosphere through the "building [of] institutions in which the claims of technical expertise and those of a democratic citizenry would regularly meet face to face" (Winner 1986, 55). However, these calls to action have fallen more in the awareness and theoretical arenas than in actual implementable solutions. So deeply ingrained is the broadcast approach and its assumptions that it appears impossible to conceive of practical alternatives that do not require radical social restructuring or the intervention of the state.

The Distributed Approach

Despite this, and closely related to the participatory practices that flourished around digital media, an alternative approach to the development of technologies has begun to take shape. In this distributed model, the processes of technological development are open to public participation. Although they may also originate from firms, academic institutions and governmental agencies—and even if their principal development effort remains within those organizations—technologies developed according to the distributed approach can be studied, duplicated and transformed by anyone who wishes to do so. To make this possible, distributed approach creators make publicly available the hardware plans and software code necessary to enable others to understand, replicate and modify the technologies. Through these practices, the distributed approach blurs the distinction between producers and users and views each user as a potential co-creator.

In the arenas of information and cultural production, the distributed approach has, in the last decades, extended its reach from virtually unnoticeable fringe practices at the edges of the broadcast model to a series of highly visible phenomena. This is demonstrated by the multiplication of user-generated content and the emergence of mass collaboration projects, of which Wikipedia is perhaps the most prominent example. In technological fields, distributed practices have also played an increasingly central role in the production of software—epitomized by large scale open source software projects such as the Linux operating system, the Apache server software, and the smartphone operating system Android. In the Wikipedia, Linux, Apache and Android projects, information and software are publicly shared, and collectively and openly generated.

The ease with which computational devices and the Internet allow digital information to be created, altered, and disseminated enables these new practices, but also spells the limits of the medium: although bits can be duplicated and transmitted at marginally zero cost by anyone with a computer and an Internet connection, the same cannot be done with atoms. For this reason, until less than a decade ago, the application of the distributed approach to the development of technologies was mostly confined to software. This began to change in the mid-2000s with the parallel and interrelated emergence of do-it-yourself (DIY) hardware communities and personal fabrication tools.

The first transformative aspect that allowed participatory practices to extend from the digital into the physical realm was the increasing digitization of goods through Computer-Aided Design (CAD). CAD software, which is now extensively used in the design of a wide range of products, allows creators to produce digital 2D or 3D models and then manipulate, alter or even simulate their behavior in virtual 3D space. These digital representations of physical objects exhibit the same properties as all other digital information: they can be created, copied, combined, modified and distributed digitally at marginally zero cost. This is the property that led Chris Anderson, then editor-in-chief of *Wired* magazine, to proclaim in early 2010 that “Atoms are the new bits” (Anderson 2010).

Nevertheless, the correlation between bits and atoms could not be completed without the ability to effectively convert the former into the latter. The solution appeared in the form of digital fabrication tools, machines such as 3D printers, CNC mills and laser cutters that create physical objects from digital designs, just like document printers materialize digital information on physical sheets of paper. However, even though digital fabrication tools have been in existence since at least the 1980s, by the mid 2000s they were still large, complex and extremely expensive. Thus, although digital models could be easily manipulated in personal computers and shared via the Internet, the technologies necessary to transform bits into atoms were still the purview of a small number of organizations. The ensuing shift in the development direction of digital fabrication tools—from exclusively professional to personal applications—emerged not from industry, but from the alternative cultural setting formed by the maker, hackerspaces and open source hardware communities.

The origins of the maker community can be traced to the launch, in 2005, of an American publication dedicated to do-it-yourself projects—ranging from small electronic devices to land, air and ocean vehicles. The magazine was titled *Make* and on its first issue Dale Dougherty, the publication's editor, wrote: "More than consumers of technology, we are makers, adapting technology to our needs and integrating it into our lives" (Dougherty 2005). Around this identity of the maker as an independent creator and re-creator of technologies, a number of hobbyists—from electronics tinkerers and amateur scientists to jewelry makers and garment designers—began to gather. Within a few years, the maker community (which often refers to itself as the "Maker Movement") had grown to hundreds of thousands of participants, and captured the attention of the public, the media, and even some governments. In these makers' view, the broadcast approach deprives technologies' users of an important creative aspect of their lives. Thus, through a series of practices and outreach initiatives, they seek to engage citizens in the production of material culture and, in the process, develop a more participatory and meaningful relationship with the production system.

Several years before the launch of *Make*, another community with a similar ethos was forming around a computer club in Berlin, Germany. The Chaos Computer Club (CCC), as it was named, was originally conceived as a gathering place for computer hobbyists and other independent explorers of technologies. This type of club house became know as a hackerspace, in reference to the hacker culture that emerged at the Massachusetts Institute of

Technology (MIT) in the 1950s and 60s. Today, the term "hacker" is often used to depict technically-savvy individuals who illicitly penetrate digital systems. However, for the CCC and other hackerspaces, hackers are those passionate explorers of technologies who, not content with what is provided by professional producers, seek to actively shape their own technological artifacts.

Inspired by the CCC, several other similar clubs emerged first in Europe, then in the U.S, and eventually around the globe. By 2013, practically all major cities in the world had a hackerspace—from Sydney and Saigon to Lagos and Lisbon. These contemporary hackerspaces are typically shared workshops, equipped with an assortment of design and production machinery, where amateurs and professionals collaborate on the DIY creation and recreation of technologies—through projects ranging from the whimsical or playful to the practical or politically-oriented. According to the community-maintained hackerspaces.org database, in 2013 there were approximately 700 of these clubs worldwide (Hackerspaces Wiki 2013).

Although the origins of the open source hardware community cannot be traced to a specific moment in time, its ethos and practices first became visible in the late 1990s, when open source software developers began to shift their attention to the hardware it runs on. Shortly thereafter, a young generation of engineers, who had grown accustomed to openly sharing source code, began to publish online the designs and schematics of their devices for others to replicate, study, and modify. In 2010, these practices were formalized on the "Open Source Hardware Definition," which states that:

> *Open source hardware is a hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design. The hardware's source, the design from which it is made, is available in the preferred format for making modifications to it. Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open source design tools to maximize the ability of individuals to make and use hardware. Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging*

commerce through the open exchange of designs. (Open Source Hardware Definition 2011)

By 2010, the practice of openly sharing digital plans for physical objects had caught the attention of the media. Prominent articles in wide-reaching publications—such as the *New York Times* (Vance 2010), *The Wall Street Journal* (Lahart 2009), and *Wired* magazine (Thompson 2008; Anderson 2010)—further contributed to expand the practice. In early 2013, open source plans for automobiles, 3D printers, laser cutters, aerial drones, sailing drones for oil-spill cleanup, sub-aquatic drones, book scanners, toys, houses, and agricultural and construction machinery could be found online. Although open source hardware was initially associated with electronic devices, it soon expanded to other areas and began including items as diverse as recipes for raw materials and chemical compounds, designs for reactive garments, biomedical devices, brain wave monitoring tools, and radiation monitors for civilian use, to mention only a few.

These three interrelated and overlapping communities—makers, hackerspaces and open source hardware—will be collectively referred to here as the contemporary DIY hardware communities that advocate for and practice the distributed approach to the development of technological artifacts. Although the identities of DIY hardware communities are multifaceted and diverse, the historical origins of their ethos can be broadly traced to what Steven Levy (2010) identified as the "hacker ethic:" a set of six principles which state that users' access to technologies should be unlimited and total. In the hacker ethic, access is not limited to the ability to use—in the sense that individuals currently use computational devices. Rather, it refers to the freedom to study, modify, and improve technologies. The exercise of this freedom requires access to technological artifacts' mechanisms and information about their design, as well as distributed, open access development systems that allow everyone to participate in the creation and recreation of technologies.

Thus, contrary to the broadcast approach, DIY hardware communities maintain that users should be allowed and enabled to participate in the shaping of technological artifacts. This is based on the beliefs that important lessons about the world can be learned from studying, repurposing, repairing, and assembling technological devices; that the public and collective creation of technological artifacts leads to faster development processes and better technologies; that amateurs, not just experts, can make significant contributions to the resolution of problems; that access to tools of production can provide individuals with economic autonomy; that users should be able to adapt technologies to their own specific purposes and needs, rather than settling for mass produced, one-size-fits-all goods; and that individuals should have access to devices that allow them to independently collect information and address problems, rather than relying exclusively on institutional assistance.

DIY hardware activities often assume an advocacy mantle—expressed in several educational and outreach programs—and its practitioners may at times be overtly critical of broadcast approach practices. However, rather than seeking change strictly through discourse, DIY hardware communities primarily challenge the broadcast model through a practical implementation of the distributed approach. This is achieved through a combination of do-it-yourself design and production of technologies with grassroots knowledge sharing and collaboration.

The RepRap 3D printer is one of the most striking examples of the ways in which DIY hardware practices defy the broadcast approach though the implementation of alternatives. In 2005, at a time when digital fabrication tools available in the market were still priced beyond the reach of most individuals, Adrian Bowyer, an engineering professor at the University of Bath in the U.K., launched the RepRap project: a research effort dedicated to creating a self-replicating, highly affordable, personal 3D printer. The stated goal of the project was to "put manufacturing power into the hands of the people by delivering a manufacturing technology which can self-replicate" (Sells 2009). For this reason, Bowyer released the RepRap designs under a distribution license that allows anyone to view, modify, produce and redistribute the machines.

With the RepRap plans publicly available, an initially small number of hobbyists around the world began building self-replicating machines and using them to produce parts to make more machines. By 2013, personal 3D printing had become a popular phenomenon in the U.S. and Europe. After the launch of RepRap, as interest in low-cost fabrication technologies continued to expand both within and beyond DIY hardware communities, open source 3D printers were soon joined by open source CNC mills and laser cutters.

Fabrication tools were further complemented by other projects meant to provide individuals with the ability to create their own technological artifacts. Of these, one of the most widely used is Arduino—a small open source microcontroller designed to facilitate the creation of electronic devices by amateurs.

None of these technologies is new—3D printers, laser cutters, CNC mills and microcontrollers were invented long before the advent of contemporary DIY hardware communities. The significance of these open source projects does not lie, therefore, in the introduction of new technologies. It hinges, rather, on the role they played in widening access to technologies that were beyond the reach of average citizens—be it for their cost, complexity or unavailability.

This emphasis on disseminating production capabilities—which are typically controlled by firms—demonstrates how, in DIY hardware practices, technologies and the distributed approach feed back into each other. Open source plans for DIY tools allow the technologies to be collaboratively developed and more widely distributed. In turn, the devices built from these open source plans provide users with prototyping and production capabilities—and thus enable the distributed creation of more technological artifacts. In these brief examples it can be glimpsed how DIY hardware communities use the distributed approach to develop the very technologies that enable the distributed approach.

The practices of DIY hardware communities elicit provocative questions about the shaping of technologies in democratic societies: if different technological configurations can either stimulate participation or apathy, enable freedom or control, support autonomy or dependence, are not these choices of great importance to all citizens? If technologies are now inextricably linked to individual and social life, shouldn't technological artifacts be collectively shaped rather than defined solely by the dynamics of markets?

DIY hardware communities thus challenge the broadcast approach's understanding of the functioning of the market as a "democratic" process by enacting an alternative, participatory model in which citizens are empowered to directly shape technologies. In this context, the significance of the distributed approach to the development of technological artifacts—as enacted by the maker, hackerspaces and open source hardware communities—is that it offers a practical and grassroots model for the transformation of the technosphere into a public sphere.

Thesis Statement

Through a comparative analysis of the ethoi, practices and implications of the broadcast and distributed approaches, it is argued here that the distributed approach, when applied to the development of technological artifacts, offers a practical path towards a participatory democratization of the technosphere by: 1) demystifying technologies, 2) providing the public with the tools and knowledge necessary to understand and shape technologies on both an individual and a collective level, and 3) encouraging citizen participation in the development of technologies.

Terms

Technologies: In the specific context of this dissertation, the terms "technology" (singular) and "technologies" (plural) refer to discrete types of electromechanical artifacts—such as automobiles or computers. Constellations of several interconnected technical artifacts and components—such as an electric grid—will be designated as technological systems. It may be argued that this narrow understanding of technologies as hardware and software eschews fundamental social aspects by focusing on their technical aspects—thus implying that technologies are essentially neutral tools dependent only on what uses are made of them (Katz, Light and Thompson 2003). However, as it will be elaborated in the following chapters, it is maintained here that every technological artifact or system is a configuration of technical elements arranged according to the ethos of the context in which it is developed and used—that is, the logic presiding over these arrangements is not purely technical, but the result of human choices. In this sense, technological artifacts and systems are viewed here as embodied configurations of technical and human elements.

Technosphere: As they are understood in this context, technologies cannot be fully grasped in isolation from their social contexts of production and use. Around each type of technological artifact there is typically a system—television sets, for example, cannot be explained without the broadcast system, the television industry, and the organizations and practices that emerged around them. The word "technosphere" is thus used here to designate the aggregate of these various elements that surround, define and interact with technological artifacts. This term seeks specifically to encapsulate the arena in which artifacts, organizations, individuals, ethics and practices interface to form a broader socio-technical ecosystem.

Democratization of the Technosphere: This phrase seeks to describe the processes through which participation in the technosphere is expanded from specific groups to the wider population. Participation, as it is understood here, does not refer simply to individuals' ability to acquire and use technological artifacts; it includes and emphasizes mostly their ability to understand, create, and transform them. Thus, a democratization of the technosphere, in this context, necessarily requires the direct participation of citizens in the shaping of technologies.

The Shape of Technologies: The word "shape" is used throughout this dissertation to denote the particular configuration of each technology (the ways in which its technical components are combined and organized to produce a whole), which greatly influence its affordances and uses.

A Practical Path Towards a Democratization of Technology: The word "practical" is adopted here to emphasize the effective implementability of the distributed approach model enacted by DIY hardware communities. This emphasis seeks to distinguish this model from theoretical proposals for a democratization of the technosphere. By "path towards" it is meant here that the approach implemented by DIY hardware communities consists, not in a democratization of the technosphere per se, but in a potential model towards it.

Contributions

In recent years, a number of significant works has analyzed the application of (what is designated here as) the distributed approach to the creation and dissemination of cultural goods, information, and software[4]. However, no comprehensive academic studies were found that address specifically the application of the distributed model to the development and dissemination of material technological artifacts. This is perhaps due to the fact that participatory phenomena, although now highly visible in the realm of digital media, are still relatively recent in the corresponding material arena.

Similarly, despite some attention paid by scholars[5] to technological artifacts and the ways in which these affect social and individual practices, no systematic analysis has yet been undertaken to uncover the relationship between the particular affordances of technologies and the characteristics of the broader contexts in which they are developed. This can be attributed to the fact that technology studies are often split into two disparate scientific areas: engineering fields, which frequently focus on the technical characteristics of technologies, but not on their social aspects; and humanistic and social studies, which tendentially approach technologies as black boxes, focusing instead on their social impacts.

This dissertation thus seeks to address this gap and contribute to this field of knowledge by:

1) Identifying two differentiated approaches (contexts)—here labeled "broadcast" and "distributed"—to the development of technologies and systematizing their ethoi, historical evolution, and practices. These two categories provide a frame of reference and an analytical tool meant to facilitate the identification of broader trends and traits at play in the contemporary technosphere.

2) Establishing a connection between each of these approaches and the characteristics of the technologies they generate. This is achieved through a comparative analysis of the relationships between the ethos of each model and the broader technical traits of their technologies.

3) Presenting an original account of the origins, practices and characteristics of the European and North American DIY hardware communities that currently apply the distributed approach to the development of technological artifacts.

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[4] Notable authors in this area include Yochai Benkler, Neil Gershenfeld, Nicholas Negroponte, Clay Shirky, Steven Weber, Lawrence Lessig, Don Tapscott and Anthony Williams, Howard Rheingold, and Steven Johnson.

[5] Such as Trevor Pinch and Wiebe Bijker, Langdon Winner, David Noble, Andrew Feenberg, Tim Jordan and Paul Taylor.

4) Demonstrating how the practices of these communities offer a practical path towards a democratization of the technosphere.

5) Discussing the broader importance and implications of a more participatory approach to the shaping of technologies.

Scope and Methodology

Scope

Most of the specific phenomena described in this dissertation originated in Europe and the U.S.: *Make* magazine was launched by a North American publishing firm, the first hackerspaces emerged in Germany, RepRap was created in the U.K., and Arduino was initially designed in Italy. Since then, hackerspaces have emerged around the world; Maker Faires (large gatherings of the maker community) have taken place in Nigeria, Australia, and China; and open source hardware has been used and developed around the world.

This does not necessarily mean, however, that DIY hardware communities extended from the U.S. and Europe to other regions of the world. Rather, it indicates that these identities have also been progressively adopted, adapted and appropriated by other groups who—although they did not call themselves makers, hackerspace members or open source hardware developers—already shared and, in some cases, practiced the same fundamental values. Thus, far from being West-centric, DIY hardware culture should be understood as the grassroots convergence and unifying process of several pre-existing, diverse and disperse DIY traditions across the globe.

The intercontinental spread of DIY hardware communities—and the fact that the same ethos resonated with individuals across cultures and national borders—speaks to the significance of these phenomena. However, this very breadth and fluidity also poses major challenges to any systematic study of DIY hardware communities, as each local instance typically blends transregional identities with region-specific cultural idiosyncrasies. Therefore, although they share major traits, no two local maker, hackerspace and open source hardware groups are exactly alike.

Further complexity is added by the fact that, since these communities challenge established production systems, their practices and ethos have important implications for areas as broad and diverse as economics, law, culture, politics, and education. Thus, given the breadth of this object of study—both in terms of geographical locations and areas of activity—one of the greatest challenges encountered in this research process was to circumscribe its focus enough to allow for an in-depth study.

For practical reasons, therefore, the scope of work of this dissertation was limited to European and North American DIY hardware communities and to the analysis of the ways in which their practices enable a more participatory approach to the shaping of technologies. Other local implementations and aspects—such as economic and legal—will be mentioned, to the extent that they are relevant to this specific discussion, but not analyzed in depth.

This research seeks specifically to uncover whether a democratization of the technosphere is possible and the ways in which the practices of DIY hardware communities create this possibility. Such a focus on a *path towards the democratization of the technospher*e served as the filter to determine which aspects to include in the present work and which will be the object of future analysis. For this reason, the emphasis here is on motivational and enabling aspects—more specifically on why DIY hardware communities seek to enable citizen participation in the shaping of technologies and which design and dissemination practices make this practically feasible. To achieve this goal, the present work includes: 1) analytical descriptions of the maker, hackerspaces and open source hardware communities, as well as of their cultural origins and histories; 2) a study of their ethos and motivations; 3) an analysis of their technological design and dissemination practices; 4) and an examination of how their practices enable citizen participation in the shaping of technologies. Such delimitation of the scope of work required the exclusion of several other parallel and related phenomena—such as collaborative consumption, crowdsourcing, and enterprise networks, to name a few—which would benefit from future work.

Perhaps the greatest challenge faced throughout this process was the difficulty inherent in capturing and examining rapidly evolving phenomena. In 2008, when this project was initiated, DIY hardware communities were still relatively obscure, personal 3D printers were very limited in both their numbers and capabilities, and the first of the third wave hackerspaces were only one year old. By the time this dissertation was completed—in mid-2014—DIY hardware communities were frequently mentioned by media outlets, personal digital fabrication tools had become part of the public imaginary, and hackerspaces had spread across the globe. This text offers a look into a formative period in which new practices were emerging and beginning to expand, but had not yet crystallized.

Thus, to some extent, the present study ends in the beginning; it seeks to demonstrate that a democratization of the technosphere is possible and is in the early stages of implementation, but does not yet delve into an analysis of its (potential) functioning. A more in-depth survey of a democratized technosphere offers a relevant object of future work and may include topics such as: quality control and legal liability of distributed technologies, demographic makeup of the technosphere, distributed innovation processes, distributive organizational structures, and the ways in which the distributed and broadcast approaches may coexist and interact[6].

Approach and Sources

It is also important to specify the realm in which this dissertation seeks to position itself. Although drawing from various theoretical works, the focus here is on presenting and discussing the specific characteristics and implications of the distributed approach, as enacted by DIY hardware communities, as well as the ways in which their practices offer a *practical* path towards a democratization of the technosphere. Thus, rather than attempting to make a contribution to a theoretical body of work, this text is centered specifically on non-abstract phenomena situated in particular historical contexts.

Even with the topic thus circumscribed, it was still necessary to draw from a variety of disciplines and methodological approaches to study these phenomena. Accounts and research methods from the field of history were necessary to uncover and explain the cultural roots of the broadcast approach, the distributed approach, and DIY hardware communities—without which it would not have been possible to truly understand their present traits. A variety of social sciences theories, schools of thought and fields—ranging from communication and media studies to sociology and political science—were needed to explain

[6] Some of these topics are described in some detail in the future work section of the conclusion chapter.

the social and cultural aspects of these phenomena. An understanding of technological design and engineering was required to analyze the technological artifacts created by DIY hardware communities. And theories from the field of psychology were required to reveal and explain the motivations and behaviors of DIY hardware practitioners.

Thus, drawing from a range of disciplines and approaches, data for this research was collected through: literature review, ethnographic methods, first person accounts, and the analysis of documents and technological artifacts.

A variety of texts and theories was analyzed to shed light into the historical and theoretical backgrounds of distributed approach practices. Given the fundamental role played by technologies in contemporary societies, a vast number of texts has been written on the topic throughout the last two centuries. Not wishing to provide a comprehensive overview of the relationship between technologies and society—and focusing instead on shedding light on specific aspects of the distributed approach as applied by DIY hardware communities—only a comparatively limited number of works is referenced here. These were selected for their direct relevance to the topic and a deliberate effort was made not to expand beyond it in order to avoid a loss of focus. These texts originate from a variety of disciplines: sociology, communications and media, economics, history, psychology, political science, design, and engineering. For the most part, these theories, which were proposed by their authors in the context of different fields, were used here as *instruments* to study the specific topic at hand. For example: concepts originating from media theories were transposed to material production; psychology theories were used to analyze specific beliefs, behaviors and practices; and design theories were used to shed light into the configuration and implications of technological artifacts.

Although the application of the distributed approach to the realms of information and culture has been substantially studied in the last decade, no comprehensive academic works have focused on the application of this model to the development of material artifacts. For this reason, in order to both describe and analyze these phenomena, it was necessary to first collect data on the origins, practices and ethos of DIY hardware communities. Given the lack of previous work on this specific topic, an ethnographic approach was adopted. Through direct participation in maker, hackerspaces, and open source hardware activities it was possible to witness, experience, record and explain the practices and culture of these communities.

To further complement this ethnographic approach, first person accounts were collected via interviews and personal communication with key intervenients in these communities. These intervenients were selected for their ability to shed light into specific unanswered questions and included: Dale Dougherty, Nathan Seidle, Phil Torrone, Marcin Jakubowski, Adrian Bowyer, Tom Igoe, Dan O'Sullivan, Dustyn Roberts, Emeka Okafor, Windell Oskay, Max Whitney, Matt Joyce, Trammell Hudson, Nick Vermeer, and William Byrd. Two surveys were also conducted in 2012 and 2013 (Mota, Mellis and Cristofaro 2012; Mota and Mellis 2013), in collaboration with the Open Source Hardware Association, in order to obtain statistical data on the open source hardware community. Additional statistical data was used from three other surveys conducted by the Karlin Associates firm (2012) and by researchers Jarkko Moilanen (2012a), and Martin Charter and Scott Keiller (2014).

Finally, the information collected was complemented with the analysis of several documents—such as mailing list correspondence, manifestos, media articles, blog posts, and images—and of a selection of technological artifacts. These technological artifacts were first categorized in order to identify trends, and their technical characteristics then studied, in light of several theories, with the goal of understanding: 1) how distributed approach artifacts differ from their broadcast counterparts, 2) how objects embody biases, and 3) how, in turn, particular arrangements of technical elements constrain or expand the possibilities they offer to users.

Perspectives

In an essay titled "The Cathedral and The Bazaar," Eric S. Raymond (2005) identifies two models for the development of software. In the one adopted by most firms, software is built like cathedrals, "carefully crafted by individual wizards or small bands of mages working in splendid isolation, with no beta to be released before its time" (Ibid.). The other resembles "a great babbling bazaar of differing agendas and approaches" in which software is concurrently and collaboratively developed by a multitude of organizations and individuals (Ibid.). This is also an apt analogy to describe the two approaches to the development of technological artifacts that concern this dissertation. On the first, technologies are shaped by a relatively small number of professional producers—primarily within firms, but also in academic institutions or governmental agencies—and then disseminated to the masses for consumption. On the second, technologies are collectively shaped by both professionals and amateurs in a system open to public participation.

Raymond's analogy also describes the approach adopted here to describe and analyze these two models of development, production and dissemination of technologies. The broadcast model—whose constitutive elements are (often large) organizations, rather than individuals—is approached as a cathedral and analyzed from the distanced perspective its ethos and practices entail; that is, it is outlined mostly through the broad trends and widespread practices of broadcast approach organizations. The result is a panoramic view of the ensemble of "cathedrals" that make up the broadcast model.

The distributed model, on the other hand, is addressed on a human scale—as "a great babbling bazaar of differing agendas and approaches." The focus here is on the myriad of perspectives that makeup the "bazaar," and the overall panorama they jointly form is conveyed through individual voices, stories, and case studies. This is not, however, a first person account. Although an active member of the maker, hackerspaces and open source hardware communities, I chose to discuss the distributed approach practiced by these communities through the testimonials of others—as a means to convey the multitude of voices and initiatives that characterize the bazaar-style of DIY hardware communities.

Structure

The first chapter, "Literature Review," seeks to contextualize the topic of this dissertation within relevant theories concerning the relationship between technologies and society. However, given that this broad topic has received extensive attention from scholars and other analysts, and given the vast number of volumes dedicated to it in the last two centuries, it is not attempted here to provide a comprehensive overview of all such theories. Rather, a small number of authors and positions were selected for the relevance of their theories and findings for this thesis.

The Literature Review chapter is subdivided into four sections, each of which addresses a particular sub-topic. Part one seeks to briefly describe the processes through which technologies became first associated with progress, during the eighteenth century Enlightenment, and then with the subsequent expansive processes of rationalization. The second part focuses specifically on some of the writings of the Frankfurt School and aims to succinctly illuminate key problematics of the relationship between rationality and ideology in the techno-social realm. The third section, through an overview of several studies and positions, presents the theory, adopted here, that technologies are socially shaped. Finally, the fourth section focuses on an analysis of the socio-political dynamics of technological artifacts, as previously studied by several authors. Together, parts three and four of this chapter set the conceptual framework for this thesis: an understanding of technological artifacts as assemblages of technical and social elements whose specific shapes largely depend on the ethos of the contexts in which they are developed.

In the second chapter, "Two Approaches," two alternative—and at times conflicting—approaches to the development of technologies are presented. The first half of this chapter describes the characteristics of the broadcast approach, identifies three of its foundational tenets and traces their origins to a series of historically contextualized transformations that led to the increasing centralization of the design of technologies. This section wraps up with an analysis of the broader implications of the broadcast approach's design practices for the relationship between individuals and technologies. The second part focuses on the distributed approach, which is here delineated through the histories of four types of technologies: radio, the personal computer, open source software, and the Internet. The brief recounting of the origins and evolution of these technologies seeks to illuminate the characteristics of both the broadcast and distributed approaches, the ways in which they have, in the past, clashed, and the role each played in shaping some of the most important technologies of our time.

Having situated the topic of this dissertation in both a theoretical and historical framework, chapter three—titled "The Rise of DIY Hardware"—provides an analytical portrayal of the makers, hackerspaces and open source hardware communities. Opening with an overview of a number of recent technologies and services that are making the design and fabrication of physical goods accessible to individuals, this chapter subsequently traces the origins, evolution and principal traits of these communities. The fifth section then brings them together under the label “DIY hardware communities” and seeks to provide a more in-depth analysis of their ethos and practices. This is achieved through the application of Self-Determination Theory, as an instrument of analysis, to several DIY hardware projects and initiatives with the goal of uncovering deeper motivations, values, undercurrents, attitudes, and perspectives. The overall objective of this chapter is to bring to the forefront the cultural aspects of these communities that underlie and sustain their distributed approach to the development of technological artifacts.

The first section of chapter four, “Shaping Technologies,” looks specifically at the characteristics of DIY hardware technologies and explains them in light of the ethos of these communities. It is argued here that DIY hardware artifacts are typically configured in specific forms to enable the distributed shaping of technologies—that is, they are often designed to facilitate the understanding, recreation and transformation of artifacts. The second half of this chapter then brings together all the elements and theories presented on previous chapters to arrive at the thesis defended here. This is achieved through a summary of the ways in which the distributed approach practiced by DIY hardware communities provides a practical path towards a participatory democratization of the technosphere by: 1) demystifying technologies, 2) providing the public with the tools and knowledge necessary to understand and shape technologies on both an individual and a collective level, and 3) encouraging citizen participation in the development of technologies.

Lastly, the “Conclusion” chapter delineates some of the most important implications of a democratization of the technosphere, as enacted by DIY hardware communities, and offers an examination of the limitations, challenges and opportunities presented by this approach. The chapter then wraps up with a brief description of a series of related topics, which were not explored in this dissertation, that offer additional and relevant avenues for further research.

I. LITERATURE REVIEW

In light of the increasing centrality of technologies in human affairs—and more specifically in the wake of the profound social transformations emerging from the introduction of industrial technologies in the nineteenth and early twentieth century—the understanding of the character of technologies, and the ways in which they both result from and influence society, has been the topic of an extensive number of works. A central theme in these writings is the relationship between technologies and human liberty. From the eighteenth century Enlightenment to the present day, artists and thinkers have grappled with profound questions concerning this relationship: Do modern technologies free or enslave humankind? Are technologies purely rational, and therefore asocial and autonomous, or are they historically conditioned? If technologies can be understood as social constructs, how do modern technologies assume their shape and who participates in these definitional processes? How do specific technological artifacts embody the social dynamics of the contexts in which they emerge and what consequences does this have? Can the Enlightenment's promise of technologies in the service of human betterment and an equitable society ever be realized?

Although a comprehensive analysis of these important questions, and of all the theories that have been proposed around them, is beyond the scope of this dissertation, the following chapter presents of a brief overview of the most relevant theories for the topic in discussion here: the understanding of the particular shapes of technologies as the product of human choices and the opportunities this offers for a transformation of the technosphere.

I.2 Technologies and Progress

This technocratic idea may be seen as an ultimate, culminating expression of the optimistic, universalist aspirations of Enlightenment rationalism. But it tacitly replaced political aspirations with technical innovation as a primary agent of change, thereby preparing the way for an increasingly pessimistic sense of the technological determination of history.

—Leo Marx (1994, 251)

Throughout the nineteenth and early twentieth centuries, the introduction of profoundly transformative technological innovations led to an understanding of machines as engines of progress (Neufeldt 1977; Postman 2011). This idea can be traced to the celebrations of the mechanical arts by leaders of the eighteenth century Enlightenment—such as Denis Diderot (Diderot and d' Alembert 1751), Benjamin Franklin and Thomas Jefferson (M. R. Smith 1985)—who viewed the epoch's mechanical inventions as instruments with which a more equitable society could be built[7] (Smith and Marx 1994; Pannabecker 1994, 1996). However, despite its initial association with ideals of liberty and social change, such faith in technologies as enablers of progress soon proved particularly useful in the search for political and economic order.

As industrial capitalism began to play an increasingly central role in Western economies during the early nineteenth century, the focus shifted from the idea of technologies in the service of human betterment towards the more practical notion of technologies as engines of economic development (Postman 2011). At this time, historian Merritt Roe Smith (1994) argues, politicians and journalists began projecting technologies not just as examples of progress, but as the very generators of progress. This generalized fascination with the new

[7] An idea pioneered by Francis Bacon, who not only asserted the connection between science, the mechanical arts and the improvement of the human condition, but also advocated for institutions to promote technical and scientific development, as well as the transfer of such information to the public (see, for example, Postman 2011).

technologies of the time and with the rapid transformations they brought about, Smith contends, was further reinforced by the then emerging field of professional advertising—which greatly contributed to establishing the idea that technologies engender not only personal benefits but also social advancements. Thus, as Leonard Neufeldt notes:

> *The prevailing tendency was . . . to identify the new characteristics of the age with progress. Even the low hanging smoke of the industrial valleys, slum cities and worker unrest, and the increased savagery of war as a result of the invention of modern fire-power, did little to check an unexamined and smug utopianism.* (Neufeldt 1977, 1).

During this period, the character and representation of technologies also underwent important changes. In the early phase of industrialization, Leo Marx (1994) argues, individual mechanical inventions—from the cotton gin and the steam engine to the telegraph and the locomotive—were portrayed in popular discourse as the symbols of the new age of progress. However, as mechanical, chemical and electric machinery gave rise to railroads, power grids and mass manufacturing, large technological systems progressively replaced discrete artifacts as the symbols of the new technological power (Ibid.). At the same time, the sheer scale and complexity of these systems, Alfred Chandler (1977) argues, required the development of equally complex, centralized, hierarchical and bureaucratic organizations—which eventually replaced the, until then, more common model of the family-owned and operated small firm.

While artifacts were being replaced in the popular imaginary with the large technological systems of industrial society, Marx explains, the more specific terms "mechanical arts" and "machines," which had until then been used to denote the new artifacts of the age, were also replaced by the modern notion of technology (Marx 1994, 246). For Marx, this more abstract concept—which "had a kind of refining, idealizing, or purifying effect" (Ibid., 248)—further enhanced a belief in technological systems as autonomous engines of progress:

> *Perhaps the crucial difference is that the concept of "technology" with its wider scope of reference, is less closely identified with—or defined by—its material or artifactual aspect than was "the mechanical arts." This fact comports with the*

material reality of the large and complex new technological systems, in which the boundary between the intricately interlinked artifactual and other components—conceptual, institutional, human—is blurred and often invisible. . . . By virtue of its abstractness and inclusiveness, and its capacity to evoke the inextricable interpenetration of (for example) the powers of the computer with the bureaucratic practices of large modern institutions, 'technology' (with no specifying adjective) invited endless reification. The concept refers to no specifiable institution, nor does it evoke any distinct associations of place or of persons belonging to any particular nation, ethnic group, race, class, or gender. A common tendency of contemporary discourse, accordingly, is to invest "technology" with a host of metaphysical properties and potencies, thereby making it seem to be a determinate entity, a disembodied autonomous causal agent of social change—of history. (Ibid., 249)

In parallel with the emergence of several large scale technological systems and of the concept of technology, the ideology of progress underwent a related change. Exponents of the Enlightenment, Marx argues (Ibid.), had understood science and technological artifacts as essential but not sufficient means for political liberation. For them, "the chief value of those [mechanical] arts was in providing the material means of accomplishing what really mattered: the building of a just, republican society" (Ibid., 251). However, the combined advent of the concept of technology and of large industrial systems, Marx suggests, contributed to a subtle but profound revision of the ideology of progress, one in which technology would assume a much more central role:

. . . the growing scope and integration of the new systems made it increasingly difficult to distinguish between the material (artifactual or technical) and the other organizational (managerial or financial) components of "technology." At this time, accordingly, the simple republican formula for generating progress by directing improved technical means to societal ends was imperceptible transformed into a quite different technocratic commitment to improving "technology" as the basis and the measure of—as all but constituting—the progress of society. (Ibid.)

As the Enlightenment's notion of technological progress aimed at a more just society was replaced by a "politically neutral, technocratic idea of progress whose goal was the continuing improvement of technology" (Ibid., 241), instrumental rationality increasingly expanded beyond the confines of machinery. Perhaps the most visible epitomes of this process were the Taylorism and Fordist systems, in which the principles governing the functioning of machines were transposed to the workers who made up the larger industrial "machine." While Henry Ford introduced important changes in the organization of factories and mass production through the assembly line, which paced the rhythm of work according to the logic of the machine, Taylor took this approach to new heights. According to his *Principles of Scientific Management* (Taylor 1911), the system of production, made up of workers and machines, would be converted into a single, well-oil mechanism in which both humans and the technical apparatus were but equivalent parts of a system. "In the past, the man had been first," Taylor wrote, "in the future the system must be first" (Ibid., 7). Thus, as noted by historian Thomas Hughes, while "Ford's image was of a factory functioning as machine, . . . Taylor imagined a machine in which the mechanical and human parts were virtually indistinguishable" (Hughes 1989, 187).

Technologies Out of Control

Although the technocratic idea of progress was accepted with widespread enthusiasm and rapidly assumed a central place in Western culture, it was also, early on, received with skepticism and criticism by some. As early as 1829, for instance, Thomas Carlyle, while acknowledging the material improvements brought about by the new industries, denounced the expansion of the "mechanical age" into all realms of mental and social life:

> *It is the age of the Age of Machinery, in every outward and inward sense of that word; the age which, with its whole undivided might, forwards, teaches and practices the great art of adapting means to ends. . . .*
>
> *What wonderful accessions have thus been made, are still making, to the physical power of mankind; how much better fed, clothed, lodged and, in outward respects, accommodated men now are, or might be, by a given quantity of labour, is a grateful reflection which forces itself on every one. What changes, too, this addition*

of power is introducing into the Social System; how wealth has more and more increased, and at the same time gathered itself more and more into masses, strangely altering the old relations, and increasing distance between the rich and the poor . . .

But leaving these matters for the present, let us observe how the mechanical genius of our time has diffused itself into quite other provinces. Not the external and physical alone is now managed by machinery, but the internal and spiritual also. Here too nothing follows its spontaneous course, nothing is left to be accomplished by old natural methods, Everything has its cunningly devised implements, its preestablished apparatus; it is not done by hand, but by machinery. . . .

These things, which we state lightly enough, are yet of deep import, and indicate a mighty change in our whole manner of existence. For the same habit regulates not our modes of action alone, but our modes of thought and feeling. Men are grown mechanical in head and in heart, as well as in hand. They have lost faith in individual endeavor, and in natural force, or any kind. Nor for internal perfection, but for external combinations and arrangements, for institutions, constitutions,—for Mechanism of one sort or other, do they hope and struggle. Their whole efforts, attachments, opinions, turn on mechanisms, and are of mechanical character. (Carlyle 2013)

Carlyle was not alone in his perception that the means had become the ends. Although an inventor himself, Henry David Thoreau lamented in *Walden* that "Men have become tools of their tools:"

Our inventions are wont to be pretty toys, which distract our attention from serious things. They are but improved means to an unimproved end, an end which it was already but too easy to arrive at; as railroads lead to Boston or New York. We are in great haste to construct a magnetic telegraph from Maine to Texas; but Maine and Texas, it may be, have nothing important to communicate. (Thoreau 2008, 34)

Even Ralph Waldo Emerson, whose work had celebrated the possibilities opened by science and technologies for the improvement of individuals and culture (Neufeldt 1977), eventually questioned whether the mechanical arts had not replaced the moral achievements they were meant to support:

> *What have these [mechanical] arts done for the character, for the worth of mankind? Are men better? 'Tis sometimes questioned whether morals have not declined as the arts have ascended. Here are great arts and little men. Here is greatness begotten of paltriness. . . . 'Tis too plain that with the material power the moral progress has not kept pace. It appears that we have not made a judicious investment. Works and days were offered us, and we took works.* (Emerson 1902)

Thus, as instrumental rationality escaped the confines of machines and expanded to all areas of human experience, the initially hopeful view rapidly gave way to bleak, pessimistic assessments of a besieged technocratic society in which the means had replaced the ends. This sentiment, echoed in the writings of numerous other European and American artists (Marx 2000) (Neufeldt 1977), was just as manifest in the works of humanistic scholars. Amongst these discordant voices were notably those of Lewis Mumford and Jacques Ellul.

Lewis Mumford

In *Technics and Civilization*, Lewis Mumford contends that what is typically designated as the industrial revolution—the series of technical and organizational transformations that began in the eighteenth century—was in fact a process that occurred over a much longer period of time. Underlying the material transformation of this period, he argues, was not simply the development of technologies, but also a transformation of minds: "Before the new industrial processes could take hold on a great scale, a reorientation of wishes, habits, ideas, goals was necessary" (Mumford 1934, 3). For Mumford, modern technologies cannot be understood if viewed as mere technical applications of scientific discoveries. Rather, he argues, the specific shape of industrial technologies was determined early on by the social context in which they emerged and developed:

> *Technics and civilization as a whole are the result of human choices and aptitudes and strivings, deliberate as well as unconscious, often irrational when apparently they are most objective and scientific; but even when they are uncontrollable they are not external. . . . No matter how much technics relies upon the objective procedures of the sciences, it does not form an independent system, like the universe; it exists as an element in human culture and it promises well or ill as the social groups that exploit it promise well or ill. The machine itself makes no demands and holds out no promises: it is the human spirit that makes demands and keeps promises.* (Ibid., 6)

Thus, in order to explain the central role played by technologies in modern society, it is necessary to first understand "the culture that was ready to use them and profit by them so extensively" (Ibid., 4). This culture, Mumford argues, was that of capitalism. Whereas the investments required by artisanal production were minimal, the large and complex technological systems of modern industry placed much greater demands on capital. For this reason, the ability to operate factories was limited to those who could support the large financial investments they required. The push towards industrialization was, therefore, driven by the lure of the profits that could be extracted from the mechanization of production.

From the beginning, capitalism and "technics" conditioned and amplified each other. In this relationship, technological development was alternatively encouraged by commerce—as new machines promised greater profits—and hindered by it—as further technical advancements were at times curbed to protect monopolies. In these disparities and conflicts between technological development and commerce, Mumford argues, trade tended to prevail as the "older partner" with "higher authority:"

> *It was trade that gathered new materials from the Indies and from the Americas, new foods, new cereals, tobacco, furs: it was trade that found a new market for the trash that was turned out by eighteenth century mass-production: it was trade—abetted by war—that developed large-scale enterprises and the administrative capacity and method that made it possible to create the industrial system as a whole and weld together its various parts.* (Ibid., 26)

This alliance meant that, from very early on, industrial technologies assumed characteristics that were not inherent in the technical processes themselves nor in other forms of work. Technologies were utilized by capitalism, Mumford argues, not to improve the conditions of human living, but to augment private profit and serve the ruling classes, regardless of broader consequences:

> *It was because of the possibilities of profit that the place of the machine was overemphasized and the degree of regimentation pushed beyond what was necessary to harmony and efficiency. It was because of certain traits in private capitalism that the machine—which was a neutral agent—has often seemed, and in fact had sometimes been, a malicious element in society, careless of human life, indifferent to human interests.* (Ibid., 27)

Through its support of technological development, Mumford contends, capitalism was able to accelerate its own pace and contributed to making technical innovation a primary goal to strive for. For him, this resulted in an over-accelerated pace of technological development, which robbed society from the time it needed to assimilate these changes and integrate them into a proper pattern. As capitalism itself continued to expand, Mumford asserts, “these vices have in fact grown more enormous, and the dangers to society as whole have likewise grown proportionately” (Ibid.).

Although clearly concerned with the threats posed by the capitalism-shaped technologies to the social and spiritual aspects of human life, Mumford nevertheless ends *Technics and Civilization* with the hope that “a re-orientation of all forms of thought and social activity toward life” would provide a means to “transform the nature and function of our mechanical environment and to lay wider and firmer and safer foundations for human society at large” (Ibid., 234). By the early 1950s, however, Mumford’s stance had shifted to a harsh denouncement of what he termed an “overmechanized culture:”

> *In terms of the currently accepted picture of the relation of man to technics, our age is passing from the primeval state of man, marked by his invention of tools and weapons for the purpose of achieving mastery over the forces of nature, to a*

radically different condition, in which he will have not only conquered nature, but detached himself as far as possible from the organic habitat.

With this new "megatechnics" the dominant minority will create a uniform, all-enveloping, super-planetary structure, designed for automatic operation. Instead of functioning actively as an autonomous personality, man will become a passive, purposeless, machine-conditioned animal whose proper functions, as technicians now interpret man's role, will either be fed into the machine or strictly limited and controlled for the benefit of de-personalized, collective organizations. (Mumford 1967, 3)

In Mumford's definition, these "Megatechnics" are an integral part of the wider "megamachine:" an all-encompassing, albeit invisible, entity that comprises not just technical equipment, but also the political, economic, and military organizations that control it. The megamachine, Mumford concludes, has become so powerful and pervasive that individuals may only free themselves through withdrawal:

Each one of us, as long as life stirs in him, may play a part in extricating himself from the power system by asserting his primacy as a person in quiet acts of mental or physical withdrawal—in gestures of non-conformity, in abstentions, restrictions, inhibitions, which will liberate him from the domination of the pentagon of power. (Mumford 1970, 430-433)

Jacques Ellul

The notion that technologies have escaped the control of their human masters is equally central in the writings of Jacques Ellul. For Ellul, "technique" has expanded to such extents that it is no longer possible to distinguish the human from the technical:

As long as technique was represented exclusively by the machine, it was possible to speak of 'man and machine'. The machine remained an external object, and man (though significantly influenced by it in his professional, private, and *psychic life) remained none the less independent. He was in a position to assert himself apart from the machine; he was able to adopt a position with respect to it.*

But when technique enters into every area of life, including the human, it ceases to be external to man and becomes his very substance. It is no longer face to face with man but is integrated with him, and it progressively absorbs him. . . . This transformation, so obvious in modern society, is the result of the fact that technique has become autonomous. (Ellul 1964, 6)

In Ellul's meaning, "technique" is both efficiency itself and the disseminator of efficiency; it is the process through which the entirety of human experience is clarified, arranged, rationalized. Technique, Ellul maintains, "evolves in a purely causal way: the combination of preceding elements furnishes the new technical elements" (Ibid.). It is incapable of distinguishing between moral and immoral uses, and, therefore, cannot be seen as a means to an end: "Technique worships nothing, respects nothing. It has a single role: to strip off externals, to bring everything to light, and by rational use to transform everything into means" (Ibid., 143). "Our civilization," he asserts, "is first and foremost a civilization of means; in the reality of modern life, the means, it would seem, are more important than the ends" (Ibid., 19). Thus, breaking free from the grip of the all-encompassing technique entails significant, perhaps insurmountable, obstacles. "As long as man worships Technique," Mumford concludes, "there is as good as no chance at all that he will ever succeed in mastering it" (Ellul 1997, 225).

This notion that technocratic thinking has escaped the control of humankind and infiltrated all aspects of experience, so central in the writings of Mumford and Ellul, echoes the process Max Weber conceptualized as rationalization: the expansion of rational decision processes, based on efficiency and calculability, into all realms of human existence. For Weber (2012), this process would eventually lead to an "iron cage" of efficient, rational control.

I.2 Rationality and Ideology

The prevailing forms of social control are technological in a new sense.

—Herbert Marcuse (1964, p.18)

In *Dialectic of Enlightenment*, critical theorists Theodor Adorno and Max Horkheimer argue that the "technical apparatus" of modern society serves simultaneously as an instrument of power wielded by those who control it—to keep individuals compliant through improved material conditions—and as a justification for such power:

> *On the one hand the growth of economic productivity furnishes the conditions for a world of greater justice; on the other hand it allows the technical apparatus and the social groups which administer it a disproportionate superiority to the rest of the population. The individual is wholly devalued in relation to economic powers, which at the same time press the control of society over the hitherto unsuspected heights. Even though the individual disappears before the apparatus which he serves, that apparatus provides for him as never before. In an unjust state of life, the impotence and pliability of the masses grow with the quantitative increase in commodities allowed them.* (Horkheimer and Adorno 1997, xiv)

The rise of mass production and mass media systems, Horkheimer and Adorno (Ibid.) note, is justified by "interested parties" as stemming from a technological system designed to provide quality of life: the material needs of populations require the production and distribution of standard products to meet identical needs across geographically disperse regions—which, in turn, requires that the technical apparatus and system of production be organized and planned by those who control it. The resulting standardization, it is claimed, stems directly from the needs of consumers.

In reality, Horkheimer and Adorno argue, this technical justification conceals "that the basis on which technology is gaining power over society is the power of those whose economic position in society is strongest." For these critics, "the objective social tendency of this age is incarnated in the obscure subjective intentions of board chairmen" of the technological industries. Thus, the adverse effects of industrial and mass media technologies "should not be attributed to the internal laws of technology itself but to its function within the economy today" (Ibid., 95).

For these authors, industrial technologies are thus wielded as instruments of domination that serve "the agreement, or at least the common determination, of the executive powers to produce or let pass nothing which does not conform to their tables, to their concept of the consumer, or, above all, to themselves" (Ibid., 96). This process requires a centralization of the production of both media and goods, according to which needs that do not fit central control must be repressed. The telephone and radio technologies epitomize this shift towards centralization: while the former allows participants to assume the role of subjects, the latter converts them into listeners and exposes them to similar programs broadcast by different stations (Ibid.). Thus, on the one hand, mass media technologies do not offer any mechanisms of reply, on the other hand, private transmissions are relegated to the realm of amateurism.

This domination, Adorno and Horkheimer argue, hinges on a unifying and standardizing process epitomized in the abundance of products, which, although cloaked under the appearance of great choice and diversity, effectively conform to the sweeping sameness of the mass society:

> *The schematic nature of this procedure is evident from the fact that the mechanically differentiated products are ultimately all the same. That the difference between the models of Chrysler and General Motors is fundamentally illusory is known by any child, who is fascinated by that very difference. The advantages and disadvantages debated by enthusiasts serve only to perpetuate the appearance of competition and choice. It is no different with the offerings of Warner Brothers and Metro Goldwyn Mayer. But the differences, even between the more expensive and cheaper products from the same firm, are shrinking—in cars to the different number of cylinders, engine capacity, and details of the gadgets, and in films to the different number of stars, the expense lavished on technology, labor and costumes, or the use of the latest psychological formulae. The unified standard of value consists in the*

> *level of conspicuous production, the amount of investment put on show. The budgeted differences of value in the culture industry have nothing to do with actual differences, with the meaning of the product itself.* (Ibid., 97)

Such minor but emphasized distinctions between products, Horkheimer and Adorno suggest, serve not only to create an illusion of abundance and choice but also to classify consumers:

> *Sharp distinctions like those between A and B films, or between short stories published in magazines in different price segments, do not so much reflect real differences as assist in the classification, organization, and identification of consumers. Something is provided for everyone so that no one can escape; differences are hammered home and propagated. The hierarchy of serial qualities purveyed to the public serves only to quantify it more completely. Everyone is supposed to behave spontaneously according to a 'level' determined by indices and to select the category of mass product manufactured for their type. On the charts of research organizations, indistinguishable from those of political propaganda, consumers are divided up as statistical material into red, green, and blue areas according to income group.* (Ibid.)

Thus, for Horkheimer and Adorno, "Technical rationality today is the rationality of domination" (Ibid., 95), in that it serves as a justification for the domination of those who control the technical apparatus. Adopting a similar position, Hebert Marcuse argues in *One Dimensional Man* that rationalization has led to a "comfortable, smooth, reasonable, democratic unfreedom" (Marcuse 1964, 13).

For Marcuse, the industrial system promised freedom both from want and labor. Automation, he argued, could simultaneously enable the satisfaction of more needs for more individuals and allow for the reduction of the labor necessary to provide it. Labor, Marcuse maintained, represented a realm of unfreedom which technologies promised to minimize:

> *"Progress" is not a neutral term; it moves toward specific ends, and these ends are defined by the possibilities of ameliorating the human condition. Advanced industrial society is approaching the stage where continued progress would demand the radical subversion of the prevailing direction and organization of progress. This stage would be reached when material production (including the necessary services) becomes automated to the extent that all vital needs can be satisfied while necessary labor time is reduced to marginal time. From this point on, technical progress would transcend the realm of necessity, where it served as the instrument of domination and exploitation which thereby limited its rationality; technology would become subject to the free play of faculties in the struggle for the pacification of nature and of society.* (Ibid., 22)

In Marcuse's view, freedom meant not only freedom from economic forces and the struggle for subsistence, but also a liberation of individuals from political forces which they do not control and "the restoration of individual thought now absorbed by mass communication and indoctrination" (Ibid.,15). Although labor necessarily preceded the reduction of labor and industrialization preceded the satisfaction of needs, it was expected that, once mature enough, technologies would eventually provide freedom from both. However, just as scientific and technological advancements were reaching the point of delivering on this promise, the mature industrial society kept individuals tightly bound within its structure and refused to be transcended. That is, rather than allowing technologies to free individuals from labor, the industrial society turned to containment of technical progress as a means to maintain the status quo. This suppression of the freeing power of technologies, Marcuse argues, is epitomized in the increasing demands of the industrial system on both labor and free time visible in "the overwhelming need for the production and consumption of waste; the need for stupefying work where it is no longer a real necessity; the need for modes of relaxation which soothe and prolong this stupefaction; the need for maintaining such deceptive liberties as free competition at administered prices" (Ibid., 17).

Although the industrial economy conveys an illusion of liberty by providing an abundance of products, Marcuse argues, it is not this range of choice that determines human freedom, but rather "what can be chosen and what is chosen by the individual." Thus, for Marcuse, the rights and liberties at the root of industrial society were lost in the very same process of industrialization. The critical ideas underlying the freedoms of thought, speech, conscience and enterprise had served to replace a declining material and intellectual culture with one that was both more productive and rational. However, once institutionalized, the achievements eventually canceled the premises and therefore the rational system became irrational:

> *The most advanced areas of industrial society exhibit throughout these two features: a trend toward consummation of technological rationality, and intensive efforts to contain this trend within the established institutions. Here is the internal contradiction of this civilization: the irrational elements in its rationality. It is the token of its achievements. The industrial society which makes technology and science its own is organized for the ever-more-effective domination of man and nature, for the ever-more-effective utilization of its resources. It becomes irrational when the success of these efforts opens new dimensions of human realization.* (Ibid., 23)

The legitimation of the status quo, Marcuse argues, is based on the demands of the very technologies and processes that provide a rising standard of living. A society that provides for the material needs of its citizens "may justly demand acceptance of its principles and institutions, and reduce opposition to the discussion and promotion of alternative policies within the status quo" (Ibid., 13). In other words: the organizational demands of industrial technologies must be accepted if the needs of individuals are to be satisfied, and individual liberties must be sacrificed to economic prosperity.

Efficiency and technical apparatus have throughout modernity served to subject individuals to the socially established division of labor. This integration was, however, achieved mostly through compulsion—be it by the threat of losing one's livelihood or through the intervention of force. What is different in the contemporary period, Marcuse argues, is that these technological controls now "appear to be the very embodiment of Reason for the benefit of all social groups and interests—to such an extent that all contradiction seems irrational and all counteraction impossible" (Ibid., 18). That the system appears to be purely rational, and therefore necessary and neutral, wilts any opposition and leads to an internalized identification with the system. "The people recognize themselves in their commodities," Marcuse writes, "they find their soul in their automobile, hi-fi set, split-level home, kitchen equipment. The very mechanism which ties the individual to his society has changed, and social control is anchored in the new needs which it has produced" (Ibid.).

Such an absorption of ideology does not, however, represent the end of ideology. On the contrary, Marcuse suggests, the advanced industrial society is more ideological than its predecessor in the sense that it incorporates ideology into the very process of production:

> *In a provocative form, this proposition reveals the political aspects of the prevailing technological rationality. The productive apparatus and the goods and services which it produces 'sell' or impose the social system as a whole. The means of mass transportation and communication, the commodities of lodging, food, and clothing, the irresistible output of the entertainment and information industry carry with them the prescribed attitudes and habits, certain intellectual and emotional reactions which bind consumers more or less pleasantly to the producers and, through the latter, to the whole. The products indoctrinate and manipulate; they promote a false consciousness which is immune against its falsehood. And as these beneficial products become available to more individuals in more social classes, the indoctrination they carry ceases to be publicity; it becomes a way of life. It is a good way of life—much better than before—and as a good way of life, it militates against qualitative change. Thus emerges a pattern of one-dimensional thought and behavior in which ideas, aspirations, and objectives that, by their content, transcend the established universe of discourse and action are either repelled or reduced to terms of this universe. They are redefined by the rationality of the given system and of quantitative extension.* (Ibid., 19-20).

Such unfreedom is neither perceived as irrational nor as political, but as the unavoidable requirement of a technical system that increases productivity and provides material comfort. Such rationality, Marcuse asserts, legitimizes the domination it should be challenging. The result is thus "an advanced society which makes scientific and technical progress into an instrument of domination" (Ibid., 22). In Max Weber's (2012) conception, rationalization was an integral part of industrialization. In Marcuse's view, however, Weber mistakenly conflated the characteristics and requirements of capitalist industry with the functional requirements of industry in general (Habermas 1971).

This domination cannot be circumscribed to the uses that are made of essentially rational and neutral technologies. Rather than purposes and interests being imposed on technologies from the outside, Marcuse contends, they are embedded in the very construction of the technical apparatus of industrial society. The Fordist assembly line could be seen as an example of this: although it was ostensibly created and adopted to increase productivity, its technical design effectively enforces a specific form of labor discipline that imposes top-down control and serves the interests of management. The assembly line and the machinery of mass production, thus, are not the product of technical rationality but the embodiment of specific interests. For Marcuse then, "The techniques of industrialization are political techniques" (Marcuse 1964, 23).

Thus, the specific technologies of advanced industrial society—rather than being the apolitical products of pure technical necessity—are socially and historically shaped. For this reason, the contemporary technical apparatus of production and distribution cannot be seen as mere instruments, independent of their social and political applications. Rather, they constitute "a system which determines a priori the product of the apparatus as well as the operations of servicing and extending it" (Ibid., 11). In short, technology cannot be conceived as neutral:

> *Technology as such cannot be isolated from the use to which it is put; the technological society is a system of domination which operates already in the concept and construction of techniques. The way in which a society organizes the life of its members involves an initial choice between historical alternatives which are determined by the inherited level of the material and intellectual culture. The choice itself results from the play of the dominant interests. It anticipates specific forms of transforming and utilizing man and nature and rejects other modes. It is one "project" of realization among others.* (Ibid.)

However, if the assemblage of contemporary technologies is but one possible project, Jurgen Habermas asks, “Must not the rationality of science and technology, instead of being reducible to unvarying rules of logic and method have absorbed a substantive, historically derived, and therefore transitory a priori structure?” (Habermas 1971, 961-967). If that is the case, Habermas suggests, “social emancipation could not be conceived without a complementary revolutionary transformation of science and technology themselves” (Ibid., 982). Marcuse does indeed conceive of such a new science, one in which the hypothesis “without losing their rational character, would develop in an essentially different experimental context” and, “consequently, science would arrive at essentially different concepts of nature and establish essentially different facts” (Marcuse 1964, 122). It is to this notion that Habermas objects:

> *To this view it must be objected that modern science can be interpreted as a historically unique project only if at least one alternative project is thinkable. And, in addition, an alternative New Science would have to include the definition of a New Technology. This is a sobering consideration because technology, if based at all on a project, can only be traced back to a ‘project’ of the human species as a whole, and not to one that could be historically surpassed. . . .*
>
> *Technological development thus follows a logic that corresponds to the structure of purposive-rational action regulated by its own results, which is in fact the structure of work. Realizing this, it is impossible to envisage how, as long as the organization of human nature does not change and as long therefore as we have to achieve self-preservation through social labor and with the aid of means that substitute for work, we could renounce technology, more particularly* our *technology, in favor of a qualitatively different one. . . . The idea of a New Science will not stand up to logical scrutiny any more than that of a New Technology, if indeed science is to retain the meaning of modern science inherently oriented to possible technical control. For this function, as for scientific-technical progress in general, there is no more “humane” substitute.* (Ibid., 995-1003)

Habermas thus suggests that industrially advanced societies must accept the current shape of its technologies as long as individuals must subsist through labor and rely on technical means that substitute for work. That is, if a society is to satisfy its citizens' material needs, there is no alternative; the current shape of technologies—"*our* technology"—is necessary and therefore could not be qualitatively different. The methods employed by science and technology are therefore perfectly appropriate within their own domains.

For Habermas, rather, the issue lies not on science and technologies per se, which are both irreversible and necessary, but on the application of their rationalizing methods to other realms of human experience. The problem, he suggests, is the intrusion of scientific methods in the lifeworld thus converting ethical and political issues, which ought to be addressed by citizens through communicative processes, into technical questions to be decided by experts according to criteria of efficiency—therefore removing them from the sphere of public discussion where they belong. For Habermas, thus, the problem lies in the "scientization of politics and public opinion" (Ibid., 720) and the application of technical solutions to social issues.

I.3 Technologies as Social Constructs

We must conceptualize a world in which technology can develop in various ways: a world that might have turned out differently from the way it did, and thus a world with a history of abandoned but viable alternatives to what exists.

—Michael Piore and Charles Sabel (1984, 5)

The notion that technical progress necessarily leads to the particular shape of contemporary technologies—which are, in this view, unavoidable—has been increasingly challenged by more recent research work. A number of scholars[8] has argued, rather, that there are several possible paths along which any given technology can develop and that social forces influence the choices between these alternative paths.

Trevor Pinch and Wiebe Bijker (1984), proponents of the social construction of technology theory (SCOT), maintain that technological artifacts should be understood as social constructs. More specifically, they contend that the development process of technological artifacts is characterized by a combination of variation and selection. At its onset, there are several possible paths along which a given technology might develop (variation). Which paths are pursued and which are abandoned (selection), Trevor and Bijker suggest, is decided by the interest groups who define and give meaning to an artifact. The process of attributing meaning to technological artifacts is closely related to each group's understanding of what problems the artifact solves and how they wish them to be solved. Thus, these authors maintain, there is great interpretative flexibility in the early stages of a technology and, by defining what a technology is and what problems it is meant to address, social interests effectively determine its design.

Thus, in order to understand how technologies assume particular shapes, rather than viewing them as a black boxes, it is necessary to study these artifacts in light of the social

[8] Langdon Winner (1986), Michael Piore and Charles Sabel (1984), Trevor Pinch, Thomas Hughes, Wiebe Bijker (2012), Andrew Feenberg (2002), Donald MacKenzie and Judy Wajcman (1999), and Paul Josephson (2003), to name a few.

contexts in which they are shaped. For this purpose, Pinch and Bijker propose the SCOT method of inquiry.

To explain why some variants of a technology eventually "succeed" and others are abandoned it is necessary to understand technological artifacts as subject to different interpretations and to examine both the problems they are meant to address and the solutions they present. Since, as Pinch and Bijker point out, "a problem is only defined as such, when there is a social group for which it constitutes a 'problem'" (Ibid., 414), it is essential for the understanding of technologies to identify the interest groups concerned with the artifact. In these relevant social groups are included institutions, organizations, and organized or unorganized groups of individuals for which the artifact has any meaning.

Once the relevant social groups are identified, it becomes necessary to uncover the functions and meanings each group attributes to both the artifact and the variant solutions that emerge around it. To illustrate this process, Pinch and Bijker put forward the example of the bicycle, which, in its first years of development, was the object of several conflicting perspectives and approaches: moral conflicts (such as whether women should wear skirts or trousers when riding particular bicycle models), conflicting technical requirements (some groups emphasized safety, while others emphasized speed, depending on what meaning/ purpose each attributed to the bicycle), and conflicting solutions to the same problem. The variety of solutions presented in these conflicts were not just technical, but also judicial and even moral (such as changing attitudes towards female attire).

Thus, Pinch and Bijker content, different "social groups have radically different interpretations of one technological artefact . . . 'radical' because the content of the artefact seems to be involved" (Ibid., 423). Such flexibility refers not only to the differing meanings and interpretations individuals and groups attribute to artifacts, but also to the design of the technologies themselves. "There is not just one possible way, or one best way, of designing an artefact," these authors argue (Ibid., 421). Rather, artifacts are shaped by the alternative interpretations of concerned groups which "lead via different chains of problems and solutions to different further developments" (Ibid., 423). The shaping of technological artifacts is seen here not as an evolutionary process—in which the most efficient technologies triumph—but as something shaped as much by technical discoveries as by social interests.

However, although technologies are initially open to interpretation by the various groups concerned with their development, they eventually undergo a process of stabilization:

> *By using the concept of stabilization, the 'invention' of the Safety Bicycle is seen not as an isolated event (1884), but as a nineteen-year process (1879-98). For example, at the beginning of this period the relevant groups did not see the 'safety bicycle', but a wide range of bi- and tricycles . . . . By the end of the period, the word 'safety bicycle' denoted a low-wheeled bicycle with rear chain drive, diamond frame, and air tyres. As a result of the stabilization of the artefact after 1898, one did not need to specify these details: they were taken for granted as the essential 'ingredients' of the safety bicycle.* (Ibid., 416)

This stabilization of technological artifacts is achieved through closure mechanisms. Closure, for Pinch and Bijker, does not necessarily mean the actual resolution of problems. Rather it refers to the interest groups' perception of whether or not the problems have been addressed. Possible closure mechanisms, therefore, include rhetorical closure or a redefinition of the problem. Rhetorical closure occurs when social groups perceive the problem as solved and the need for alternative designs diminishes. A redefinition of the problem takes place when a design that is the object of conflicts is redefined as addressing a different problem. However, closure is not necessarily permanent. As technological artifacts draw the attention of new social groups, they may once again become the object of reinterpretations and conflicts. The automobile is an example of this: while in the late nineteenth-century it was viewed as a cleaner alternative to horse-drawn carriages, by the mid twentieth-century it had become cleat that fossil fuel -based vehicles are themselves a source of pollution (albeit a different one).

Departing from Pinch's and Bijker's notion of closure, Thomas Hughes (1994) proposes the concept of momentum, according to which technologies, in particular large technological systems—which, in Hughes conception, include both technical and social aspects—become increasingly more rigid over time. As large systems, such as power grids, evolve, they tend to generate a wealth of special purpose machinery and processes, a set of particular skills and knowledge, large physical structures, and a managerial bureaucracy responsible for maintaining and expanding the system. The dimension and influence of such technological systems, as they gain momentum, means that "the interaction of technological systems and society is not symmetrical over time. Evolving technological systems are time dependent" (Hughes 1994, 108). As these systems become larger and more complex—as they gain momentum—they "become more shaping of society and less shaped by it" (Ibid., 112).

Thus, in Hughes understanding, "a technological system can be both a cause and an effect; it can shape or be shaped by society" (Ibid.), but once a technological system gains momentum it becomes increasingly more rigid and dominant and, therefore, less pliable to change:

> *Because social and technical components interact so thoroughly in technological systems and because the inertia of these systems is so large, they bring to mind the iron-cage metaphor that Max Weber used in describing the organizational bureaucracies that proliferated at the beginning of the twentieth-century. Technological systems, however, are bureaucracies reinforced by technical, or physical, infrastructures which give them even greater rigidity and mass than the social bureaucracies that were the subject of Weber's attention. Nevertheless, we must remind ourselves that technological momentum, like physical momentum, is not irresistible.* (Ibid., 113)

For Hughes, this means that the deliberate shaping of technologies is more easily achieved before the systems that emerge around them acquire political and economic components. It does not necessarily mean, however, that systems which have acquired momentum are unchangeable. Even a "system with great technological momentum," Hughes notes, "can be made to change direction if a variety of its components are subjected to the forces of change" (Ibid., 112).

The Political Contexts of Technologies

Pinch's and Bijker's focus on the role played by interest groups in the shaping of technologies also draws attention to the larger contexts in which technologies are developed, since, as these authors point out, "the sociocultural and political situation of a social group shapes its norms and values, which in turn influence the meaning given to an artefact" (Pinch and Bijker 1984, 428). These social and political contexts of technologies are precisely what Paul Josephson's analysis centers on.

It may appear, Josephson suggests, that technologies are "value-neutral, serving the rational ends of achieving a desired outcome in the 'one best way'" by maximizing efficiency (Josephson 1991, 4706). The notion of "one best way" implies that, regardless of social context, the science-based solution to any engineering problem would be universal. However, Josephson argues, technologies cannot be reduced to assemblies of components put together in the "one best way." Rather, technologies are subject to the economic and social pressures of the contexts in which they are developed and used:

> *Engineers trained in a given milieu tend to accept the broader cultural values of their system. What are rational means for achieving desired ends in one society may be abhorrent in another. For example, the mass production of consumer goods through the "American system" of interchangeable parts and Fordism (standardized production; a controlled and steady flow of energy and materials in production processes from acquisition to the assembly line; and mass production to lower unit costs) will be crass materialism to conservative German engineers. The factory assembly line symbolized the exploitation of the proletariat to Soviet engineers. On the other hand, Soviet leaders idealized Taylorism (a doctrine of scientific management in industry) and established an officially sponsored materialism. And when the ends are full employment, social welfare, inexpensive housing, or universal health care . . . disagreements over the means and ends pour forth.* (Ibid., 4713-4718)

To further the understanding of how political contexts influence the shapes of technologies, Josephson undertakes a comparative analysis of the technologies of totalitarian regimes—namely those of Nazi Germany and the Stalinist USSR—and identifies three main differences between the artifacts and development processes of these regimes and their pluralist counterparts.

The first and most visible of these differences is the role played by the state, which in totalitarian regimes serves as the prime mover of the development and diffusion of technologies. Josephson then shows that both in the Soviet research institutes and the Nazi ordnance laboratories, the central role played by the state led to what he terms “big science” approaches. The absence of market dynamics and the lack of public participation in decisions about these technologies, Josephson concludes, “permits the development of technologies that persist no matter their questionable efficacy or environmental soundness” (Ibid., 4735).

The second feature of totalitarian technologies is the highly centralized administration of the processes of research and development. Although this appears evident in state socialist regimes, in which the state owns the large majority of the means of production, Josephson found that state funded projects are common in fascist regimes as well. In these settings, he argues, “Major industrialists prosper in close cooperation with the state, while smaller businesses are subjugated to the ‘national good’” (Ibid., 4741). Thus, while in pluralist regimes engineers and scientists have greater freedom to set their research agendas, in totalitarian regimes researchers are constrained and subjugated to single-party organizations and ruled from above.

Lastly, Josephson maintains, the technologies produced in the context of totalitarian regimes suffer from what he calls “gigantomania” (Ibid., 4748). This characteristic is exemplified by Speer’s plans for four-meter wide railroad tracks with two-story-high train cars and by Stalin’s skyscrapers. This gigantomania, Josephson argues, often leads to wasteful uses of resources, particularly in centrally planned economies in which the state plays a pivotal role. “In totalitarian regimes,” Josephson writes, “projects seem to take on a life of their own, so important are they for cultural and political ends as opposed to ends of engineering rationality” (Ibid.)

Through this comparative analysis, Josephson suggests that political regimes—be they socialist, fascist or capitalist—not only influence the shape technologies assume, but also tend to generate different technologies through different social processes. This view of technologies as tied to the regimes in which they take shape echoes Marcuse’s understanding of technological systems as historically conditioned. For Marcuse, it is worthwhile recalling:

> *The way in which a society organizes the life of its members involves an initial choice between historical alternatives which are determined by the inherited level of the material and intellectual culture. The choice itself results from the play of*

the dominant interests. It anticipates specific forms of transforming and utilizing man and nature and rejects other modes. It is one 'project' of realization among others. (Marcuse 1964, 11)

Technological Divides

The notion that the technologies of contemporary society are but "one project of realization among others" is also the topic of *The Second Industrial Divide*. In this work, Michael Piore and Charles Sabel (1984) adopt the theory that technologies are socially shaped to suggest that the rise of mass production, rather than being an unavoidable necessity—as the only way to increase efficiency and production—was the result of social, economic and political circumstances.

For these authors, industrial technologies did not arise from self-contained technical necessity. Rather, they argue, the choices of which technologies are developed—and eventually become the standard—and which are lost in time depends heavily on the structures of the markets in which they emerge. In turn, these markets are largely shaped by political aspects, including, but not limited to, rights to property and the distribution of wealth. "Industrial divides" is the phrase adopted by these authors to describe the historical moments when technological development branches into two or more possible paths. In these moments, a variety of social conflicts eventually determines the direction of technological development that will affect the following decades. Although those involved in such processes—engineers, entrepreneurs, workers, and politicians, for example—may not be aware, their cumulative individual actions eventually converge to define the future of technological systems and the socio-economic contexts in which they are put to use.

The first industrial divide, Piore and Sabel suggest, occurred at a time when the emergence and diffusion of mass production limited the growth, and eventually displaced, a set of more flexible manufacturing technologies and techniques. During the nineteenth century, two different types of manufacturing technologies and models were in collision. Craft production, the oldest of these models, hinged on the notion that flexible machinery and widely applicable processes served to augment the craftsman's skill and allowed him or her to produce a variety of goods. In the most advanced of these systems, craftsmen employed sophisticated tools to produce a wide variety of goods for large but constantly changing markets. These craft industries, unlike mass production systems, relied on a combination of cooperation and competition, in which the costs of permanent innovation were divided amongst firms—as well as between entrepreneurs and workers—to ensure that no one blocked the introduction of changes. This sharing of costs, Piore and Sabel maintain, was in turn based on institutions that protected the most vulnerable on behalf of the entire community.

The other, newer model was mass production, in which production costs were reduced and production rates accelerated through the replacement of the craftsman's skill by machinery and the deconstruction of work into ever simpler and smaller tasks that could be executed by both machines and unskilled labor. Unlike craft production technologies, which were flexible and multipurpose, mass production required highly specialized machines to be operated by unspecialized workers.

Thus, Piore and Sabel reason, while proponents of the craft model "foresaw a world of small producers, each specialized in one line of work and dependent on the others," adopters of mass production "foresaw a world of ever more automated factories, run by ever fewer and ever less skilled workers (Piore and Sabel 1984, 19-20). By the end of World War II, mass production had gained enough momentum to become the standard it still is today: "industry after industry came under the domination of giant firms using specialized equipment to turn out previously unimagined numbers of standard goods, at prices that local producers could not meet" (Ibid., 20).

However, under different historical conditions, Piore and Sabel maintain, the combination of craft techniques with flexible production machinery might have assumed a more central role in the industrial economy, rather than being pushed to its periphery. "Had this line of mechanized craft production prevailed," the authors suggest, "we might today think of manufacturing firms as linked to particular communities, rather than as the independent organizations—barely involved with their neighbors—that, through mass production, seem omnipresent" (Ibid., 2-3)

Classical explanations for the wide adoption of mass production—notably those of Adam Smith and Karl Marx—rather than fully accounting for this phenomena, Piore and

Sabel assert, "illuminate crucial features of the way current industrial economies work" by plausibly accounting for the economic success of leading industry powers and theoretically confirming "everyday experience of the limited plasticity of technology" (Ibid., 21-22). In other words, these accounts offer more of a justificatory narrative than a full explanation.

The classical theory at the base of mass production states that the increase of productivity (the ratio of inputs to outputs) requires the highly specialized use of resources. For Adam Smith (2009) this meant a division of labor in which each task was decomposed into ever smaller elements, which could then be executed by machines and workers in a precise sequence. Such a system, however, required that the entire production process be configured around very specific machinery and procedures, thus leading to an increased rigidity and specificity which did not allow for the rapid conversion of resources to other purposes or products.

Another crucial aspect of this model was the need to increase demand for products. The cost of product-specific machinery and processes, and the fact that it was not possible to easily divert those resources to alternative production lines, meant that the investment could only be sustainable if there was a market for those particular products. The efficiencies provided by this model lowered production costs and, therefore, were able to make goods available to a wider portion of the population, thus creating the demand mass production required. This linkage between progress and specialization, Piore and Sabel contend, leads to the fundamental "metaphysical theme of the classical writers:"

> *To both Smith and Marx, the triumph of mass-production capitalism was proof that humankind was constrained to play out a paradoxical drama in history. The struggle to survive and prosper in a world where every satisfaction created new wants led to the constant improvement of productive efficiency; yet the constant improvement of efficiency subjected individuals to ever greater restrictions, according to the logic of divided labor and mechanization. The price of human liberation was thus subjugation . . . to the inhuman logic of specialization. Progress was both inevitable—in that political interference could retard but not stop it—and uncontrollable—in that it required the elimination of skill and the product-specific*

automation of manufacturing. Competition assured that those who did not bow to these necessities were crushed by those who did. (Piore and Sabel 1984, 25)

However, the authors note, this account fails to explain the vitality of the most notable industrial districts of the nineteenth century—namely those of Lyon, Solingen, Remscheid, Sheffield, Alsace, Roubaix, Philadelphia and Pawtucket. In these districts, small firms developed and adopted new technologies without increasing in size, and large firms used sophisticated machinery but did not produce standardized goods. According to Piore and Sabel, the technological sophistication and dynamism of these industrial districts challenges the notion that craft production could not assume a central role in advanced economies. Rather, they argue, it suggests that craft technologies may in fact be a viable alternative to mass production technologies.

These craft districts exhibited three characteristics that appear disconcerting in light of contemporary practices: they produced a wide variety of products for very different markets and constantly altered goods in response to changes in taste or to create new markets; they used flexible, widely applicable technologies which were also increasingly productive; and they balanced competition and cooperation between firms:

> *Technology had to be flexible in both a narrow and broad sense. It has to permit quick, inexpensive shifts from one product to another within a family of goods, and it had to permit a constant expansion in the range of materials worked and operations performed, in order to facilitate the transition from one whole family of products to another. Institutions had to create an environment in which skills and capital equipment could be constantly recombined in order to produce a rapidly shifting assortment of goods. As a precondition of this, firms were discouraged from competition in the form of wage and price reduction, as opposed to competition through the innovation of products and processes.* (Ibid., 29-30).

Thus, Piore and Sabel conclude, the decline of mechanized craft production cannot be explained by its inferior model of technological development. For these authors, it is necessary to conceive of a world in which social processes select between several viable technological alternatives:

> *A first postulate of such a world is that any body of knowledge about the manipulation of nature can be elaborated and applied to production in various ways; some of these ways are more flexible than others. A further postulate is that the technological possibilities that are realized depend on the distribution of power and wealth: those who control the resources and the returns from investment choose from among the available technologies the one most favorable to their interests. A third technological postulate is that technological choices, once made, entail large investments in equipment and know-how, whose amortization discourages subsequent different choices.* (Ibid., 38)

Thus, rather than being the "one best way", the result of evolutionary processes that weeded out lesser systems, mass production's triumph can be explained by its emergence in a propitious economic and political context. However, once a particular system gains momentum, as argued by Hughes (1994), alternatives tend to be abandoned. The abundance of variants—as in the case of the bicycle cited by Pinch and Bijker (1984), but also demonstrated by the histories of the automobile, aircraft and personal computer—often lead to a technological impasse. This impasse, Piore and Sabel argue, is typically resolved by an "exercise of economic power" (Piore and Sabel 1984, 40). Thus, although the "winning" design must meet performance standards, this does not mean that it is the only, or even the superior, technical solution to a problem. Other, alternative approaches may have solved the same problem. The choice between competing technologies or technological systems, Piore and Sabel conclude, is more often decided by power in the market than by pure efficiency (Ibid.).

Efficiency and the Technical Code

While Piore and Sabel contend that, if allowed to evolve, craft production may have been just as efficient as mass production, Andrew Feenberg points out that even the notion of efficiency is context specific:

> *Efficiency . . . is defined formally as the ratio of inputs to outputs. This definition would apply in a communist or a capitalist society, or even in an Amazonian tribe. It seems, therefore, that efficiency transcends the particularity of the social. However, concretely, when one actually gets down to the business of applying the notion of efficiency, one must decide what kinds of things are possible inputs and outputs, who can offer and who can acquire them and on what terms, what counts as waste and hazards, and so on. These are all socially specific, and so, therefore, is the concept of efficiency in any actual application.* (Feenberg 1996, 51)

As proposed by Pinch's and Bijker's (1984) social construction of technology theory, the notion of efficiency also depends greatly on the problems an artifact is meant to address, which in turn depend on the meaning attributed to them by interest groups—e.g. is an efficient bicycle design one that is fast or one that is safe? Moreover, as Piore and Sabel (1984) argue, for the same problem it may be the case that several technical solutions exist that present equivalent levels of efficiency. The choice between such equivalent solutions is thus not based on the most technically or economically efficient solution, but on how well the solution fits its social environment.

The combined notions that the shapes of technologies depend largely on the definition of the problems they are meant to address and that for a given problem there is often more than one technical solution also means that the transformation of technologies does not necessarily require a "New Science" as Habermas (1971) and Marcuse (1964) suggested. To question whether a particular technological system, such as that of industrial manufacturing, is the only approach to increasing efficiency and production is not necessarily to question the universal validity of the science-based technical elements that compose technological artifacts.

Feenberg (2002) offers a useful approach for reconciling rationality and historical contingency by comparing technical components with a vocabulary from which different sentences—and, therefore, different meanings—can be created. These parts result from basic discoveries which, although they may have initially served a specific purpose, are so fundamental that they may be used in a variety of applications in very different contexts.

"Like the vocabulary of a language," Feenberg writes, they can be "strung together—encoded—to form a variety of 'sentences' with different meanings and intentions" (Feenberg 2002, 77-78). For Feenberg, discrete technologies "are constructed from just such decontextualized technical elements combined in unique configurations to make specific devices" (Ibid., 78).

Since these basic elements, which originate from scientific discoveries, can be arranged into different configurations, which may be equally "efficient," the choices involved are not strictly technical, as Habermas himself has noted in *Theory and Practice*:

> *. . . we employ techniques placed at our disposal by science for the realization of goals. If, however, there is a choice between actions of equal technical appropriateness, a rationalization on the second level is required. The translation of technical recommendations into praxis—thus the technical utilization of theories of the empirical sciences—is also subject to the conditions of technological rationality. But the information furnished by empirical science is not sufficient for a rational choice between means that are functionally equivalent, given concrete goals, and which are to be realized within the framework of a value system.* (Habermas 1974a, 270-271)

In this context, for Feenberg, the creation and shaping of technologies cannot be conceived in exclusively technical terms. Rather, the particular arrangements of technical elements that form a technology are configured to fit into specific social contexts:

> *Technologies, as developed ensembles of technical elements, are thus greater than the sum of their parts. They meet social criteria of purpose in the very selection and arrangement of the elements from which they are built up. These social purposes are embodied in the technology and are not therefore mere extrinsic ends to which a neutral tool might be put. The embodiment of specific purposes is achieved through the 'fit' of the technology and its social environment. The technical ideas combined in the technology are relatively neutral, but one can trace in it the impress of a mesh of social determinations that preconstruct a domain of social activity in accordance with certain interests or values.* (Feenberg 2002, 78)

Thus, Feenberg argues, “Ethics is realized not only discursively and in action but also in artifacts” (Ibid., 21). The example of the bicycle analyzed by Pinch and Bijker can also illustrate this point: while, at first, the issue of safety was an object of conflict, and thus formulated discursively, it eventually became incorporated into the design of bicycle models that are common today and, therefore, entered what Feenberg conceptualizes as the technical code: “the realization of an interest in a technically coherent solution to a general type of problem,” which then “serves as a paradigm or exemplar of a whole domain of technical activity” (Ibid., 21). When what once was an ethical issue enters the technical code, by regulation or commonly accepted practice, it sinks “beneath the surface in a kind of technological unconscious” (Ibid.).

In Feenberg’s definition, “code” is understood simultaneously as a rule that classifies activities as either permitted or prohibited, and as the purpose or meaning of that norm (its justification or reason of existence). Feenberg’s technical code is thus “the rule under which technical choices are made” (Ibid., 15). It includes both the technical and social functions that govern the design of technologies, and it “invisibly [sediments] values and interests in rules and procedures, devices and artifacts” (Ibid.). Thus, in Feenberg’s view, signifying particular designs as “efficient” is also a way to legitimize choices that are both technical and social:

> *. . . the intervention of interests does not necessarily reduce efficiency, but biases its achievements according to a broader social program. . . . Thus, two different configurations of production technology might each achieve high levels of efficiency . . . Under different social conditions and with different values in view, each could be successful.* (Ibid., 21)

This is not to say that technologies do not have a technical coherence of their own, but that the choices involved in how to arrange technical elements in particular configurations are not merely technical. “Were that the case,” Feenberg argues, “by analogy one could also explain the choice of individual sentences in speech by their grammatical coherence. The social character of technology lies not in the logic of its inner workings, but in the relation of that logic to a social context” (Ibid., 79). For Feenberg then, technological rationality is neither pure ideology nor value neutral. It results, rather, from the intersection of ideology with technique. Therefore, although advances in technologies may be of general purpose, the concrete forms in which these advances are realized is determined primarily by the social contexts in which they emerge and the interests they serve.

I.4 The Social Dynamics of Technological Artifacts

What is needed is an understanding of technology from inside, both as a body of knowledge and as a social system.

—Edwin Layton (1977, 198)

Recent studies and theories have sought to demonstrate that there is no "one best way" to design technologies. Rather, human choices between alternative technical configurations are largely responsible for the particular shapes of technologies: for the possibilities, freedoms, constraints and impositions they present. Given that technical appropriateness is not the only factor in technical decisions, creators make choices which, deliberately or unknowingly, reflect their perspectives and goals. At the most basic level, these choices are based on assumptions about who will want to use a device, how they will want to use it, and for what purposes. At a more complex level they are also a reflection of broader values. As Eric Katz, Andrew Light and William Thompson pointed out, these are "Moral, or more generally 'normative,' choices (choices about how we ought to live rather than mere descriptions of how we do live) based on personal values" (Katz, Light and Thompson 2003, 117). This means that technological artifacts embody perspectives, interests, values and, more generally, assumptions about how the world works or how it should work. In other words, technologies are not simply neutral assemblages of technical elements, they are reflections of human biases.

For this reason, it is essential to understand the assumptions and values technologies embody, the purposes they seek to address, and the ways in which these manifest themselves in the particular shape of artifacts. Although this has not been widely studied, a number of analysts has looked into the ways in which technological artifacts are shaped by individual or collective perspectives, cultural biases and even political goals.

Langdon Winner's Political Artifacts

In an essay titled "Do Artifacts Have Politics?" Langdon Winner suggests that "the machines, structures, and systems of modern material culture" can in fact "embody specific forms of power and authority" (Winner 1980, 121). For Winner, there are two ways in which artifacts can contain political properties. The first one consists in "instances in which the invention, design, or arrangement of a specific technical device or system becomes a way of settling an issue in the affairs of a particular community;" the second "are cases of what can be called 'inherently political technologies', man-made systems that appear to require or to be strongly compatible with particular kinds of political relationships" (Ibid., 123).

Winner contends that throughout the histories of architecture, city planning and public works it is possible to identify several examples of physical arrangements which, explicitly or implicitly, seek to achieve political purposes. To illustrate the deliberate imprint of politics in design, he offers the case of the low overpasses at the Long Island Park (NY, U.S.), which, he claims, were "deliberately designed and built that way by someone who wanted to achieve a particular social effect" (Ibid.). In Winner's interpretation, architect Robert Moses built these particularly low overpasses with the goal of discouraging the presence of buses in the parkways—the bridges, therefore, "reflect Moses social-class bias and racial prejudice" (Ibid.). Many of Moses's "monumental structures of concrete and steel," Winner contends, "embody a systematic social inequality, a way of engineering relationships among people that, after a time, became just another part of the landscape" (Ibid., 124).

Another instance in which political goals presided over technological choices, Winner suggests, involved the Cyrus McCormick's reaper manufacturing plant in Chicago (U.S.), which, in the mid-1880s, was said to adopt pneumatic molding machines—shown to produce inferior castings at a higher cost, but which could be operated by unskilled workers—with the goal, not of increasing productivity, but of dispensing with the factory's union-organized skilled workers. In Winner's view, these examples demonstrate the significance of technical decisions that precede the use of the artifacts:

> *It is obvious that technologies can be used in ways that enhance the power, authority, and privilege of some over others . . . In our accustomed way of thinking technologies are seen as neutral tools that can be used well or poorly, for good, evil,*

or something in between. But we usually do not stop to inquire whether a given device might have been designed and built in such a way that it produces a set of consequences logically and temporally prior to any of its professed uses. (Ibid., 125).

Winner thus suggests that, rather than technologies serving simply to increase efficiency, they express "a panoply of human motives, not the least of which is the desire of some to have dominion over others" (Ibid., 124). However, he points out, an acknowledgement of the political essence of artifacts does not necessarily mean that these processes are always conscious or malicious. In fact, he argues, the most important examples of technologies with political consequences are those that transcend the categories of intended or unintended. That is the case of technologies which—like the mechanical tomato harvester which benefited large growers and contributed to the decline of other agricultural communities (Ibid., 126)—are "so thoroughly biased in a particular direction" that they lead to "results heralded as wonderful breakthroughs by some social interests and crushing setbacks by others" (Ibid., 125). For Winner, therefore, the mechanical tomato harvester is an example of:

. . . an ongoing social process in which scientific knowledge, technological invention, and corporate profit reinforce each other in deeply entrenched patterns, patterns that bear the unmistakable stamp of political and economic power. . . . For the harvester is not merely the symbol of a social order that rewards some while punishing others; it is in a true sense an embodiment of that order. (Ibid., 126).

David Noble's NC Machine Tools

David Noble's analysis of the history of numerically controlled (N/C) machine tools offers still another example in which, he suggests, labor politics influenced the evolutionary direction of a technology. Noble's account begins in the early twentieth century when the full automation of machine tools—which, up until that point, had typically been operated by skilled machinists—was first attempted.

The first viable approach to machine tool automation was the record-playback system developed by General Electric and Gisholt in the mid 1940s. In this system, the machinist would make the first part as the machine recorded his or her movements on magnetic tape. Once the first piece was completed, the tool could then make copies by playing back the tape and reproducing the machinist's motions. With this technology, although the machine was capable of producing parts on its own, the skill involved in the process was still that of the machinist. In the N/C system, the second solution, the specifications for a part, contained in engineering blueprints, were translated into numerical instructions which the machine then read and executed. N/C, Noble argues, was essentially "a means of formally circumventing the role of the machinist as the source of intelligence of production" (Noble 1979, 18).

For Noble, the eventual triumph of N/C over record-playback was not due to the technical superiority of the former over the latter[9], but to the support N/C received from the North American air force. According to Noble's study, between 1949 and 1959 the U.S. military invested $62 million in the research, development and diffusion of N/C (Ibid.). Although, before 1953, both the air force and MIT—the university contracted for the development of the N/C system—had mounted a large campaign to encourage adoption of the technology, only one firm showed enough interest to invest in it. In 1955, however, the U.S. Air Material Command budget allocation shifted from tracer-controlled machines to N/C machines. The air force then invested in the acquisition, installation and maintenance of N/C tools in the factories of its main subcontractors (as part of this process, the contractors, aircraft manufacturers, and their suppliers also received paid training in the use of the machines). In sum, Noble concludes, "the air force created a market for N/C. Not surprisingly, machine-tool builders got into the action, and research and development expenditure in the industry multiplied eightfold between 1951 and 1957" (Ibid., 25).

The efforts of the U.S. air force to drive adoption of this technology resulted not only in its greater dissemination, Noble argues, but also influenced the shape of the machines themselves. While choices in the design of machinery typically take into account the cost for adopters, in the case of N/C this was not a consideration—the air force was funding the introduction of the technology. Rather, the tool designers and builders focused on meeting the

[9] In fact N/C would later prove problematic for the metalworking industry.

performance and competence requirements of government-funded firms in the aircraft industry. Given the specificity of their target market, these designers, Noble argues, were not concerned with cost effectiveness and had no incentive to develop less expensive versions for commercial markets.

Another aspect of the technology in which its social shaping becomes apparent, Noble contends, was its software, which was equally influenced by the role played by the air force in its development. The Automatically Programmable Tools (APT) software devised by the MIT engineers not only met air force specifications, but was also flexible: it allowed for rapid design changes as well as interchangeability between users and vendors, contractors and subcontractors—in short, it fitted the air force requirements perfectly. Thus, a joint effort by the Air Material Command and the Aircraft Industries Association Committee on Numerical Control to make APT the industry standard eventually led to the adoption of the system by several other machine tool manufacturers.

Although APT quickly became a standard in the aircraft industry, it was initially met with resistance by firms which had already developed their own programming languages for N/C tools. These in-house languages, although less flexible than APT, were easier to use and appropriate to the needs of the originating firms. The sophisticated and complex APT software, on the other hand, required significantly more skilled programmers and greater computing power than the languages previously used by these firms. However, despite this initial resistance, Noble notes, the exclusive adoption of APT was enforced by "higher level management, who had come to believe it necessary to learn how to use the new system 'for business reasons' (cost-plus contracts with the air force)" (Ibid., 27).

The air force driven standardization of APT, Noble argues, had two primary consequences. The first was the stifling of alternative, simpler programming languages that might have made contour programming accessible to small shops. The second was an increasing dependence of N/C adopters on large computational devices, sophisticated software, and the organizations that controlled the development of APT. Although APT was initially developed at MIT, in 1961 the project was transferred to the Illinois Institute of Technology Research Institute (IITRI) and came under the purview of a consortium formed by the air force, the Aircraft Industries Association (AIA), and several major manufacturers of machine tools and electronic controls. Given that the cost of membership in this consortium was beyond the means of smaller metalworking firms, the APT system "tended to be restricted to those who enjoyed privileged access to information about the system's development" (Ibid., 27). Additionally, given that APT was proprietary software, programmers within user factories were required to sign out for manuals, forbidden to remove them from the premises, and prohibited to discuss the contents of the manuals outside their firms. Thus, APT, Noble maintains, contributed to increasing disparities between larger, government-funded firms and smaller firms, as those who wished to obtain military contracts had to adopt the APT system and those who could not afford its costs were left out.

The effort undertaken by the U.S. air force to turn N/C and its APT software into an industry standard was not, however, the only factor responsible for the abandonment of the record-playback system. "Here was a technology," Noble writes, "that was apparently well-suited to the small shop: tapes could be prepared by recording the motions of a machine tool, guided by a machinist or a tracer template, without programmers, mathematicians, languages or computers" (Ibid., 28). Despite this, initial demonstrations of record-playback elicited little interest in the part of machine-tool and aircraft firms. The explanation for this lack of interest, Noble contends, lies in "reasons that have more to do with the ideology of engineering than with economic calculations" (Ibid., 29).

As the first automated machine tools were being developed, the aircraft industry was also experiencing labor unrest—reflected in the several strikes that, during this period, took place at the largest aircraft manufacturing plants. It is not surprising then that managers of these firms became interested in replacing workers with machines and looked to technologies that would allow them to regain control over the shop floor. Although the record-playback system was developed with the goal of replacing machinists, its method of tape preparation still depended entirely on a skilled machinist. This was the primary reason, Noble argues, why the system was met with so little enthusiasm by managers, a hypothesis confirmed by the head of the Industrial Applications Group:

> *. . . with record-playback the control of the machine remains with the machinist—control of feeds, speeds, number of cuts, output; with N/C there is a shift of control to management. Management is no longer dependent upon the operator*

and can thus optimize the use of their machines. With N/C, control over the process is placed firmly in the hands of management—and why shouldn't we have it? (as cited by Noble 1979, 34)

Noble thus concludes that if the adoption of N/C technologies appears to have led to organizational changes that enhanced the control of managers over the shop floor, it is precisely because the technology was partially selected for that very purpose[10]:

> *Technology thus does not develop in a unilinear fashion; there is always a range of possibilities or alternatives that are delimited over time—as some are selected and other denied—by the social choices of those with power to choose, choices which reflect their intentions, ideology, social position, and relations with other people in society. In short, technology bears the social "imprint" of its authors. It follows that "social impacts" issue not so much from the technology of production as from the social causes that brought it into being: behind the technology that affects social relations lie the very same social relations. Little wonder, then, that the technology usually tends to reinforce rather than subvert those relations.* (Ibid., 18-19)

Tim Jordan's and Paul Taylor's Politico-Technological Formations

In a comprehensive analysis of hacktivism (a portmanteau of the words hack and activism), Tim Jordan and Paul Taylor explore the relationship between politics and technology through the identification of two different approaches to technological activism. In the first one, which the authors term "mass virtual direct action hacktivism," activists *use* digital technologies as means, platforms and tools for political action. In the second one, "digitally correct hacktivism," activists "work inside technologies, imbuing the very fabric of

[10] However, this did not come to pass as envisioned. Even today, despite significant technical advances, the operation of the more complex N/C machines still requires a considerable amount of skill. Furthermore, the cost of the most sophisticated N/C tools (such as large nine and twelve axis mills capable of carving an engine from a block of aluminum), usually induces firms to allocate their most experienced and knowledgeable operators to these machines. Thus, as Noble notes, "while it is true that many manufacturers initially tried to put unskilled people on the new equipment, they rather quickly saw their error and upgraded the classification." (Noble 1979, 42)

cyberspace with their political values” (Jordan and Taylor 2004, 110). Underlying this second approach is a “clear intermingling, the inextricable intertwining, of politics and technology” (Ibid.). To illustrate this point the authors describe peek-a-booty, a network created by digitally correct hacktivists to circumvent national censorship mechanisms.

The peek-a-booty network, Jordan and Taylor explain, was designed with several technical characteristics to prevent censorship. First, is was configured as a distributed network: a centerless mesh of interconnected, equipotent nodes. In this type of network architecture, the intelligence of the system is distributed across all its nodes, and therefore, shutting down one or more nodes does not effectively disable the rest of the network—unlike centralized networks in which the intelligence of the system resides in strategic nodes which, if disabled, will impair the functioning of large portions of or even the entire network. This is, Jordan and Taylor reason, both a technical and a political choice. Technical in the sense that it is an efficient way to make the network more resilient,. But also political since—in light of its stated purpose of circumventing national censorship—it is expected that the peek-a-booty network will be the target of attacks by those who seek to counteract its political agenda.

Furthermore, the selection of a distributed architecture also has legal ramifications. Legally disabling a network requires locating the individuals or organizations who are responsible for it, determining in which jurisdiction they reside in, and prosecuting them. In a centralized network this is relatively easy to do as the responsible parties are those who control the center of the network. In a distributed network, on the other hand, all participants are equally responsible. Therefore, legally shutting down a distributed network requires that all participants be located and prosecuted in their multiple physical locations. In practical terms, this means that it is considerably harder to disable a distributed network, be it through technical or legal mechanisms—a difficulty that serves the political agenda of peek-a-booty.

Another politico-technological characteristic of this network is its use of steganography—the practice of disguising messages as something innocuous and thus enable them to pass across censorship firewalls without being recognized. In peek-a-booty, Jordan and Taylor indicate, this is achieved through the use of secure socket layer (SSL) protocols. SSL protocols—which are built into the majority of browsers and web servers—are predominantly used in financial transactions and, for this reason, are not commonly blocked by national firewalls as this would inhibit e-commerce transactions. The use of SSL serves the political goals of peek-a-booty in two interrelated ways. First, it discourages nations from inspecting peek-a-booty's SSL encrypted messages: if these activities were to become public, they would compromise the security of online trading—which would likely have negative economic repercussions. Secondly, SSL uses strong encryption and is so common that the sheer number of SSL messages makes it very difficult to decrypt every single one in order to uncover which carry financial information and which carry peek-a-booty's messages.

The political mission of peek-a-booty is thus fulfilled through these and other embedded technical tactics. This means that the technical configuration of this network—from the selection of its elements to the particular ways they are strung together—is itself political. Jordan and Taylor conceptualize these types of technologies as "politico-technological formations:" technologies which are not just a medium for enacting politics, but are themselves the embodiment of political values. "Whereas mass action hacktivists look to networks to do things for them, to be a place in which protest can occur just as roads are places in which demonstrations can occur," they write, "digitally correct hacktivists attempt to form the nature of the roads and passages of cyberspace" (Ibid., 114).

Lawrence Lessig's Cyberspace Code

Like the digitally correct hacktivists described by Jordan and Taylor, Lawrence Lessig's work focuses on the liberties, and threats to liberties, enabled by software. For him, one of the most pressing aspects of the intermingling of politics with technologies concerns the regulatory aspects of the code that makes up cyberspace. In an article suggestively titled "Code is law," Lessig writes:

> *Every age has its potential regulator, its threat to liberty. Our founders feared a newly empowered federal government; the Constitution is written against that fear. John Stuart Mill worried about the regulation by social norms in nineteenth-century England; his book On Liberty is written against that regulation. Many of the progressives in the twentieth century worried about the injustices of the market. The reforms of the market, and the safety nets that surround it, were erected in response.*

Ours is the age of cyberspace. It, too, has a regulator. This regulator, too, threatens liberty. . . . This regulator is code—the software and hardware that make cyberspace as it is. This code, or architecture, sets the terms on which life in cyberspace is experienced. It determines how easy it is to protect privacy, or how easy it is to censor speech. It determines whether access to information is general or whether information is zoned. It affects who sees what, or what is monitored. In a host of ways that one cannot begin to see unless one begins to understand the nature of this code, the code of cyberspace regulates.

This regulation is changing. The code of cyberspace is changing. And as this code changes, the character of cyberspace will change as well. Cyberspace will change from a place that protects anonymity, free speech, and individual control, to a place that makes anonymity harder, speech less free, and individual control the province of individual experts only. (Lessig 2000)

The functioning of the Internet is based on TCP/IP protocols, which enable the transmission of data between interconnected networks. Due to the characteristics of these protocols, the Internet's process of information exchange is largely anonymous: the networks do not know the real identity of the senders nor the content of the messages. For this reason, it is difficult to regulate what types of data are transmitted or to trace messages to a particular individual. These features of the Internet, Lessig points out, make it difficult to regulate or otherwise control behavior on the Internet. However, given that this code is a human construct, it can also be altered to produce the inverse effect:

But no thought is more dangerous to the future of liberty in cyberspace than this faith in freedom guaranteed by the code. For the code is not fixed. The architecture of cyberspace is not given. Unregulability is a function of code, but the code can change. Other architectures can be layered onto the basic TCP/IP protocols, and these other architectures can make behavior on the Net fundamentally regulable. Commerce is building these other architectures; the government can help; the two together can transform the character of the Net. They can and they are. (Ibid.)

In 2000, when Lessig's article was published, architectures for facilitating the identification of users and for rating content were already emerging. The main difference between these two approaches, Lessig notes, is that one enables privacy and the other does not. And this level of privacy is coded into the very architecture of the Internet. Architectures that reverse the anonymity of TCP/IP protocols, which are often developed without public scrutiny, could facilitate "an extraordinary degree of control over behavior on the Net" (Ibid.). "Could," Lessig notes, is the keyword. Given that there is no "one best way" to design and implement a network, the choices defining what the architecture of the Internet enables, and how much control it permits, are made by those who write and rewrite its code. Therefore, the degree of liberty and control provided by and within the Internet depend largely on the choices of those who program it, and their choices, in turn, are contingent on both their goals and the incentives they face.

Who Shapes Technologies

The examples and theories described above concern the shaping of technologies by their originators, developers, and organizers—be it as a result of intentional goals or as a reflection of broader cultural contexts. However, in such a complex landscape it is hardly ever the case that the shape of artifacts, and their "effects" on society, can be traced to the straightforward imposition of some individuals' and groups' wills over others.

The case of Moses' bridges advanced by Winner, for example, was carefully deconstructed by Bernward Joerges (1999), who contends that the relationship between the low bridges and Moses's politics was not as clear and direct as Winner suggests. The shape of the bridges, Joerges argues, may have resulted from several other factors. They might have been made low for aesthetic reasons (to better integrate them into the landscape) or to comply with what were at the time established regulations and practices: trucks, buses and other commercial vehicles were prohibited on all parkways, and therefore the shape of Moses's bridges was not uncommon. Furthermore, there were several other ways for those who could not afford an automobile to access Long Island—therefore, Moses's bridges, even if they had been built for the purpose Winner attributes to them, would still not be sufficient to achieve the desired effect.

Proponents of the labor process theory like Noble (1979) and Feenberg (1996) argue that in capitalist societies production technologies are primarily shaped by management's need to control workers; that is, since workers have no direct stake in the profits of firms, strategies must be devised to command compliance and these strategies are often enforced through technologies—of which the assembly line is an example. Robert Thomas (1999), on the other hand, maintains that these processes of selecting and shaping production technologies are not determined solely by upper management—although he concurs that choices between technologies are shaped by the interests of those involved in them, rather than resulting simply from rational economic and technical calculations.

Thomas's (Ibid.) study of the development of flexible machining systems revealed that tensions within management and the personal ambitions of engineers also play an important role in the selection of tools. Decisions made at the lower levels of firms, he argues, are just as significant as those made by upper management, in the sense that they frame the alternatives presented to the higher echelons. Moreover, Thomas notes, managers do not solely seek to control workers, but also to control other managers, and this influences their decisions. Thus, he suggests, while the design and adoption of technologies is indeed shaped by power relations within organizations, the variety of intervenients and interests at play in these processes cannot be reduced to a conflict between workers and upper management.

What can be extracted from all these accounts is that those involved in the design, production and dissemination of technologies seek to shape them, deliberately or unknowingly, according to either individual interests and goals or in response to hegemonic beliefs. Technologies are thus locus of social struggle which are not controlled solely by those in positions of power. They are, however, shaped by those who have an opportunity to do so, those who have a say in which technologies are developed, what forms they assume and which are adopted. And the contexts in which technologies are developed greatly contribute to determining who is in a position to participate in this contested terrain.

The Shaping of Technologies by Users

To say that creators shape technological artifacts according to their biases and goals is not to say that this necessarily leads to predictable results or that users can be utterly manipulated. That is, it would be a mistake to assume that the intentions and values producers embed in artifacts necessarily lead to the intended effects. Understanding how social biases and politics become embedded in technological artifacts does not fully explain the social aspects of technological artifacts.

This has, in fact, been one of the greatest criticism of Winner's theory of political artifacts. According to Joerges, Winner "insinuates that with the help of building and other technologies one can predetermine effects, make them durable, without being there: real effects, which cannot be interpreted away and which cannot be reduced to some symbolic characteristics of particular technologies. Technologies, he says, have calculable characteristics . . ." (Joerges 1999, 421). Joerges argues, rather, that:

> *. . . not only did Moses's overpasses not control much, but that similar non-effects of intentional control via building can be demonstrated for almost any randomly chosen physical set-up. . . . Like all texts, everyone may read them differently: buildings must and can be read anew all the time. Authorial intentions (that is, designers' purposes) sometimes play a rôle in this, but usually a peculiarly indeterminate one. In a highly contingent process, many others will decide over and over again which meanings and uses are inscribed into built spaces.* (Ibid., 423)

Similarly, Claude Fischer suggests that "instead of reasoning from the properties of the tools . . . one might look at what people do with the tools" (C.S. Fischer 1992, 188). For Fischer, users are also represented in negotiations "that reshape innovations and channel their use by interest groups and ultimately by the purchase decisions of individual customers and the actual use to which those individuals put the technology. By this process the technology is transformed into something different" (Ibid., 256-260). Therefore, Fischer suggests, it should not be assumed that the uses of technologies can be derived directly from the intentions of their creators. Rather, it is necessary to also study how devices are disseminated and adopted, how they are used, how use practices change over time, and how, in turn, these uses alter behaviors and the technologies themselves.

Strategies and Tactics

Michel de Certeau's analysis of everyday practices focuses on ”the ways in which users—commonly assumed to be passive and guided by established rules—operate” (Certeau 1988, xi). For Certeau, these "ways of operating" should not be seen as "merely the obscure background of social activity" (Ibid.). Rather, he argues, in these "minuscule" practices can be glimpsed an element of resistance which "manipulates the mechanisms of discipline and conforms to them only to evade them" (Ibid., xiv).

In *The Practice of Everyday Life*, Certeau (1988) establishes an important distinction between the role played by strategies and tactics in what Blauvelt calls the "battle of repression and expression" (Blauvelt 2003, 20). For Certeau, strategies are the mechanisms deployed by the "subjects of will and power (a proprietor, an enterprise, a city, a scientific institution)" against some external entity (Certeau 1988, xix). The strategic model, Certeau argues, is the basis for political, economic and scientific rationality. Tactics, on the other hand, are employed by the "weak" who "must continually turn to their own ends forces alien to them" and therefore "manipulate events in order to turn them into 'opportunities'" (Ibid.). Tactics, lacking their own place, are defensive and opportunistic, seized in the moment with what is available in the spaces governed by strategies. Through the employment of tactics, the practices of everyday life effectively poach on the territory of others, appropriating its rules and products to signify different interests and perspectives:

> *As unrecognized producers, poets of their own acts, silent discoverers of their own paths in the jungle of functionalist rationality, consumers produce through their signifying practices . . . "indirect" or "errant" trajectories obeying their own logic. In the technocratically constructed, written, and functionalized space in which consumers move about, their trajectories form unforeseeable sentences, partly unreadable paths across a space. Although they are composed with the vocabularies of established languages (those of television, newspapers, supermarkets, or museum sequences) and although they remain subordinated to the prescribed syntactical*

forms (temporal modes of schedules, paradigmatic orders of spaces, etc.), the trajectories trace out the ruses of other interests and desires that are neither determined nor captured by the systems in which they develop. (Ibid., xvii)

Thus, Certeau suggests, it is both possible and necessary to determine the use to which representations, products and spaces are put to:

> *. . . the analysis of the images broadcast by television (representation) and of the time spent watching television (behavior) should be complemented by a study of what the cultural consumer "makes" or "does" during this time and with these images. The same goes for the use of urban space, the products purchased in the supermarket, the stories and legends distributed by newspapers, and so on.*
>
> *The "making" in question is a production, a poesis—but a hidden one, because it is scattered over areas defined and occupied by systems of "production" (television, urban development, commerce, etc.), and because the steadily increasing expansion of these systems no longer leaves "consumers" any place in which they can indicate what they make or do with the products of these systems.*
>
> *To a rationalized, expansionist and at the same time centralized, clamorous, and spectacular production corresponds another production, called "consumption." The latter is devious, it is dispersed, but it insinuates itself everywhere, silently and almost invisibly, because it does not manifest itself through its own products, but rather through its ways of using the products imposed by a dominant economic order.* (Ibid., xii)

Transposing Certeau's dichotomy to the context of this analysis it is possible to see technologies as enactments of strategies by producers which, nevertheless, may be tactically appropriated and repurposed by consumers. That is, although defined by strategies that determine its characteristics—the rules and possibilities they offer to users—the use of these technologies can nevertheless be a locus of, often improvised, micro resistances.

Building on Certeau's theory, Feenberg suggests that as "coded objects, cultural artifacts resemble a syntax regulating behavior that, like speech, follows the rules of code"—but, in turn, speech can also alter syntax (Feenberg 1996, 84). This means that the use of technological artifacts may, at times, effectively modify not only the meaning of technologies but also the direction of their development. The interplay and tension between the rules of use defined by producers and the ways in which these are, sometimes, subverted through practice by consumers can be glimpsed in the cases of the Minitel and Kinect technologies.

The Minitel network, a videotex online service spearheaded by the French Direction Genérale des Télécommunications (DGT) in the late 1970s and early 1980s, was designed to improve the state of telecommunications in France. The network, which was supposed to eventually reach every French household, was implemented through the free distribution of millions of terminals called Minitels. Minitel terminals provided several services, from a phone directory and transport ticket purchases to mail-order catalogs and databases. The goal of the project was to provide a wide variety of information services. However, Feenberg recounts, adopters made little use of this wealth of information beyond consulting the electronic directory (Feenberg 1992, 6). Rather, the most prolific users focused on an obscure feature of the system which allowed for point-to-point synchronous communication.

In 1984, Grétel, one of the three key municipal services that provided information services to the Minitel network, was cracked by a user and transformed into the first online messaging system (Feenberg 1992, 6; Rheingold 2000, 239). According to Michel Landaret, the head of Grétel:

> *We were running an experiment with a very small number of users, to determine whether professional associations and institutions would use data banks. The DGT had not focused on Minitel's communication functions. What happened with Grétel altered the users' relationship to the service in a crucial way. We had only a few dozen users who called into the service. For research purposes, we monitored their usage. . . . So we designed a system to communicate with those users by sending a message directly to their screen, and receive messages back from them . . . . One of our users just cracked that part of the system and used it to talk with friends. As soon as we found out what was happening, we made improvements*

on the service and made it a legitimate part of the system. They loved it. (as cited by Rheingold 2000, 239)

Within six months, according to Rheingold, the system registered 700 hours of connection time per day, more than double the 100 to 300 hours it had achieved before the introduction of communication capabilities (Ibid.). Usage continued to increase to such a n extent that, in the summer of 1985, the volume of traffic eventually exceeded the network's capacity and brought down the entire system (Feenberg 1992, 6). According to Feenberg, by 1987, 40% of the domestic traffic time was spent on messaging (Ibid.) and, in 1986, French students used the Minitel network to coordinate a national strike (Kahn and Douglas 2008, 24).

Although the original plans for the Minitel network did not exclude communication between users, they underestimated its importance by focusing on databases, online transactions and other unidirectional services. Once the preferences of users and the importance of communication became apparent through usage, a number of small firms redesigned the network to enable communication and handle large numbers of users who were more interested in exchanging than receiving information (Feenberg 1992, 6). This eventually led to a profound transformation of the Minitel system:

> *Once communication became a major functionality of the system, its social definition was radically changed. From an original image as "cold" medium, based on wholly impersonal individual transactions between users and machines, [Minitel] evolved toward a new, "warmer" image based on communication with other human beings.* (Ibid.)

Another, more recent example of the transformation of technologies through unintended uses, concerns the Microsoft Kinect, a hands-free controller for the Xbox 360 game console capable of tracking body motion. Shortly after the controller's launch in 2010, Adafruit—an electronics firm with ties to open source communities—hosted a competition for the creation of an alternative open source driver for the Kinect. This call, which had not been sanctioned by the device's producer[11], quickly led to what became known as a frenzy of "kinect hacking" (Hudson and Kelly 2010). Initially launched by Microsoft as just a sophisticated game controller, the Kinect was soon turned by several of its users into a multipurpose computer-vision device with numerous other applications, including 3D mapping for robotic devices (Tanz 2011), a navigational system for the visually-impaired (Fish 2011), and a hands-free tool allowing surgeons to view patients' imaging data (Dotson 2011). While initially opposed to these unauthorized uses of the device—a Microsoft spokesperson stated that the firm "does not condone the modification of its products" and that it had "built in numerous hardware and software safeguards designed to reduce the chances of product tampering" (Wilson 2010)—Microsoft eventually changed its position and began to freely distribute Kinect software development kits to encourage creative applications of the device.

Both the Minitel and the Kinect are instances in which unintended uses that subvert the producers' intentions can transform the meaning and development direction of technologies. Similarly, in a comprehensive study of the introduction and evolution of the telephone in the U.S., Claude Fischer concludes that:

> *While a material change as fundamental as the telephone alters the conditions of daily life, it does not determine the basic character of that life. Instead people turn new devices to various purposes, even ones that the producers could hardly have foreseen or desired. As much as people adapt their lives to the changed circumstances created by a new technology, they also adapt that technology to their lives.* (C.S. Fischer 1992, 113)

The Significance of Technological Configurations

Throughout the histories of technologies, several other cases of unintended and unforeseen applications and consequences can be found. Radio was originally conceived by Marconi as a point-to-point communication system for firms, but was eventually transformed by users first into a grassroots communication system and then into a more centralized

[11] It was later revealed that Johnny Lee, a member of the Kinect development team, had independently and secretly suggested and financed the kinect hacking contest (Terdiman, 2011).

broadcasting system. The Internet was initially created to facilitate secure military communication, but, through the practices of its users-developers, was transformed into what Castells conceptualizes as a system of "mass self-communication" (Castells 2010, xxvii). In short, both producers and users contribute to changing the meanings, uses and roles of technologies.

However, technologies are not endlessly malleable nor defined primarily by what uses are made of them. As noted by Feenberg (2002), Noble (1979), and Winner (1986), the particular characteristics of technologies—the specific ways in which their technical elements are arranged—presuppose some applications and not others prior to any actual use. In other words, the characteristics and affordances of each technology influence action by facilitating some behaviors while hindering others, as observed by Yochai Benkler:

> *Neither deterministic nor wholly malleable, technology sets some parameters of individual and social action. It can make some actions, relationships, organizations, and institutions easier to pursue, and others harder. . . . However, within the realm of the feasible—uses not rendered impossible by the adoption or rejection of a technology—different patterns of adoption and use can result in very different social relations that emerge around a technology.* (Benkler 2007, 17-18)

Although users of the Minitel network and of the Kinect controller seized obscure technical features of the systems to transform them, the possibility for such transformation must be enabled by the technologies in the first place. And these possibilities depend largely on their technical configurations. Even if not entirely determinative, technologies define the realm of the feasible by opening some paths and closing others. And some technological configurations are more open to appropriation, adaptation and transformation than others. This is obvious, for example, in the cases of the television and the Internet. While the former only allows for unidirectional communication, the latter enables a series of alternative—one-to-one, one-to-many, many-to-many—communication processes to take place.

In the sense that they open or close spaces of feasibility, technologies can therefore be conceived as structures within which human practices take place. They are, in the poetic words of Claude Fischer, "The prosaic objects of our culture [that] form the instruments *with* which and the conditions *within* which we enact some of the most profound conducts of our lives" (C.S. Fischer 1992, 140). Thus, Donald MacKenzie and Judy Wajcman contend, deterministic accounts of the role played by technologies in human affairs are partly right: although technologies are socially shaped, their characteristics matter "not just to the material conditions of our lives and to our biological and physical environment—that much is obvious—but to the way we live together socially" (MacKenzie and Wajcman 1999, 5). Langdon Winner takes this notion even further by affirming that technologies are just as influential as legislative and political acts:

> *The things we call "technologies" are ways of building order in our world. Many technical devices and systems important in everyday life contain possibilities for many different ways of ordering human activity. Consciously or unconsciously, deliberately or inadvertently, societies choose structures for technologies that influence how people are going to work, communicate, travel, consume, and so forth over a very long time. In the processes by which structuring decisions are made, different people are situated differently and possess unequal degrees of power as well as unequal levels of awareness. By far the greatest latitude of choice exists the very first time a particular instrument, system, or technique is introduced. Because choices tend to become strongly fixed in material equipment, economic investment, and social habit, the original flexibility vanishes for all practical purposes once the initial commitments are made. In that sense technological innovations are similar to legislative acts or political foundings that establish a framework for public order that will endure over many generations. For that reason the same careful attention one would give to the rules, roles, and relationships of politics must also be given to such things as the building of highways, the creation of television networks, and the tailoring of seemingly insignificant features on new machines. The issues that divide or unite people in society are settled not only in the institutions and practices of politics proper, but also, and less obviously, in tangible arrangements of steel and concrete, wires and semiconductors, nuts and bolts.* (Winner 1986, 29)

Thus, the characteristics of the technologies, which play such an important role in social and individual life, are both socially and technically shaped during formative periods, eventually congealing in the architectures of prevalent machines and systems of machines. Although several social and technical factors may contribute to the shaping of each technology, to a greater or lesser degree the politics, goals, intentions and assumptions of the contexts in which they are created and developed become embedded in the devices. In turn, despite some latitude for adaptation and (mis)use, these assumptions are translated into affordances which greatly influence what can and cannot be done with a given technology. Since the characteristics of technologies are defined by those in a position to shape them, how and by whom technologies are shaped becomes a critical question.

In recent years, an increasing awareness of the processes through which technologies are shaped, along with the transformative and influential role these choices play in contemporary society, has led several thinkers to call for a more democratic approach to the development of technologies. These appeals can be divided into two large categories: the ones that focus mostly on raising awareness, and the ones that propose practical approaches to a democratization of the technosphere.

The first category includes the work of scholars—such as Katz, Light, Thompson, MacKenzie and Wajcman—whose focus has been on providing the theoretical frameworks for a more active involvement in the development of technologies. In *The Social Shaping of Technology*, MacKenzie and Wajcman note that "technological change is a key aspect of what our societies need actively to shape, rather than passively respond to," and thus seek to encourage a more engaged and conscious shaping of technologies (MacKenzie and Wajcman 1999, xv). Likewise, Katz, Light and Thompson state that, although the compilation of essays in their book *Controlling Technology* does not offer definitive answers to the problems raised by and around technologies, its stated purpose is "to understand and to control technological development." For these authors, "In the ideal of a democratic society, the management of technology must be everybody's business" (Katz, Light and Thompson 2003, 144).

Although these scholars draw attention to the need for a more democratic approach to the development of technologies, so that the choices they embody can better reflect the wills and needs of citizens, the real question becomes: how to organize the processes of technological development to enable a greater level of involvement and a wider participation of citizens? The second category thus includes the work of those analysts and critics who have proposed more specific models for a democratization of the technosphere. That is the case of Andrew Feenberg who argues that:

> *A good society should enlarge the personal freedom of its members while enabling them to participate effectively in a widening range of public activities. At the highest level, public life involves choices about what it means to be human. Today these choices are increasingly mediated by technical decisions. What human beings are and will become is decided in the shape of our tools no less than in the action of statesmen and political movements. The design of technology is thus an ontological decision fraught with political consequences. The exclusion of the vast majority from participation in this decision is profoundly undemocratic.* (Feenberg 2002, 3)

Feenberg suggests that a more democratic approach to technological development would include "extensive (if not universal) public ownership, the democratization of management, the spread of lifetime learning beyond the immediate needs of the economy, and the transformation of techniques and professional training to incorporate an ever wider range of human needs into the technical code" (Ibid., 148).

For Langdon Winner, "technology is itself a political phenomenon" that "legislates the conditions of human existence" (Winner 1977, 324). For this reason, it can be subject to political influence. In *Autonomous Technologies*, Winner proposed a "decentralized democratic politics" of technologies "with the express aim of studying their interconnections and their relationships to human need" (Ibid., 324-330), which he further explored in *The Whale and the Reactor*. His central premise is that technologies carry and enact political values, which tend to be more compatible with some social relations than others. For Winner, therefore, a socially conscious and just political system should publicly debate the implications of technologies and democratically decide whether or not to adopt them:

> *We should try to imagine and seek to build technical regimes compatible with freedom, social justice, and key political ends. Insofar as the possibilities present in a given technology allow it, the thing ought to be designed in both its hardware and*

social components to accord with a deliberately articulated, widely shared notion of a society worthy of our care and loyalty. . . .

What I am suggesting is a process of technological change disciplined by the political wisdom of democracy. . . . It would, presumably, produce results sometimes much different from those recommended by the rules of technical and economic efficiency. Other social and political norms, articulated by a democratic process, would gain renewed prominence. Faced with any proposal for a new technological system, citizens or their representatives would examine the social contract implied by building the system in a particular form. They would ask, How well do the proposed conditions match our best sense of who we are and what we want this society to be? Who gains and who loses power in the proposed change? Are the conditions produced by the change compatible with equality, social justice, and the common good? To nurture this process would require building institutions in which the claims of technical expertise and those of a democratic citizenry would regularly meet face to face. Here the crucial deliberations would take place, revealing the substance of each person's arguments and interests. The heretofore concealed importance of technological choices would become a matter of explicit study and debate. (Winner 1986, 55)

Whereas Feenberg advocates a radical approach that would involve a profound social transformation, Winner proposes a more balanced solution based on the deliberate formation of a technological public sphere—understood in the Habermasian sense of "a society engaged in critical public debate" (Habermas 1991, 52). Although Winner's emphasis on the necessity to bring moral and political principles to the processes of shaping technologies is an important step towards the formulation of practical programs, it is still essentially theoretical and has, for this reason, been criticized for its lack of specificity (Smith 1994, 33). Moreover, while advocating for a more democratic approach to the shaping of technologies, Winner appears to also be proposing the creation of institutions that require the enactment of new laws and organizations—that is, of institutions that can only be created and governed from the top down. The following chapters suggest that there is another, more practical path towards a democratization of the technosphere, one that shares Winner's vision of a public sphere in which technologies are publicly shaped, but that is based on grassroots practices, rather than on state-based initiatives.

II. TWO APPROACHES

In an essay titled "The Cathedral and The Bazaar," Eric S. Raymond (2005) identifies two models for the development of software. In the one adopted by most firms, software is built like cathedrals, "carefully crafted by individual wizards or small bands of mages working in splendid isolation, with no beta to be released before its time" (Ibid.). The other resembles "a great babbling bazaar of differing agendas and approaches" in which software is concurrently and collaboratively developed by multiple organizations and individuals (Ibid.). This is also an apt analogy to describe the two approaches to the development of technological artifacts that concern this dissertation. On the first, technologies are shaped by a relatively small number of professional producers—primarily within firms, but also in academic institutions or governmental agencies—and then disseminated to the masses for consumption. On the second, technologies are collectively shaped by both professionals and amateurs in a system open to public participation. The first approach will be referred to here as the broadcast approach, given that it echoes the centralized networks and one-to-many model characteristic of broadcast media. The second will be designated the distributed approach in reference to the architecture of the Internet and the peer-to-peer communication and organizational systems it enables.

II.1 The Broadcast Approach

No cultural image better captures the way that mass industrial production reduced workers to cogs and consumers to receptacles than the one-dimensional curves typical of welfare economies—those that render human beings as mere production and demand functions.

—Yochai Benkler (2006, 137)

Since the early twentieth century, the broadcast approach has been the dominant model for the production of both information and goods. Nowhere has this been more studied, debated, and criticized than in the media arena. With the firm establishment of unidirectional mass communication media in the twentieth century, individuals were turned into recipients of information produced and broadcast by the television, radio, newspaper and book industries. Although several media analysts have argued that mass media serve dominant groups by transmitting their views of the world to the rest of the population (the "magic bullet" or "hypodermic needle" model), other theories suggest that, rather than absorbing information passively, media audiences are actively involved in interpreting messages according to their own personal and social contexts (the active audience theory). Nevertheless, despite the interpretative flexibility proposed by the active audience theory, in the broadcast model the media product remains one that most individuals consume, not one that they actually generate (Benkler 2006).

This centralized and unidirectional production and dissemination model is not, however, exclusive to the media arena. It extends beyond the realm of information into the production of most goods. In the technosphere, more specifically, technological artifacts are typically designed and produced by firms where groups of professionals craft finished devices—and sophisticated factories manufacture them in often large quantities—which are then "broadcast" to the public for consumption. This is the process through which most technological artifacts individuals use on daily basis are currently produced and disseminated—from cellphones and computers to appliances and automobiles. Although there is great latitude in terms of what a cellphone or computer can be used for, their properties and affordances are primarily defined by the professionals firms employ and hardwired into the devices. Users are thus limited to selecting from the options offered by these producers, just as television audiences are limited to selecting from the programs broadcast by television stations.

Three fundamental assumptions underlie the practices of the broadcast approach in the technosphere. The first assumption is that technological innovation and development are complex processes requiring large investments in equipment and expertise, and must therefore be conducted by organizations capable of providing such resources. The second, which derives from the first, is that exclusive rights over the use and distribution of technologies are necessary to offset the investment in expertise and development made by these organizations. The third states that, due to the complexity and costs of technological development, average users of technologies cannot, need not and want not to know how technologies work.

1) *Technological innovation and development are complex processes requiring large investments in equipment and expertise.* *Therefore, they are best conducted in professional organizations by teams of formally-trained experts with sophisticated laboratories. The days of untrained independent inventors like Thomas Edison are long gone. Today, non-experts are no longer capable of keeping pace with, much less leading, technological development.*

The origins of this tenet can be traced to the first stages of the Industrial Revolution. The greatest contribution of this period, Alfred Whitehead argues, was not the manufacturing machinery and large technical systems that would define industrial society, but "the invention of the method of invention" (Whitehead 1997, 96).

In the nineteenth century, as the transformative power of technologies was becoming apparent, a culture of invention began to take shape in Europe and the U.S. (Klein 2007). During this period of unprecedented innovation, before the emergence of corporate and governmental industrial research laboratories, the invention of new technologies was primarily undertaken by independent inventors (Hughes 1984). Between 1870 and 1920, the groundbreaking creations of Alexander Graham Bell, Thomas Edison, Nikola Tesla, Guglielmo Marconi, and the Wright brothers, to name a few, fueled the emergence of new industries and profoundly transformed modern experience. These remarkable inventors were not alone, though. Thousands of others, encouraged by the figures of the most prominent inventors and working at a grassroots level, undertook the development of new technologies and contributed with discoveries of their own (Hughes 1984) (Giedion 2014) (Postman 2011).

In the U.S., the era of independent inventors, as Hughes (1984) designates this period, would, however, come to an end after World War I when the phrase "research and development" replaced "invention" and the independents gave way to industrial scientists. Up until this moment, the large corporate producers of technologies had relied mostly on the acquisition of patents from independent inventors. This began to change when industrial corporations turned to internal laboratories—a strategy pioneered in the U.S. by the firms AT&T and General Electric and which was soon replicated by several others[12]. According to Hughes, the shift from independent inventors to corporate laboratories as the center of technological innovation resulted from the large enterprises' need to better enable and control the expansion of already existing technological systems. These firms, Hughes argues, "wished to choose the problems that inventors would solve, problems pertaining to patents, machines processes, and products in which the corporations had heavily invested" (Ibid., 151).

In this process, the generalist inventor-entrepreneur, epitomized by Thomas Edison, was replaced by teams of scientists and engineers employed by the new larger-than-life organizations. "Independent inventors had boasted of their craft and art," Hughes writes, "scientists would take pride in the objectivity, universality, and transfer ability of their knowledge" (Ibid., 139). This shift was also accompanied by the notion that, although independent inventors had made important scientific and technological contributions in the early days of the Industrial Revolution, their untrained and intuitive approach had been outclassed by the formally trained specialists of corporate, military and academic organizations. This perspective can be glimpsed in the terms in which Frank Jewett, a Ph.D and the vice-president of AT&T, framed "Edison's contributions to science and technology:"

[12] Such as Du Pont, Kodak, Standard Oil, and General Motors.

Despite the fact that Edison was imbued to the highest degree with that characteristic which is the hallmark of science, namely, the characteristic of subjecting every theory to the acid test of controlled experiment, he lacked nevertheless the formal training which we normally associate with men of science and engineering. . . . as science itself developed, the practical application of new knowledge came to require a type of training which Edison did not possess. (Jewett 1932, 66)

The process of institutionalization, systematization and professionalization of invention, Whitehead argues, was pioneered by German technological schools and universities in which "progress did not have to wait for the occasional genius, or the occasional lucky thought" (Whitehead 1997, 97). Rather, it was pursued through a systematic process in which professors and students conducted highly specialized research work (Hughes 1984). For Whitehead:

. . . the full self-conscious realization of the power of professionalism in knowledge in all its departments, and of the way to produce professionals, and of the importance of knowledge to the advance of technology, and of the methods by which abstract knowledge can be connected with technology, and of the boundless possibilities of technological advance,—the realization of all these things was first completely attained in the nineteenth century; and among the various countries, chiefly in Germany. (Whitehead 1997, 97).

Thus, at the dawn of the twentieth century invention and innovation had become primarily the purview of corporate and academic research laboratories. "Gradually," Maury Klein writes, "the tinkerers evolved into professionally trained scientists and engineers who became a staple of the corporate as well as academic worlds" (Klein 2007, 672). The replacement of self-identified inventors with a much more centralized system pivoted by well-funded organizations signaled a move towards the broadcast model: as the locus of invention shifted from independent citizens to corporate research and development laboratories, firms became the primary originators and producers of technologies.

2) ***Exclusive intellectual property rights are essential for the survival of enterprises and, therefore, for the technological advancement they provide****. Given the large investments required by technological innovation and manufacturing, enterprises must ensure future revenues in the form of monopolies over the distribution, production and commercialization of the technologies they create, as well as the knowledge behind them.*

The replacement of independent inventors with corporate laboratories and the large investments made by firms in research and development also gave rise to a system in which industrial corporations sought to control both the invention and the subsequent development of technologies through what Hughes describes as "a monopolistic structure of interrelated basic and dependent patents" (Hughes 1984, 143). This was the case, for example, of the American Bell Telephone Company, which, from early on, focused on the accumulation of patents as a means to establish a monopoly over telephone services in the U.S. (Wasserman 1985).

Patents and other intellectual property legal mechanisms were originally conceived to provide incentives to invention by granting creators exclusive rights over the products of their work for a given period of time. The rationale behind the implementation of intellectual property laws was that, although inventors would hold a monopoly over their creations for a short period of time, the knowledge they generated would eventually become publicly available and benefit society at large. Despite this, throughout the twentieth and twenty-first centuries, the scope and breadth of intellectual property rights has continuously expanded in both the U.S and Europe. While in 1790 a U.S. copyright term had a duration of 14 years (W. W. Fisher 1999), at the time of writing the period covered by copyrights had expanded to 70 years after the author's death in both the U.S. and the European Union. As part of the same process, patent law has expanded to cover an increasing number of items, from plant varieties and common business models (Cox and Jenkins 2005) to software and surgical procedures (Fisher 1999).

This expansion of the duration and breadth of intellectual property laws, Yochai Benkler (2006) argues, is both the source and the result of the increasing reliance of firms on exclusive proprietary rights. In other words, the expansion of intellectual property laws not only encourages the development of business models based on exclusive rights, but further contributes to the expansion of these laws as an increasing number of firms advocates for the augmentation of the terms and scope of their intellectual property:

> *Strong, broad, exclusive rights like these have predictable effects. They preferentially improve the returns to business models that rely on exclusive rights, like copyrights and patents, at the expense of information and cultural production outside the market or in market relationships that do not depend on exclusive appropriation. They make it more lucrative to consolidate inventories of existing materials. The businesses that developed around the material capital required for production fed back into the political system, which responded by serially optimizing the institutional ecology to fit the needs of the industrial information economy firms at the expense of other information producers.* (Benkler 2006, 57)

Such business models based on the acquisition and exercise of exclusive rights are now so widely established in industrial economies that, in some instances, appear to defeat the original purpose of intellectual property laws by taking precedence over invention and innovation. According to the *New York Times*, for example, Apple and Google—two of the most prominent producers of technologies—spent more on patents than in research and development of products during 2011 (Duhigg and Lohr 2012).

However, this reliance on exclusive rights has also grown problematic in a world in which many goods have become digital. While most pre-digital content production and distribution businesses were based on the fact that information could not be easily reproduced and distributed, today digital goods can be duplicated with a click of the mouse and distributed worldwide via the Internet. This shift from information encoded in material supports to digital data meant a shift from rival to non-rival goods—that is, from goods whose consumption by one consumer prevents simultaneous consumption by others (rival) to goods that can be consumed simultaneously by multiple consumers (non-rival). Independently the cost involved in the production of the first instance of a non-rival good, the cost of providing it to additional (marginal) consumers is zero. This is the case of digital information: whatever the cost of producing the first instance, once it exists, the cost of duplicating it is marginally zero.

As more and more cultural products are created and distributed in digital form, and therefore can be easily copied and redistributed, it has become increasingly difficult to enforce ownership over information and content, leading to disruptions in traditional business models based on sales of exclusive content. For this reason, several content producers in pre-digital industries—primarily the movie, music, and publishing industries—have turned to legal and technical mechanisms in order to reintroduce rivalry into non-rival goods. Digital Rights Management (DRM)—a set of technologies, usually embedded in digital information products, meant to impede or limit copying, altering and viewing of digital products—are the most common technical mechanisms to achieve this. DRM attempts to enforce intellectual property by not only preventing the duplication of digital files but also by restricting the number and types of devices it can be viewed on—an extreme example of this is a recent DRM technology embedded in game consoles with computer vision capabilities, which is capable of detecting how many people are present in a room and shut down if there are more than the copyright owner allows (Parfitt 2013).

Closely related to DRM mechanisms is the increasingly heated debate about whether or not users have the right to modify or even open their own computational devices. In the U.S., for example, Section 1201 of the Digital Millennium Copyright Act states that "No person shall circumvent a technological measure that effectively controls access to a work protected under this title"[13]. This has often been interpreted as a prohibition of what is commonly termed jailbreaking: modifying a device to run independent software. In the last few years, additional constrains have been put in place by the custom adopted by some manufacturers, such as Apple, to determine which applications can be installed on the mobile devices they produce. Additionally, technical measures such as Apple's tamper-resistant screws—which are non-standard and thus cannot be removed with common screwdrivers—serve to further discourage tinkering with one's own devices.

In this context, digital technologies and the practices that surround them introduced important changes in the use of cultural and informational goods. On the one hand, the non-rival nature of digital information means that a good can be simultaneously owned and given away and, for this reason, has greatly increased sharing practices amongst strangers. On the

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[13] *Copyright Law of the United States of America and Related Laws Contained in Title 17 of the United States Code*. http://www.copyright.gov/title17/92chap12.html.

other hand, the push from exclusive rights -based businesses to counteract this practice has meant the introduction of artificial restrictions on what users are allowed to do with these goods. Thus, in the broadcast model, the maintenance of exclusive rights often requires the limitation or elimination of one of digital's most fundamental properties: the ability to easily duplicate and transmit information.

The tension between the possibilities opened by digital technologies and the efforts of older industries to preserve pre-digital business models has led to a clash between two fundamentally different views: those who see digital communication technologies as enablers of civil liberties and free speech, and those who emphasize the economic need to support exclusive rights -based business models. These differences can be clearly discerned in the conflicts surrounding three pieces of legislation intended to curb digital piracy: the Stop Online Piracy Act (SOPA) and the Protect IP Act (PIPA) in the U.S., and the international Anti-Counterfeiting Trade Agreement (ACTA).

The PIPA bill, which was introduced in the U.S. Senate in May 2011, intended to combat the distribution of illegal copies of copyrighted materials, of counterfeit goods, and of technologies capable of disabling DRM mechanisms. For this purpose, the bill would provide the American Department of Justice with the ability to require "information location tools" (such as search engines and certain domain servers) to delete all hyperlinks to the target website—as well as "take technically feasible and reasonable measures, as expeditiously as possible, to remove or disable access to the Internet site associated with the domain name set forth in the order"[14].

Similarly, the SOPA bill, which was also introduced in the U.S. Senate in 2011, sought to radically strengthen the U.S. government's ability to punish websites that distribute unauthorized copyrighted material, turn the streaming of movies or music without approval of copyright owners into a felony punishable with up to five years in prison, allow courts to demand that search engines remove all links to offending sites, and provide the Department of Justice with the ability to close down an entire top-level domain due to the activity of a single user.

[14] *Protect IP Act*. http://www.leahy.senate.gov/imo/media/doc/BillText-PROTECTIPAct.pdf.

Along similar lines, ACTA, a multinational treaty with the goal of establishing international regulations for the enforcement of intellectual property, focuses on countering online counterfeit goods and copyright infringement. The agreement's signatory parties are "obligated to provide enforcement procedures that permit effective action against any act that infringes upon the IP rights covered by the agreement, including expeditious remedies to prevent infringements and remedies to deter infringements" (Holm 2011).

All three bills were supported by the largest media firms and organizations[15], but were also met with strong opposition from a number of organizations and individuals who publicly displayed concern with the threats to civil liberties and free speech enabled by the proposed legislations.

In an article titled "Should Copyright be Allowed to Override Speech Rights?," for example, scholar Marvin Ammori argued that PIPA "would dangerously limit both user privacy and social networking sites' ability to create open forums for free speech" (Ammori 2011). Constitutional law professor Laurence Tribe contended that SOPA "would dramatically chill protected speech by undermining the openness and free exchange of information at the heart of the Internet" (Tribe 2011, 4). A 2009 open letter[16] maintained that "the current draft of ACTA would profoundly restrict the fundamental rights and freedoms of European citizens, most notably the freedom of expression and communication privacy" (Free Knowledge Institute 2009). Kader Arif, a French Member of the European Parliament, argued that "by focusing on the fight against violation of intellectual property rights in general," ACTA "treats a generic drug just as a counterfeited drug. This means the patent holder can stop the shipping of the drugs to a developing country, seize the cargo and even order the destruction of the drugs as a preventive measure" (as cited by Arthur 2012). And in 2010, the European Parliament passed a resolution criticizing some of the ACTA dispositions as failing to "respect fundamental rights, such as the right to freedom of expression and the right to privacy" (European Parliament 2010).

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[15] The Motion Picture Association of America, the International Trademark Association, the Recording Industry Association of America, the Entertainment Software Association, and Viacom, to name a few.

[16] Signed by, amongst others, the European Digital Rights, Consumers International, the Free Software Foundation, the Electronic Frontier Foundation (EFF), and the Free Knowledge Institute.

In late 2011, posts and comment threads describing SOPA's and PIPA's provisions began appearing in influential websites such as Reddit and Boing Boing. Scholars, artists, entrepreneurs, and even venture capitalists further spread the message through editorials describing the chilling effects the bills would have on life in cyberspace. This wave of protest grew across the Internet and eventually culminated in a day of online protest—January 18, 2012—when approximately 7,000 websites went dark or replaced their homepages with anti-censorship messages. Notably, the English language Wikipedia replaced all its articles—with the exception of the SOPA and PIPA articles—with a banner that read: "Imagine a world without access to free information." Within a few days of these protests, U.S. Senate voting on SOPA and PIPA was postponed indefinitely.

ACTA, however, was signed in 2011 by Australia, Canada, Japan, Morocco, New Zealand, Singapore, South Korea, and the United States, and in 2012, by Mexico, the European Union and 22 member states of the European Union. The signing of ACTA by the European Union was followed by vigorous protests across Europe—demonstrations against the agreement took place in February 2012 in dozens of European cities and attracted tens of thousands of protesters (Kirschbaum and Ivanova 2012).

Thus, the conflicts that surrounded PIPA, SOPA and ACTA aptly illustrate the character of the technosphere as a terrain of political struggle and the complex ways in which technologies and politics intertwine. In technologies—and in the social, economic, legal and political systems that rise and fall around them—fundamental values pertaining to human freedom are periodically negotiated and renegotiated.

3) ***Users of technologies cannot, want not and need not know how technologies work.*** *While the mechanisms of early cars and radios might have been typically modified and repaired by their users, contemporary technologies are far too complex for amateurs. Knowledge about the makeup and functioning of technologies, even those used by millions of people every day, is today considered to be largely the purview of technical experts. In light of this, the producer-expert seeks to design devices to be easily used with no knowledge of their inner workings.*

Most contemporary technologies are extremely complex. Even small devices, such as cellphones, are composed of a large number of interacting parts, often miniaturized. Furthermore, unlike earlier mechanical systems, their functioning can not be grasped just by observing the hardware: it is not possible, for example, to see electricity flow through an electric circuit without measuring tools; nor is it possible to understand the logic of a computational device without looking at the code that defines it. Understanding how contemporary technologies work increasingly requires not only knowledge of several technical disciplines, but also knowledge of the complex scientific phenomena that underlie them.

Due to this complexity, the design, repair and even just the understanding of how technologies work has become the purview of teams of professionals and is considered to be beyond the grasp of most others. However, devices such as automobiles, cellphones and computers are used daily by individuals with no formal training in technological fields. What makes this possible, Donald Norman (1999) argues, is the progression of technologies through consecutive phases of maturation, during which their inner complexity increases while their outer complexity and the skills necessary to use them decrease.

In their early stages, Norman (Ibid.) argues, technologies are typically simpler in technical terms, but more difficult to operate and, therefore, require a higher level of skill from the user. This could be observed, for example, in the first radios and automobiles. While the early versions of these devices were comparatively simple, they also required skilled radio operators and mechanically-savvy drivers. As technologies progress, more functions and controls are added, further increasing operational difficulty and making additional demands on the skill of users. Eventually, however, through the automation of processes and a gradual increase in stability and reliability, technologies reach a point in which their operation becomes highly simplified. Whereas early radios had to be manually tuned and early automobiles had to be manually started, contemporary versions of these devices display comparatively fewer controls and are, for the most part, automated. All technologies, Norman contends, undergo this process of maturation in which the increasing simplicity of operation is paralleled by an increase in the technical complexity of the devices.

Accordingly, Norman maintains, a technology's consumers also change as it matures. The first users of a new technology are the early adopters: enthusiasts who are primarily drawn by the technical features and performance of the devices. Once technologies mature, however, they begin to attract a different type of user: the late adopters who seek "value without hassle" and are principally interested in simplicity of use and convenience (Norman 1999, 49). These late adopters, Norman contends, make up the vast majority of technologies' users.

For Norman, the main point is that, not only most users of technologies cannot understand how devices work, but also that they do not wish to. "Normal consumers who make up the bulk of the market," he writes, "consist of people who just want to get on with life, people who think technology should be invisible, hidden behind the scenes, providing its benefits without pain, anguish and stress" (Ibid., 52). Thus, today, the job of engineers and designers consists in not only creating technologies that work, but also in designing them in such a way that their operation does not require an understanding of the underlying principles or technical functioning involved:

> *The ideal system so buries the technology that the user is not aware of its presence. The goal is to let people get on with their activities, with the technology enhancing their productivity, their power, and their enjoyment, ever the more so because it is invisible, out of sight, out of mind. People should learn the task, not the technology. They should be able to take the tool to the task, not as today, where we must take the task to the tool.* (Ibid., 75)

The evolution of the electric motor, Norman suggests, is an example of how creators should approach the design of technological artifacts. In the early twentieth century, when electric motors were still costly, consumers acquired one motor to which various attachments could be added to convert it, for example, into a fan, a sewing machine, or a vacuum cleaner. Today there are dozens of electric motors in a typical home, but they have become invisible, hidden inside various appliances:

> *The motors are embedded within these specialized tools and appliances so that the user sees a task-specific tool, not the technology of motors. Embedded*

> *motors are commonplace, but because they are invisible, the average person doesn't have to know anything about their operation or the details of their technology, or even have to know they are there.* (Ibid., 659)

In this perspective, concealing the inner workings of technological devices seeks to emphasize form and function over functioning. Hidden mechanisms, it is thought, make devices aesthetically pleasing, inviting, accessible and friendly to users. This strategy of invisibility is gaining terrain in the field of technological design and has become a goal to strive for: to make technologies disappear from view and consciousness, to make them "transparent."

Jay Bolter and Richard Grusin (1999) proposed the concept of "remediation" to describe the representation of one medium in another and, noting that contemporary culture seeks simultaneously to multiply its media and erase all traces of mediation, identify immediacy and hypermediacy as its double logic. The logic of immediacy requires that the medium become transparent and thus provide direct access to the content it represents. In this sense, a transparent interface "erases itself, so that the user is no longer aware of confronting a medium, but instead stands in an immediate relationship to the contents of that medium" (Bolter and Grusin 1999, 24). According to this logic, Mark Weiser suggests that "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser 1991, 94). Today, many contemporary designers and human-computer interaction specialists take transparency as a fundamental norm in interface design, a tendency that has found particular expression in the ubiquitous computing field. Hiroshi Ishii, head of the Tangible Media Group at MIT, bases his work precisely on the notion of transparency and argues that "Weiser's main message was not the ubiquity of computers, but the transparency of interface that determines users' perception of digital technologies embedded in our physical environment seamlessly" (Ishii 2004, 1299).

This notion of technologies seamlessly embedded in the environment was also adopted by Norman who postulates that computational devices should become increasingly like appliances. In a book aptly titled *The Invisible Computer* (1999), he argues that general purpose computers should be replaced by a multiplicity of information appliances that perform specialized tasks. Thus, rather than focusing on the computational aspects of the technology, they will be defined, and thought of, in terms of the services they enable—just as today vacuum cleaners are not thought of as electric motors with suction attachments, but as purpose-specific devices.

Although Norman finds that contemporary computers have yet to achieve the status of information appliances[17], transparency has become a consensual goal for human-computer interface design. Inspired by the Graphical User Interface (GUI), which is now the standard computer interface, contemporary designers strive to create transparent technologies that erase themselves from view and allow users to focus on the content or functions they provide. As Bolter and Gromala note, although designers might have different notions of what constitutes transparency, they "seldom seem to question that transparency itself is the goal" (Bolter and Gromala 2004, 4). This approach can be easily identified in the majority of consumer technological artifacts that permeate everyday life. Today, computational devices such as cellphones, tablets and mp3 players, are typically designed as "appliances," enclosed in sealed boxes with which users interact through carefully designed sets of icons and buttons —thus removing from the users' view and consciousness the technical specificities of the devices.

Producers and Consumers

The concentration of the design and production of technologies in firms, the reliance on exclusive rights that requires the obfuscation of technical information, and the efforts to render technologies invisible to their users mean that, as Eric von Hippel suggests, "a user's only role is to have needs, which manufacturers then identify and fill by designing and producing new products" (Hippel 2005, 50). The broadcast approach to the development of technological artifacts thus implies a staunch separation between producers and consumers in which the former create, shape, and produce, and the latter select from the options made

[17] In fact, his main criticism of computational devices is that they are "complex, difficult to learn, difficult to use, difficult to maintain" (Norman 1999, 645)

available by producers—that is, choose which devices and which predefined features to use. The underlying assumption here, as pointed out by Winner, is that:

> *"How things work" is the domain of inventors, technicians, engineers, repairmen, and the like who prepare artificial aids to human activity and keep them in good working order. Those not directly involved in the various spheres of "making" are thought to have little interest in or need to know about the materials, principles, or procedures found in those spheres.* (Winner 1986, 5)

This assumption about the roles of producers and consumers in the broadcast approach is evident not only in its model for design, production and distribution of technologies, but also in the devices and use rules that accompany them. That users are restricted to using technological artifacts within the bounds defined by producers is embodied in the shape and construction of the devices themselves, which are typically enclosed in sealed cases that hide their inner mechanisms and are not meant to be opened. The result is a —both literal and figurative—*blackboxing* of technological artifacts in which technical knowledge is monopolized by the producers.

Thus, as Yochai Benkler suggests, the industrial economy on which the broadcast model relies "specialized in producing finished goods . . . to be consumed passively, and well-behaved appliances like televisions, whose use was fully specified at the factory floor" (Benkler 2006, 126). Contemporary industrial economies, Benkler argues:

> *. . . center on market-based, proprietary models, with a professional commercial core and a dispersed, relatively passive periphery. Our conceptions of human agency, collective deliberation, and common culture in those societies are embedded in the experience and practice of capital-intensive information and cultural production practices that emphasize proprietary, market-based models and starkly separate production from consumption. Our institutional frameworks reflect those conceptual models of information production and exchange, and have come, over the past few years, to enforce those conceptions as practiced reality, even when they need not be.* (Ibid., 460)

Technological Determinism

The theory that the relationship between technologies and society is reciprocal, rather than unidirectional, is currently well established amongst humanistic and social scholars[18]. Despite this, in most popular and media narratives technologies are still predominantly portrayed as autonomous forces which unidirectionally impose demands on society (MacKenzie and Wajcman 1999; Smith and Marx 1994; Bimber 1994). This technological determinist view is typically composed of two interrelated tenets. The first asserts that technologies have profound impacts on social practices. The second postulates that technologies evolve according to the inherently rational logic of science and technology—of which "Moore's Law"[19] is an illustrative example—and are, therefore, essentially autonomous and asocial.

The transformative power of technologies—the ways in which the introduction and adoption of new technologies affect the fabric of everyday life—is experienced first hand by citizens of industrialized societies. In the nineteenth century, this became painfully apparent in the deep social transformations that accompanied the Industrial Revolution. In recent decades, it can be observed in the ways in which the widespread adoption of digital technologies transformed the realms of work, play, organization, production, consumption, and communication. Thus, the technological shaping of society, more than being conveyed as an explicit idea, is typically understood and confirmed by direct experience.

The persistence of the second tenet of technological determinism—which has been contradicted by a number of studies and theories (see chapter 1)—can equally be explained by perceptions based on direct, first hand experience under the broadcast model. In this approach, technologies are developed and manufactured by small groups of producers —"carefully crafted by individual wizards or small bands of mages working in splendid isolation" in Eric Raymond's (2005) evocative analogy—and subsequently disseminated for public consumption. Given the strict distinction between producers and consumers typical of the broadcast approach, the everyday experience of users of technologies is based chiefly on

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[18] See, for example, Croteau and Hoynes (2003), Bimber (1994), Smith and Marx (1994), MacKenzie and Wajcman (1999).

[19] In 1965, Gordon Moore suggested that the number of components in an integrated circuit doubled every two years (Moore 1998). This was later termed "Moore's Law" by Carver Mead (Moore 2005).

contact with the finished devices themselves. This conception of technologies in artifactual terms, Smith and Marx argue:

> *. . . conveys a vivid sense the efficacy of technology as a driving force of history: a technical innovation suddenly appears and causes important things to happen. Whether the new device seems to come out of nowhere, like some deus ex machina, or from the brain of a genius like Gutenberg or Whitney, the usual emphasis is on the material artifact and the changes it presumably effects. In these episodes, indeed, technology is conceived in almost exclusively artifactual terms, and its materiality serves to reinforce a tangible sense of its decisive role in history. Unlike other, more abstract forces to which historians often assign determinative power (for example, socio-economic, political, cultural, and ideological formations), the thingness or tangibility of mechanical devices—their accessibility via sense perception—helps to create a sense of causal efficacy made visible. Taken together, these before-and-after narratives give credence to the idea of 'technology' as an independent entity, a virtually autonomous agent of change.* (Marx and Smith 1994, x).

Under the broadcast model users are not privy to the processes through which most devices emerge and eventually assume their shape—which are typically enveloped in secrecy and shielded from the public eye. Such lack of familiarity with and access to the processes through which technological artifacts are developed—and the choices that are made throughout those processes—effectively conceals from everyday perceptions the very human factors that shape technologies. Thus, from the point of view of the majority of users, technologies do appear to emerge "out of nowhere, like some *deus ex machina*" (Ibid.).

The direct experience of the ways in which technological artifacts contribute to transforming human experience, along with the invisibility of the human processes that shape them, fosters the notion that technologies are essentially autonomous—shaped primarily by an asocial technical logic and the pursuit of efficiency. In turn, this conception of the development of technologies as an autonomous process eventually leads to an understanding of the specific shapes of technologies as necessary and inescapable: if technologies are asocial forces evolving according to the technical necessity of increased efficiency, individuals can be no more than mere recipients of their services and disservices. This leaves citizens of industrialized societies with only two choices: joyful acceptance or dejected resignation. If technologies are autonomous and necessarily bring progress to humankind, one need neither be concerned nor question them. If, on the contrary, technologies are autonomous and necessarily result in a degradation of individual and social experience, one can only respond with dejected acceptance—or, as Mumford suggested, extricate oneself through "quiet acts of mental or physical withdrawal" (Mumford 1970, 433).

Thus, one of the most dire effects of this view is the widespread belief that individuals cannot alter the course of technological progression and that the present shape of the technologies industrialized societies have come to rely on is both necessary and unalterable. This view promotes a passive attitude towards technological change by focusing on how to adapt to technologies, rather than on how to shape them. As MacKenzie and Wajcman (1999) point out, precisely because technological determinism is partially correct—technologies do play a fundamental role in human experience—its second tenet and the passivity it implies greatly impoverish the technosphere in particular and social life in general. This overwhelmingly passive attitude was characterized by Winner as the "technological somnambulism" typical of a culture that rarely examines, discusses or judges technologies (Winner 1986, 9).

Consumers' Sovereignty

Even where there is an understanding that technologies are shaped by social dynamics, the gap between producers and users—and the clearly defined roles attributed to each in the broadcast approach—still place technologies beyond shaping by most individuals. Under this production and dissemination model, users are once again confronted with a binary choice: to acquire or not to acquire the devices created by professional producers. These cumulative individual purchases contribute to determining which products will succeed in the market—and will therefore remain in production in response to continued demand—and which will be discontinued. This is known in economics as "consumers' sovereignty," a term coined by William Harold Hutt (1940), and often referred to in American popular culture as "voting with one's wallet." This popular expression, by relying on an analogy with the democratic process while reducing it to the act of material acquisition, equates consumption with democratic participation in the institutions of industrialized society. The shortfalls of this "democracy" are poignantly expressed by Benkler in his assertion that:

> *No cultural image better captures the way that mass industrial production reduced workers to cogs and consumers to receptacles than the one-dimensional curves typical of welfare economies—those that render human beings as mere production and demand functions.* (Benkler 2006, 137).

Thus, the broadcast approach not only tends to promote an attitude of passivity towards technology—by reinforcing and perpetuating the notion that technologies are beyond social influence—but also to limit the participation in the shaping of technologies of the vast majority of citizens to the exercise of their right to purchase or not to purchase. With technological artifacts being designed and manufactured by a minority of producers and then shipped to the masses for consumption, it is no wonder that technologies appear to be outside most individuals' realm of influence. This is further reinforced by the complexity and miniaturization of most contemporary devices and the tamper-proof cases that often enclose them—which simultaneously signify and materialize a rigid boundary between the user and the technological artifact.

II.2 The Distributed Approach

It was a philosophy of sharing, openness, decentralization, and getting your hands on machines at any cost to improve the machines and to improve the world.

—Steven Levy (2010, ix)

On the margins of the broadcast model, an alternative approach has, for several decades, both coexisted and conflicted with the now dominant model. Between the 1900s and 20s, it was common for radio enthusiasts to make their own radio receivers and emitters. In the 1950s, computer software was openly developed and shared across organizational boundaries. In the 1970s, the first personal computers were created by hobbyists who, lacking access to professionally manufactured computers, collaborated to make their own. These amateur radio operators, early programmers, and computer enthusiasts were simultaneously users and creators, emitters and receivers. They not only blurred the distinction between producers and consumers that became so evident in the last decades of the twentieth century, but actively participated in the shaping of both the technologies and the social practices that emerged around them. Today these distributed development practices are re-emerging.

In the distributed approach, contrary to the broadcast model, the development of technologies is open to public participation. Although they may also originate from corporations, academic institutions and governmental agencies—and even if the principal development efforts remain within those organizations—technologies developed according to the distributed approach can be studied, duplicated and transformed by anyone who wishes to do so. To make this possible, creators make publicly available the hardware plans and software code necessary to enable users to understand, replicate and modify their devices. With technological artifacts often designed to facilitate transformation and access to plans that explain their functioning, users are not only allowed by positively encouraged to appropriate and transform them. Given that many users also publish the plans for their modifications, all others, including the original creators, are then able to incorporate their modifications into new versions of the devices. As such, the distributed approach blurs the line separating producers from users and views each user as a potential producer. The result is a constant flow of information between producers-users who build upon each other's work to generate alternative or convergent versions of technologies. In practical terms, this means that distributed approach technologies can be both individually transformed and collectively shaped.

To better illustrate and explore the characteristics, practices, and questions raised by the distributed model, the following sections present brief overviews of the emergence and shaping of some of the most important technologies of our time—viewed from the perspective of the push and pull between the broadcast and distributed approaches. While radio and the personal computer evolved from a distributed to a broadcast model, the Internet followed the inverse path, and computer software branched into two parallel directions.

The Radio Amateurs

In its early years, radio was known as the wireless. Although it was already essentially the same technology known and used today, it was understood quite differently. Guglielmo Marconi saw radio as a point to point communication system and, therefore, as a wireless replacement for the telegraph. Its primary users, in his view, would be large firms, such as newspapers and steamships, which had a regular need for long-distance communication (Croteau and Hoynes 2003). For Marconi, thus, radio was neither a broadcast medium nor a user-oriented technology. Early radio adopters, on the other hand, saw the wireless as a means to communicate with one another by sending and receiving messages through the publicly-owned airwaves. The clash between these and other competing interpretations of the meaning of radio—as well as a series of co-optation processes—would eventually shape the organizational structures that arose around the technology and determined which of its features were developed and which languished.

In a detailed study of the evolution of radio in the U.S. between 1899 and 1922, Susan Douglas (1987) argues that the historical context in which the technology was developed and disseminated largely contributed to determining its present shape. For Douglas, the shaping of radio must be understood in light of the institutionalization and centralization processes—"private, rarely seen, often incremental and amorphous, and extraordinarily powerful" (Douglas 1987, xx)—that characterized the period:

> *Radio would . . . enter an economic milieu in which large corporations, particularly those involved in transportation and communication, were becoming more powerful and skillful at managing their interests. Business firms, determined to exert more control over market mechanisms, began coordinating their activities and strategies while reorganizing their internal structures along more efficient lines. Corporate consolidation increased; the merger movement reached its peak between 1898 and 1902. The number of managers rose, too, and they worked in bureaucracies that valued a range of technical skills over family connections or regional ties. By hiring professionally trained engineers to fill many of these administrative slots, industrial concerns sought to extend the application of science and technology to managerial activities. . . . the management and deployment of radio would be profoundly affected by this trend toward corporate centralization.* (Ibid., xxi-xxii)

In other words, the evolution of both the technology and meaning of radio would be greatly influenced by the rise of the broadcast approach. However, these would not be the only forces shaping the technology. When Marconi accomplished the first transatlantic wireless communication, many became enthralled with the new wireless communication and sought to duplicate the experiments. Since a modest investment in equipment could produce demonstrable results, a number of mostly men and teenage boys began building their own radio equipment and using it to both send and receive messages. The alternative uses of radio made by these enthusiastic middle-class users would not only set the ground for the emergence of the distributed approach, but also clearly demonstrate how different interpretations of technologies distinguish and, at times, bring into collision these two models. According to Douglas:

> *The course of radio's early development was also influenced by the professional aspirations and leisure activities of subculture of middle-class men and*

> *boys, who found in technical tinkering a way to cope with the pressures of modernization. Success, survival even, for many of these men, required adjusting to the increasing bureaucratization of the workplace and fitting into hierarchical structures that often ignored or suppressed individual initiative. Conforming to these public roles sometimes engendered rebellion, albeit a necessarily circumscribed rebellion, against regimentation and authority, and against loss of autonomy. . . . These people were seeking both more control and new bases of identification. One such basis of identification was familiarity with with mechanical and electrical apparatus. For certain upwardly mobile men, a sense of control came from mastering a particular technology rather than succumbing to the routinization and de-skilling of the factory system. Wireless telegraphy would . . . spawn such a subculture among middle-class boys and men seeking both technical mastery and contact with others in an increasingly depersonalized urban-industrial society. These men and boys were called amateur operators, and by 1910 they had established a grassroots radio network in the United States. Their use of radio, which was oppositional to both corporate and government interests, played a major role in the emergence of broadcasting.* (Ibid.)

For these radio amateurs, Douglas argues, radio served a function similar to cinema in the sense that both "blended the urge for adventure with the love of sanctuary in an ideal suspension" (Douglas 1987, 307). Unlike cinema, however, radio also imparted these early enthusiasts with the sense of control derived from building their own devices and acquiring the skills necessary to operate them. It provided them, in short, with a feeling of mastery. This combination of mastery with adventure contributed to making amateur radio a highly popular hobby in the early twentieth century.

Amateur radio operators, McQuiggin (1983, 1) maintains, not only pioneered an alternative use of the technology, but also contributed to a better understanding of radio communication, developed new radio technologies, integrated various preexisting technologies into new forms, and largely devised the operational procedures which are still in use today. Between 1904 and 1914, while firms continued to view radio as a commercial communication system, several wireless clubs emerged that served as venues for information sharing and collaborative development of the technology amongst amateurs. These clubs, Andrew Ross suggests, challenged the corporate attempts to monopolize the airwaves and therefore served as a front line of resistance against other groups attempting to control the technology (Ross 1991, 107).

Thus, in its formative years, radio was simultaneously understood as a communication medium for large firms and as a grassroots technology. These conflicting views led not only to a struggle over the definition of the meaning of radio, but also for control over the airwaves: firms attempted to obtain private control of the airwaves for commercial applications; amateur operators viewed the airwaves as public property and therefore available to all (Croteau and Hoynes 2003).

As the airwaves became increasingly populated by amateurs, commercial interests and military communications, the sinking of the Titanic in 1912 led to a turning point in the history of radio. In the aftermath of this tragic incident—which brought to the public's attention the saturation of the airwaves and the difficulty of conveying distress signals—the U.S. government passed the Radio Act of 1912. This new legislation required transmitting stations to be licensed and relegated amateurs to frequencies below 200 meters in wavelength. At the time, a still primitive propagation theory held that frequencies above 1.5 MHz would only allow communications over short distances. Therefore, the new regulation forced amateurs into what was then considered to be a useless part of the spectrum (McQuiggin 1983). This was the first sign of the transformation of radio from a de facto distributed to a broadcast technology, as expressed by Douglas:

> *The amateurs had to be purged from the most desirable part portion of the broadcast spectrum. . . . Even before the notion of broadcasting had taken hold, therefore, the institutional structure of broadcasting was in place: centralized, licensed senders and large numbers of individual listeners.* (Douglas 1987, 233)

Despite this, the Radio Act of 1912 effectively encouraged a new phase of research and discovery led by the amateurs and coordinated at first by the American Radio Relay League (the ARRL) and later by the International Amateur Radio Union (IARU). As amateurs attempted to communicate at longer distances using the shorter wavelengths available to them, they made important discoveries about the nature of radio propagation—namely that propagation of signals improved with frequency—and demonstrated that radio communication that took hundreds of thousands of watts and large antennas at commercial frequencies could be duplicated with tens of watts and much smaller antennas in bands below 200 meters (DeSotto 1981). However, once these frequencies became more useful in virtue of these discoveries, commercial wireless carriers lobbied for control over short-wave bands and, in 1924, U.S. amateurs found themselves confined to small segments of the spectrum below 200 meters (McQuiggin 1983; DeSotto 1981).

Nonetheless, amateurs continued to build and operate radios in increasingly larger numbers. By 1920, while commercial users of radio continued to focus on point-to-point communication, amateurs were already experimenting with broadcasting music and information, and some had even amassed large audiences for their programs (Croteau and Hoynes 2003). This would lead to another pivotal moment in the history of radio: in 1920, Westinghouse, a manufacturer of radio equipment, began financing a program broadcast by amateur Frank Conrad with the goal of stimulating sales of the firm’s radio equipment. The success of this strategy soon inspired department stores, newspapers, universities and other large manufacturers of radio technology to launch their own broadcasting stations.

Given that radio technology was controlled by firms, Douglas argues, it needed to be profitable. Thus, corporations such as RCA, General Electric and AT&T sought to dominate both the technology and its surrounding organizational system via patents and the imposition of license fees for the use of firm-controlled radio stations, technical apparatus, and airwaves. Large commercial interests, Douglas contends, “had the technical, financial, and organizational resources to shape programming content, to influence public policy, and to determine how broadcasting would maximize profits” (Douglas 1987, 316). By 1922, therefore, the broadcast model, as it is known today, has been put firmly in place.

For several decades after the advent of broadcast radio, and up until today, amateurs continued to pursue their alternative approach through “pirate” radio stations. They would not, however, again play a central role in the radio industry. The broadcast model triumphed over the amateurs’ distributed approach and relegated their practices to the margins of the system—heavily constrained by regulations and the dominance of large broadcasting corporations. Personal broadcasting and peer-to-peer communication gave way to professional radio stations and users of radio were, as Douglas notes, "transformed from an active to a passive audience, allowed to listen but not to 'talk'" (Douglas 1987, 233).

Nonetheless, the distributed approach pioneered by these early radio enthusiasts continued to play an important role in the creation and dissemination of new technologies. Their legacy would, in fact, inspire a generation of computer hackers who challenged the broadcast model by building their own devices and, in the process, democratized powerful technologies.

The First Hackers and The Hacker Ethic

The cultural origins of the contemporary distributed approach can be traced to the Massachusetts Institute of Technology (MIT) and the hacker culture that there emerged in the 1950s and 60s. At this time computers were still costly, large mainframes only a few universities and firms could afford. They were also acquired with no software. In order for a computer to be usable, each user had to write code for it—that is, each user was also necessarily a developer. For this reason, the distributed approach was the most practical way to both use and develop computational technologies: rather than each individual or group writing their own software, which was highly inefficient, programmers shared code within and across academic institutions, building on each other's work and collaboratively pushing the technology further.

Throughout the late 1950s and early 60s, MIT consecutively acquired several mainframes, each new model offering more and better capabilities. However, the cost of these machines, and their difficult maintenance and operation, led the university to determine that only a select group of programmers would have direct access to the mainframes. Other students handed in their perforated cards and received the results of the calculations performed by the computer, but were not allowed to use the machine themselves. The circle of programmers with hands-on access to MIT's mainframes was known as the "priesthood" (Levy 2010; Freiberger and Swaine 2000).

The majority of MIT students willingly accepted the "priesthood" system, which allowed them to obtain the calculations necessary for their research, and conformed to the view that a computer was no more than a tool to process data with. However, this arrangement was not passively accepted by all. A small group of students greatly resented the bureaucratic organization that prevented them from using, repairing and improving the machines (Levy 2010). Initially, these were mostly members of the Tech Model Railroad Club (TMRC), a group who spent hours crafting an electric system to drive and coordinate a very complex set of model trains—and who called themselves "hackers" (TRMC 2013).

At this time, "hack" referred mostly to the creative practical jokes MIT students played on each other and on faculty, but would later become closely associated with the exploration of technologies and stand for "an appropriate application of ingenuity" with a clever result (The Jargon File 2013a). Along these lines, a hacker is defined by the Jargon File, the informal hacker culture's dictionary, as "a person who enjoys exploring the details of programmable systems and how to stretch their capabilities, as opposed to most users, who prefer to learn only the minimum necessary" (Jargon File 2013b). The hackers' interest, therefore, lies in the technologies themselves. They wish to understand them, explore them, push them further.

Thus, for the 1950s-60s MIT hackers, computers were a fascinating object of research, not mere tools for research. They took great pride in the programs they wrote—which were left in a common drawer for others to study, use and improve (Levy 2010)—and developed strategies, including working around login programs and picking door locks at night, to gain hands-on access to the university's mainframes. In a detailed account of these early days of computing at MIT, journalist Steven Levy named this passionate group of early computer programmers the "True Hackers," and encapsulated their nascent culture in the Hacker Ethic (Ibid.), a set of six principles in which technology and autonomy are inextricably linked.

1. "Access to computers—and anything which might teach you something about the way the world works—should be unlimited and total. Always yield to the Hands-On Imperative!" (Ibid., 28)

Hands-on, unrestricted access to technology is arguably the most important tenet of hacker culture. As described by Levy, "Hackers believe that essential lessons can be learned about the systems—about the world—from taking things apart, seeing how they work, and using this knowledge to create new and more interesting things" (Ibid.). Unrestricted access is, therefore, a precondition for learning, experimenting with, and expanding technologies. When obstacles, such as locked doors and passwords, stand between hackers and the technologies they wish to know and improve, they often find that their quest for knowledge is justification enough to work around them. This would be the origin of the media-propagated notion of hackers as "crackers" of systems. However, in the original hacker ethic, and in the practices of most subsequent generations of hackers, this "breaking of locks" was subsumed to the goal of improving technologies, rather than criminal activity.

2. "All information should be free." (Ibid.)

The invention and reinvention of technologies requires free and unlimited access to information. Through an open exchange of knowledge, hackers are better able to understand how a technological system works and build upon each others' work. The free flow of information is, in this subculture, the main engine of creativity and advancement.

3. "Mistrust authority—promote decentralization." (Ibid., 29)

An unlimited access to technologies and a free flow of information require open systems which pose no barriers between the hackers and their quest for knowledge. For this reason, along with the freedom to shape technologies as they see fit, hackers greatly prize autonomy and abhor bureaucratic authority or anything that may stand between them and their desire to learn and experiment. For hackers, both social and technological systems should be decentralized and co-created by all those who wish to participate.

4. "Hackers should be judged by their hacking, not criteria such as degrees, age, race, sex, or position." (Ibid., 31)

Despite the previous tenet, hacker culture does not completely eschew authority. The difference, however, lies in the source of that authority. While hackers deplore bureaucratic authority, they recognize the authority of skill. Hacker communities are, therefore, typically meritocratic systems in which only one's technological prowess is a valid criteria for authority, regardless of the individual's other characteristics or social position.

5. "You can create art and beauty on a computer." (Ibid.,)

Although this statement may appear obvious in present times—when computers are increasingly used in the creation of artwork—it was not so at a time when these machines were viewed mostly as mechanical aids to perform complex calculations. However, the hackers' notion of art and beauty still differs from the one that is commonly accepted today. For hackers, art and beauty lie in the technologies themselves. The techniques devised to make a machine do something new, the programs that execute complicated tasks with as few instructions as possible, the beauty and elegance of carefully crafted code, these are a hacker's art.

6. "Computers can change your life for the better." (Ibid., 33)

For hackers, "the world opened up by the computer was a limitless one" (Ibid., 30). Computers had enriched and transformed their lives and, therefore, they believed everyone should have the opportunity to experience the wonders of computation. These machines, they thought, had the power to improve the world. Later on, this tenet would take on a more ethical mantle when computers were adopted by activist-hackers as a means to pursue political ideals.

Thus, in the hacker ethic, freedom and autonomy to participate in the shaping of technologies are seen as essential preconditions for both human and technical betterment. The hackers' quest for technological knowledge and advancement requires freedom to access and distribute technologies and information, freedom to transform and improve them, and autonomy to act without having to ask for permission. Autonomy is seen here as both freedom from restrictions (be these cultural, bureaucratic, economic, or technical) and as an acknowledgement that each user of a technology is also a potential creator.

Underlying the notion of hacking is, therefore, a deep belief in every human being's ability to create change—autonomously or in collaboration with others. In this sense, Pekka Himanen described hacking as "the imaginative use of one's own abilities, the surprising continuous surpassing of oneself, and the giving to the world of a genuinely valuable new contribution" (Himanen 2009, 1646). This same emphasis on creativity and the production of change is patent on Mckenzie Wark's definition of hacking:

> *To hack is to differ. . . Hackers create the possibility of new things entering the world. Not always great things, or even good things, but new things. In art, in science, in philosophy and culture, in any production of knowledge where data can be gathered, where information can be extracted from it, and where in that information new possibilities for the world produced, there are hackers hacking the new out of the old.* (Wark 2004, 22)

Although, at first, hacking was primarily associated with tinkering with machines, more specifically with computers, it soon evolved into a much broader concept. Today, hacking is often understood by those who practice it as a way of being in the world—an attitude shaped by curiosity and active participation in the construction of one's environment. This notion that the hacking mindset is not confined to the realms of machines and software is poignantly encapsulated in Wesley Felter's "Hack the Planet Manifesto:"

> *While Hack the Planet is powerful in its simplicity, it is weak in its vagueness. Many people do not understand what it means to hack, to be enlightened by the fire of creativity. Hack the Planet is not a destructive force; it is a creative force that aims to change things for the better. It is the optimistic belief that tomorrow can be better than today. It is based on the fundamental idea that change is good. Change brings uncertainty, but I have come to accept and even welcome uncertainty. When I tell you that I want to Hack the Planet, I do not mean merely the physical geography of earth. I want to hack technology. I want to hack the media. I want to hack the economy. I want to hack society. You name it, I want to hack it.* (Felter 1998)

Thus, from the computer subculture that arose at MIT in the 1950s and 60s emerged a philosophy that would not only shape the contemporary distributed approach, but also play a central role in the development of a world changing technology: the personal computer.

The Personal Computer Homebrewers

By the mid 1960s, another passionate group of technology aficionados located in the Silicon Valley (U.S.) was also concerned with the lack of popular access to computers and, as noted by Freiberger and Swaine, resented that "such immense power resided in the hands of a few and was so jealously guarded" (Freiberger and Swaine 2000, 113). Some of these were, like the first hackers, explorers of technologies. Others, like Lee Felsenstein, were activists who understood the potential of computation and wished to make it available to all. In university campuses, Silicon Valley garages, and intertwined with the Free Speech Movement of the mid-1960s, a grassroots computing-power-to-the-people movement was growing (Freiberger and Swaine 2000; Levy 2010; Markoff 2005). Although, at the time, many activists were suspicious of technology in general and computers in particular, the People's Computer Company (PCC) newsletter proclaimed: "Computers are mostly used against people instead of for people, used to control people instead of to free them. Time to change all that - We need a… People's Computer Company" (PCC 1972).

Amongst these initial efforts to popularize computing was the Community Memory project, led by Lee Felsenstein, Efem Lipkin, and Ken Colstad, who placed a mainframe computer in a public place and created the first computerized bulletin board system. By providing the public with a decentralized, non-bureaucratic communication system, Computer Memory sought to foster "direct contact, direct information, direct access by people affected by power to information about that power, liberation of power from the constricted grasp of the few to its rightful place as the wealth of the information-sharing community" (Resource One 1974).

As the number of politicized computer engineers and programmers grew in the Silicon Valley area, other similar initiatives appeared. In a seminal book titled *Computer Lib*, Ted Nelson postulated: "You can and must understand computers now!" (Nelson 1974). Dymax, an organization dedicated to informing the general public about computers, ran a walk-in computer center in Menlo Park. The newsletter People's Computer Company (PCC), edited by Bob Albrecht, provided the public with information about computers and intro-level programming tutorials. And Lee Felsenstein, inspired by Ivan Illich's *Tools for Conviviality* (Felsenstein 1995), began working on a new computer terminal he dubbed the Tom Swift Terminal. *Tools for Conviviality* postulated that technologies should be designed to encourage a symbiotic relationship between tools and their users; that is, convivial technologies[20], unlike industrial technologies, should allow a user to teach him or herself how to use and repair them (Illich 1973). For Felsenstein, the Tom Swift Terminal was meant to be used by the public in the same way hackers approached computers: teaching themselves how to use it, swapping parts, and making improvements to it (Felsenstein 1995).

The growing enthusiasm demonstrated by those who came to the Community Memory project and to Dymax's public computing facility indicated a shift in the nature of computing. The hacker ethic, which had previously been the purview of the small group of hackers at MIT, took a populist turn. This new generation of computer hackers believed that everyone should experience the power of computing and they were intent on bringing it to the public.

However, until the mid-1970s, computers were still large, cumbersome machines that could only be accessed through equally cumbersome time-sharing systems. This began to change in 1975 when the January issue of *Popular Electronics* announced the Altair, a personal computer kit, created by Micro Instrumentation Telemetry Systems (MITS), costing only $397.

According to Levy, when Lee Felsenstein saw the Altair on *Popular Electronics*, it was clear that this personal computer was not much more than a "box with flashing lights," but that is not what mattered most to him; he understood the significance of the Altair not as a

[20] Illich's assertion that "scientific discoveries can be useful in a least two possible ways. The first leads to specialization of functions, institutionalization of values and centralization of power. The second enlarges the range of each person's competence, control, and initiative . . ." (Illich 1973, 6) anticipates the notion that the specific designs of technologies delimit the range of possibilities they offer to users. Illich thus calls for the design of convivial tools, which he defines as those which "can be easily used, by anybody, as often or as seldom as desired, for the accomplishment of a purpose chosen by the user. The use of such tools by one person does not restrain another from using them equally. They do not require previous certification of the user. They allow the user to express his meaning in action." (Ibid., 30).

technological advance or a useful product, but as a promise of a time when everyone could build their own computers (Levy 2010, 164). Nevertheless, despite the enthusiasm with which the Altair was received, Bob Albrecht, who had dedicated several pages of PCC to the machine, was wary of the eagerness with which hackers rushed to order these kits. For him, the importance of the computer lay not in a fascination with the machine itself, a realm where politics and social causes were irrelevant, but on computing as a democratizing agent (Ibid., 165).

Following the public launch of the Altair, hackers Fred Moore and Gordon French called a meeting of all computer hobbyists in the Bay Area (U.S.) with the goal of discussing computers, sharing techniques, and demonstrating projects. This was the first meeting of the Homebrew Computer Club, which would soon become known as the fortnight gathering from which dozens of personal computer firms would emerge—leading to the creation of the multi-billion dollar personal computer industry.

Cooperation and sharing were amongst the most used words at the Homebrew's first meeting (F. Moore 1975). At the end of the meeting, one of the attendees, Marty Spergel, held up an Intel 8008 chip, asked if anyone could use it, and then gave it away (Balin 2001), thus setting the tone for the atmosphere of exchange and collaboration that would become characteristic of these gatherings. The Homebrew met every fortnight and, in accordance with the hacker tenet of decentralization, had no official membership, no dues, no elections of officers, no steering committee, and was open to everyone.

Levy describes the Homebrew attendees as "a mélange of professionals too passionate to leave computing at their jobs, amateurs transfixed by the possibilities of technology, and techno-cultural guerrillas devoted to overthrowing an oppressive society in which government, business, and especially IBM had relegated computers to a despised Priesthood" (Levy 2010, 173). Peace and social justice activist Fred Moore, one of the leading figures of the club, specifically identified the purpose of the Homebrew as a place for the free exchange of information (Markoff 2005; Levy 2010). Described by fellow Homebrewer Gordon French as an "activist's activist" (as cited by Balin 2001), Moore believed that computers could bring about social change and offer resistance to the dominant system (Markoff 2005). Nevertheless, Moore's view that the mission of the club was in some way political would at times clash with the other hackers' desire to explore technologies for their own sake, a realm in which creating social change was not necessarily a priority (Markoff 2005; Levy 2010). Moore eventually resigned his roles as treasurer, secretary and editor of the Homebrew newsletter. In addition to personal problems, he was becoming disturbed by a few attendees who, as he would later describe to Levy, would come to meetings "with dollar bill signs in their eyes, saying, 'Wow, here's a new industry, I'll build this company and make these boards, and make a million . . .'" (as cited by Levy 2010, 182).

Lee Felsenstein, who assumed the role of Homebrew's master of ceremonies, allowed the club to grow as an anarchist community and believed that in order to obtain maximum political effect in their resistance against the large firms of the computer industry, their strategy would have to remain true to the hacker ethic and could never be run as a bureaucracy. Therefore, even though his aims were overtly political, he was also willing to let hackers be hackers. The goal was the vast distribution of computers to the people, the democratization of the hands-on imperative in which everyone would have an opportunity to design, re-design and use computers. According to Levy, in a speech to the Institute of Electric and Electronic Engineers, Felsenstein postulated:

> *The industrial approach is grim and doesn't work: the design motto is 'Design by Geniuses for Use by Idiots,' and the watchword for dealing with the untrained and unwashed public is KEEP THEIR HANDS OFF! . . . The convivial approach I suggest would rely on the user's ability to learn about and gain some control over the tool. The user will have to spend some amount of time probing around inside the equipment, and we will have to make this possible and not fatal to either the equipment or the person.* (as cited by Levy 2010, 201)

Levy would later describe the club as a manifestation of Buckminster Fuller's concept of synergy:

> *. . . the collective power, more than the sum of the parts, that comes of people and/or phenomena working together in a system—and Homebrew was a textbook example of the concept at work. One person's idea would spark another person into embarking on a large project, and perhaps beginning a company to make a product*

based on that idea. Or, if someone came up with a clever hack to produce a random number generator on the Altair, he would give out the code so everyone could do it, and by the next meeting someone else would have devised a game that utilized the routine. (Levy 2010, 184)

The Homebrew Computer Club rapidly became an invaluable resource for the emerging personal computer industry, as a source of ideas and first orders, and as a group of beta-testers of prototypes. It became a habit for representatives of companies to bring their new products to the club for expert review and criticism. They would then freely distribute its technical specifications, schematics and source code. Everyone was allowed to learn from these files and improve the device if they wished to.

The 1977 Computer Faire, the first of its kind, signaled the transformation of the hackers passion for computers into a booming industry. By then the computing-power-to-the people fever had grown to such an extent that it no longer belonged just to the hackers—and this success had enormous financial implications. It was at this point that the two cultures, hacker and industry, truly began to merge. The hackers had devised computers for their own enjoyment, but the multimillion-dollar revenues of MITS, Processor Technology and IMSAI were the proof that these machines were also a powerful economic force.

Between 1975 and 77, homebrewers openly and frequently shared information despite the fact that many of them ran competing businesses. This exchange of information was vital for their work: learning from each other and building on each other's discoveries was the fastest and most direct path to creating better machines. However, once the difficulty in building or accessing computers was removed, the bond that united them began to dissipate. Business interests began to take precedence over the hacker ethic and eventually supplanted the need or desire to share information. Many hackers-turned-shareholders stopped attending Homebrew meetings, and the ones who did often avoided answering questions about their products (Levy 2010, 230).

By the 1980s personal computers were sold in thousands of retail stores, entering households and offices at an accelerated pace. Homebrewers like Felsenstein and Moore believed that the establishment of an industry of low-cost personal computers would automatically spread the ideals of openness, sharing and hands-on creativity of the hacker ethic. However, time would show that the triumph of the hands-on imperative—or a diminished version of it since contemporary computers, in their sealed boxes, are not hands-on in the sense meant by the hackers—would be achieved at the expense of the second and third principles of the hacker ethic: most information is no longer freely shared, and the production and distribution of computers is for the most part centralized. Even though they fulfilled the promise of distributing computer-power to the people—and this access to computers, coupled with the Internet, would later play a fundamental role in a reemergence of the distributed approach—the personal computer hackers of the 1970s eventually failed to live up to the hacker ethic that fueled them in the first place.

Thus, despite the grassroots origins of personal computational devices, the development of these technological artifacts rapidly shifted to the broadcast model. At the time of writing, ten[21] corporate manufacturers of mobile phones control 66.4% of the global mobile phone market—led by Samsung, Nokia and Apple with a combined 48.6% market share (Gartner 2013a). Similarly, the personal computer market is currently dominated by five[22] manufacturers with a combined global share of 57.2% (Gartner 2013b). None of these manufacturers distributes the schematics of their devices nor the source code for their programs. In fact, technical and legal mechanisms, such as tamper-proof cases and intellectual property laws, are commonly put in place to prevent or discourage users from tinkering with devices. Most computational platforms are now designed and repaired[23] by professionals.

Human-Computer Interaction

In *Second Self*, Sherry Turkle presents the results of a six-year study on how different computer languages and architectures suggest different ways of thinking. The analysis was inspired by Turkle's experience as a professor at MIT where, having trained as a humanist,

[21] Samsung, Nokia, Apple, ZTE, LG Electronics, Huawei Technologies, TCL Communication, Research in Motion, Motorola, and HTC.

[22] HP, Lenovo, Dell, Acer Group and ASUS

[23] Today, repair of computational devices commonly consists in the swapping of damaged modules by new ones, rather than actual repair of damaged parts.

she encountered people who “claimed that building and programming computers was the most powerful intellectual and emotional experience of their lives, an experience that changed the way they thought about the world, about their relationships with others, and, most strikingly, about themselves” (Turkle 2005, 1). *The Second Self* documents the moment when “people from all walks of life (not just computer scientists and artificial intelligence researchers) were first confronted with machines whose behavior and mode of operation invited psychological interpretation and that, at the same time, incited them to think differently about human thought, memory, and understanding” (Ibid.).

Human-computer interaction has changed profoundly since this period. The 1970s personal computer hackers gave commands to the Altair by flipping switches on its front panel. In turn, the machine would output the results in the form of flashing lights. In these early days, communication between humans and computers was achieved in the electrical language of the machines. Assemblers—programs that convert assembly language into binary machine language—operating systems, and simple programming languages like BASIC soon added new intermediary steps to the human-machine communication process. Still, early operating systems required users to issue commands as lines of text on a terminal and conveyed the perception of addressing a machine, of being in contact with what Turkle calls the “bare machine” (Turkle 2005, 7). The fact that the first Apple computers had exposed circuitry further reinforced this notion. Turkle, for example, recalls her experience with the “naked” Apple II, which provided her with a reference point to understand the aesthetic of computational transparency of the early days of personal computer culture—a transparency described to her by another computer user as "the pleasure of understanding a complex system down to its simplest level" (Ibid., 8).

While the DOS command-line style of the 1980s still conveyed the impression of directly addressing and controlling a machine, the introduction of the Graphical User Interface (GUI), based on the manipulation of a simulated surface through the mouse, would turn the notion of computational transparency inside out. Even before the personal computer began to take its place in homes, offices, and schools, researchers Alan Kay and Douglas Engelbart—the later having been inspired by the memex information machine described by Vannevar Bush (1945) in *As We May Think*—began working on making communication with computers more fluid and gestural. Thus, the mouse and GUI were born from the idea that the machine itself should become transparent.

With the advent and predominance of the GUI as the interface between humans and computers, the notion of transparency that had previously referred to directly manipulating the machine by issuing commands, took on a new meaning. For users of DOS, human-computer interaction felt transparent because it conveyed the impression of working on the machine directly, just as early automobile drivers often opened the hood of their cars to fiddle with the engine (Turkle 2005). By contrast, the notion of transparency introduced by the GUI referred to the act of making the machine do something without having to manipulate it directly:

> *. . . When Macintosh users spoke about transparency, they were referring to an ability to make things work without going below a screen surface filled with attractive icons and interactive dialogue boxes. Indeed, these screen objects suggested that communicating with a computer could be less like commanding a machine and more like having a conversation with a person. In only a few years, the "Macintosh meaning" of the word transparency had become a new lingua franca. By the mid-1990s, when people said that something was transparent, they meant that they could immediately make it work, not that they knew how it worked.* (Ibid., 9)

By the end of the twentieth century computers had evolved from systems one worked on, to systems one work with, to invisible gateways into simulations. The windows metaphor now applies to all computation technologies as one looks right past the machines, and the code that runs them, into the digital content that has become more real than the materiality of the device:

> *In the 1970s and early 1980s, computers carried a modernist ethos: analyze and you shall know; by the mid-1990s, the complex simulation worlds of opaque computers offered an experience that called these assumptions into question. Culturally, the Macintosh carried the idea that it is more fruitful to explore the world of shifting surfaces than to embark on a search for mechanism, origins, and structure.* (Ibid.)

Who Makes the Rules

In the early days of the personal computer, being a computer user meant being a programmer. School children who were learning how to use a computer were in fact learning how to program it. In the early 1980s, Deborah, a six-grade student at an elementary school, who had told Turkle that "when you program a computer, there is a little piece of your mind and now it's a little piece of the computer's mind" (as cited by Turkle 2005, 1), wrote a program for a microworld which allowed her to control a cursor, called a turtle, on the screen. The rules of the program were devised by Deborah herself—for example, she would allow herself only one right turn of thirty degrees—which gave her a satisfying balance between control and freedom for creative exploration. From Deborah's perspective, the microworld she had created was "both self-authored and transparent" (Ibid., 7).

Tim on the other hand, a thirteen-year-old boy interviewed by Turkle in the mid-1990s, played not on a simple system created by himself, but on an extremely complex system devised by others: the SimLife computer game. Tim did not know how to program and had not created any of the rules of the game, in fact he had only a minimal understanding of what these were: "Don't let it bother you if you don't understand. I just say to myself that I probably won't be able to understand the whole game any time soon. So I just play it" (as cited by Turkle 2005, 14).

While Deborah's game had been self-authored and based on rules she had set herself, Tim's was created by professional game designers and based on complex rules he could barely grasp. Nowadays, a child like Deborah is much more likely to be creating avatars in a virtual world, or playing a commercial computer game of someone else's creation, than to be devising and programming her own microworld. In contemporary digital culture—even though users are given an enormous array of choice of avatars, weapons, settings, and such—few are allowed to or know how to modify the algorithms that define the rules of a computer game or application. Instead, an understanding of digital environments, designed by others, is achieved through trial and error as Tim did. The "aesthetic of rule-based communication with a bare machine [of] the early days of personal computing," Turkle writes, "would not survive the computer becoming a consumer object" (Ibid., 8).

Until the 1980s being computer literate required knowing how to program, how to improve and repair the machines. Today, it mostly means knowing how to follow rules set by the professional developers of digital applications and devices. Thus, the nature of contemporary mainstream computational artifacts transformed the “socially shared activity of computer programming and hardware tinkering” (Ibid.) into users of “out of the box” online and offline applications and websites.

Technological Literacy

Turkle described hacker-activists like Lee Felsenstein as “populist computer utopians who saw the computer as providing widespread access to information (previously available only to elites) that would encourage political engagement” (Ibid., 10). Moreover, “they believed that a transparent relationship with computers would be empowering, that once people could own and understand something as complex as a computer, they would demand greater transparency in political decision-making processes” (Ibid.).

To some extent their vision came to pass in that digital technologies are increasingly used as platforms for grassroots political action, citizen journalism, and the raising of awareness for political and social causes. However, what the politicized computer hobbyists envisioned was that computers would not only democratize access to information and allow people to communicate and organize themselves directly, but also that a “particular relationship with the computer (a sense of the machine's transparency) would generalize to a new and more empowered relationship with politics” (Ibid.).

When describing the transformation of computers from artifacts only hobbyists found interesting to an ubiquitous consumer object, Levy writes that “in less than ten years, computers had been demystified” (Levy 2010, 285). In reality, however, while computational devices have in fact become pervasive and their presence familiar, for the average user they are now more mysterious than ever before. What had initially been an electrical system of inputs/outputs, a machine that offered no mysteries for the 1970s hackers, has become a black box. Moreover, it has become a black box lacking an aura of mystery to arise curiosity and entice exploration. The unfamiliarity of computers in the early 1980s helped Turkle grasp the impact they had on human thought processes. But as computers began infiltrating all aspects of social and individual lives, they also became increasingly familiar, dulling sensitivity to the way technologies shape thought processes and condition the understanding of both the digital and physical realms.

The notion of transparency epitomized by both the 1970s computer culture and the command-line style of operating system carried a political stance that hinged on the creative power of authorship and a deep understanding of how things work. What was lost with this shift from authorship to consumption of technological artifacts was the proactive, self-reliant stance derived from constructing one's own realities and virtualities, setting one's own rules, and thus developing a language for cultural and social participation. Turkle (2005) compares contemporary technological literacy of consumption to knowing how to pronounce the words in a book but not understanding what they mean. Although the utopian computer culture of the 1960s and 70s gave origin to unprecedented opportunities on the political, social and cultural arenas, it has not led to the hands-on technologically-savvy citizens it envisioned.

By the end of the twentieth century only a small number of schools—such as the Interactive Telecommunications Program (ITP) at the New York University (NYU) in the U.S., the Interaction Design Institute Ivrea (IDII) in Italy, and the Media Lab at the Massachusetts Institute of Technology in the U.S.—continued to encourage the hands-on and experimental exploration of technologies characteristic of the Homebrew Computer Club. Programming was no longer taught in most standard classrooms and many educators had come to conceive computer literacy as the ability to use utility programs (such as word processing and spreadsheet applications), to reproduce and edit content, and to navigate the internet. Individuals in industrialized societies now communicate, produce and share information on an unprecedented scale, but for the most part are unable to rewrite the rules of the environments in which they do so.

Free and Open Source Software

By the end of the 1970's, what had initially been an open and collaborative system of software development began to change as the demand for software grew and firms increasingly viewed it as a business opportunity. While some software continued to be freely shared, there was a growing amount that was proprietary—its code was not made available to users, as it had typically been until then, and restrictive distribution licenses prevented them from copying or modifying applications. It became common for firms to charge users for licenses and impose legal restrictions on new software developments through copyright and trademarks. On February 3, 1976, Bill Gates, co-founder of Microsoft, signaled this change in an “Open Letter to Hobbyists” in which he stated that "less than 10% of all Altair owners have bought BASIC" and that "as the majority of hobbyists must be aware, most of you steal your software" (Gates 1976). This was the beginning of a decades long conflict between the proprietary and free software models.

It was in this context that, in 1983, Richard Stallman announced the GNU Project, a mass collaboration project with the purpose of developing a free operating system. Stallman, a researcher at MIT's Artificial Intelligence Laboratory—where the hacker culture of information sharing and hands-on access to technologies had once been the norm—became exasperated with the university's new attitude towards software and computers which required researchers to sign nondisclosure agreements and prevented them from experimenting with and modifying (proprietary) source code as they had always done.

However, what began as a very practical matter—frustration at not being allowed to alter the software of a document printer used by MIT researchers—soon took on an ethical stance. Stallman saw the creativity manifest in software as a common social good and considered proprietary software to harm “society as a whole both materially and spiritually” (Stallman 1985). In this sense, for Stallman, the issue of software is as much about society as it is about technology.

Soon after the GNU project announcement, Stallman coined the term Free Software and published the GNU Manifesto in which he stated:

> *So that I can continue to use computers without dishonor, I have decided to put together a sufficient body of free software so that I will be able to get along without any software that is not free. I have resigned from the AI lab to deny MIT any legal excuse to prevent me from giving GNU away.* (Ibid.)

On October 1985, Stallman went on to found the non-profit Free Software Foundation (FSF) in order to provide a legal infrastructure for the free software movement and promote users' rights to access and modify software. The term "free," as he understands it, refers to freedom, not price, and includes four specific liberties encapsulated in the "Free Software Definition:"

> *Free software is a matter of the users' freedom to run, copy, distribute, study, change and improve the software. More precisely, it means that the program's users have four essential freedoms: The freedom to run the program, for any purpose (freedom 0). The freedom to study how the program works, and change it to make it do what you wish (freedom 1). Access to the source code is a precondition for this. The freedom to redistribute copies so you can help your neighbor (freedom 2). The freedom to distribute copies of your modified versions to others (freedom 3). By doing this you can give the whole community a chance to benefit from your changes. Access to the source code is a precondition for this.* (GNU 2010)

Realizing that these principles were not enough to ensure that free software would remain free—that is, they did not prevent the derivation of proprietary software from one that had originally been free—Stallman created the General Public License (GPL). Under the terms of this distribution license, all derivatives (modified versions) of free software must also abide by the "Free Software Definition," thus ensuring the continuity and expansion of the practice. GPL takes advantage of copyright law—according to which all works publicly published are automatically copyrighted—to invert it. This appropriation tactic became known as "copyleft." Rather than protecting exclusive rights, copyleft protects the right to distribute copies and modified versions of a work, and requires that the same rights be maintained in derivative versions of the work.

A second defining moment in the history of Free Software occurred in 1991 when Linus Torvalds, an undergraduate student at the University of Helsinki, posted a message on a Usenet group asking for assistance with Linux—a kernel for a new free operating system he was creating as a hobby. Collaborators began to answer the call for assistance and in the following days a few dozen downloaded the software. By 1998, Linux contained 1.5 million lines of code (Leemhuis 2013) written by close to 10,000 programmers (Vaughan-Nichols 2013). Since 1999, IBM has invested two billion dollars to improve and advertise Linux (Taft 2013) and Red Hat, a publicly traded U.S. firm that maintains its own Linux distribution for enterprise users, recently reported an annual revenue of $1.5 billion (Red Hat 2014).

Within a few years, what began as “a program for hackers by a hacker,” as Torvalds (1991) initially presented it, had become an industry standard. At the time of writing, Linux runs on 75% of the stock exchange computers worldwide; powers the servers that deliver Amazon, Facebook, Twitter, Ebay and Google; runs on 95% of supercomputers; and powers devices such as TV sets, cell phones and ATMs (Linux Foundation 2011). In parallel with the evolution of Linux, other free software projects achieved significant technical and commercial success: Apache, a free web server software initially released in 1994, eventually came to dominate the server software market (W3 Techs 2014); and Android, a Linux-based software stack for mobile devices, is responsible for over 80% of the global market share (Ong 2014).

The identity of free software would, however, come to a crossroads in 1998, after the Netscape corporation announced its decision to release the source code of its Netscape Communicator 5.0 browser. A group of free software developers and advocates—encouraged by Netscape's action, which they believed to have created a "precious window of time within which we might finally be able to get the corporate world to listen to what the hacker community had to teach about the superiority of an open development process" (OSI 2011)—began pursuing the idea of bringing its principles to the commercial software industry. Thus, on February of 1998, a strategy session was held at VA Linux in California (U.S.) to discuss this topic. The conferees present at this meeting—believing that the FSF's politically-charged activism was hindering relationships with corporations such as Netscape—decided it was time to "dump the moralizing and confrontational attitude that had been associated with ‘free software' in the past and sell the idea strictly on the same pragmatic, business-case grounds that had motivated Netscape" (Ibid.). Free software thus gave rise to open source, and a new emphasis was placed on the business potential of the open source model.

Open source now needed a statement of principles and a definition. In 1997, Bruce Perens, then leader of Debian—a free distribution of the GNU/Linux operating system—had published a social contract with the free software community promising that Debian would always remain completely free. In order to provide guidelines to determine whether a work can be considered "free," Perens also wrote the "Debian Free Software Guidelines," which the open source movement adopted as its definition. This definition (OSI 2014) states the obligation to include source code in all distributions, but also insures free redistribution, namely that "the license shall not restrict any party from selling or giving away the software as a component of an aggregate software distribution containing programs from several different sources. The license shall not require a royalty or other fee for such sale." Furthermore, it states that it "must allow modifications and derived works, and must allow them to be distributed under the same terms as the license of the original software." Additionally, it prohibits discrimination against persons or groups as well as fields of endeavor: "for example, it may not restrict the program from being used in a business, or from being used for genetic research." Finally, it states that "the license must not place restrictions on other software that is distributed along with the licensed software. For example, the license must not insist that all other programs distributed on the same medium must be open source software."

Although born out of the same historical context and practices, the philosophical differences between the open source and the free software approaches persist to this day. Richard Stallman strongly objects to open source's emphasis on source code and practicality, and considers this shift of focus from FSF's idealistic standards of freedom to more practical aspects to be a negative one:

> *Nearly all open source software is free software; the two terms describe almost the same category of software. But they stand for views based on fundamentally different values. Open source is a development methodology; free software is a social movement. For the free software movement, free software is an ethical imperative, because only free software respects the users' freedom. By contrast, the philosophy of open source considers issues in terms of how to make software "better"—in a practical sense only.* (Stallman 2013)

Despite these irreconcilable philosophical differences, Stallman notes that the similarities between the two camps are greater than their differences: "We disagree with the open source camp on the basic goals and values, but their views and ours lead in many cases to the same practical behavior—such as developing free software" (Ibid.).

The open source approach thus marked a distancing from Stallman's ethics-based defense of free software, focusing instead on practical aspects of development and deliberately moving open source software into the realm of business. This did not mean, however, that open source had become strictly utilitarian and devoid of all other values. In fact, as Steven Weber emphasizes, "Many developers believe as strongly as ever that their values around cooperation and sharing in knowledge production are the fundamental reasons why they do what they do" (S. Weber 2004, 116). The shift to open source signaled, however, that these developers did not wish to define themselves exclusively by ethics and preferred instead to work within a framework that would allow them to create the best software possible in collaboration with others. Thus, by end of the 1990s decade, open source had a distinct identity and, according to Weber, "an image of itself as a technological and political community that was building at once the very best software code and a new model of collaboration" (Ibid., 94).

The Network of Networks

Between the 1950s and 70s the personal computer and a significant portion of the software industries shifted from a distributed to a broadcast model. However, during that same period, another fundamental technology evolved along an inverse path and thus allowed the distributed approach to once again play a central role. The Internet, which resulted from an unlikely convergence of the needs and interests of U.S. military, academic culture, and hacker culture would once again give users a central role in the shaping of the technology—it would, in fact, challenge the very distinction between producers and users. Rather than being planned and administered by a central organization, the informal and distributed approach to the development of the Internet allowed it to be shaped by a variety of self-driven efforts. In turn, the resulting technology became a reflection of the ethos of the multiple the cultures that shaped it.

After the launch of Sputnik in 1957, as the cold war intensified, Paul Baran began working on a new project at the RAND Corporation: the design of a communications system that could not be easily disrupted by an eventual military attack. In the communications model adopted by the telephone industry at the time, all the intelligence of the system resided in the main switching centers. Although not as vulnerable as a fully centralized network (with a single center), the elimination of one main switching center would effectively disable a large portion of the network. Baran, therefore, focused on an alternative model: a centerless network of interconnected nodes (Fig. 1). In this type of network, even if one or more of its nodes were destroyed, messages could still be conveyed through alternative routes. Baran's model included one other important feature: since his system was digital, messages traveling across the network could also be broken down into smaller parts and then reassembled at its destination. This became known as "packet switching"[24].

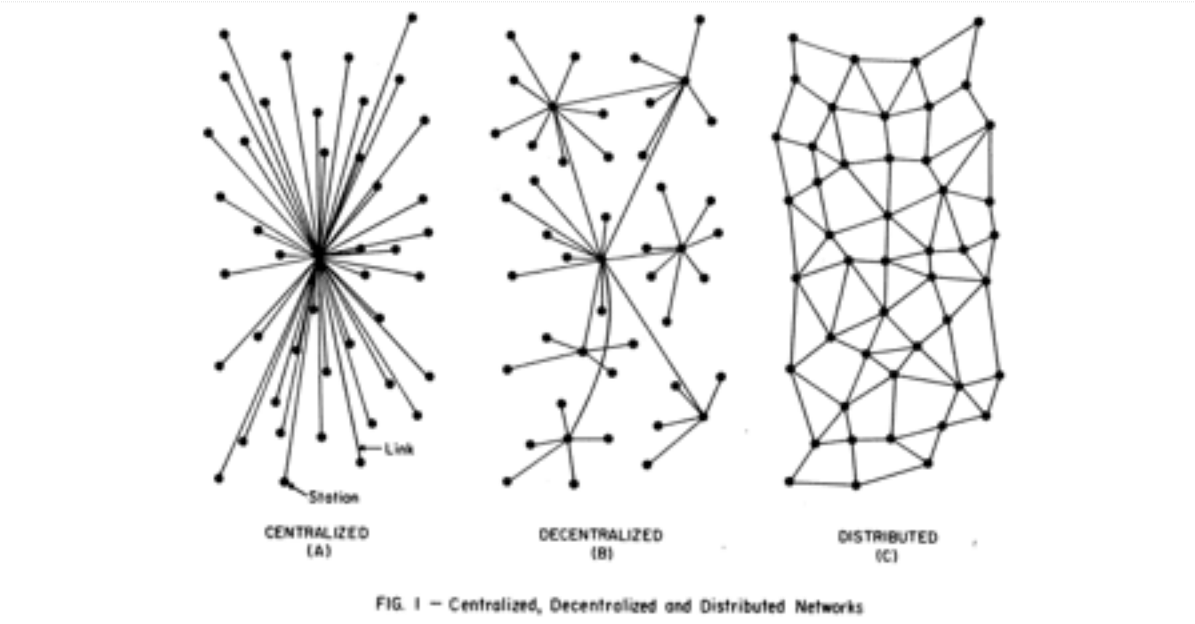


Figure 1: Paul Baran's Network Configurations

The first implementation of Baran's packet-switching network was led by the American Advanced Research Projects Agency (ARPA). The purpose of the ARPANET, as the network was named, was to connect time sharing computers located at several universities and research centers. The project was managed by Lawrence Roberts who saw it as a means to achieve "cooperative programming," foster "community use of computers," and "achieve critical mass of talent by allowing geographically separated people to work

[24] The term "packet switching" was coined by Donald Davies who independently arrived at the same model.

effectively in interaction with a system" (Roberts 1967). The ARPANET was thus conceived as simultaneously the result of a cooperative effort between scientists and engineers, the means to coordinate their disperse contributions, and a tool for collaborative research of networking systems. In other words: this network's users were also its producers. As producers, participants in the ARPANET had the ability to define its characteristics. As users, they had the incentive to shape it according to their collective needs and agendas. As a result, the network itself reflected this dual perspective of producer-user.

The ARPANET was also the first instance of what is today called a peer-to-peer network. Rather than relying on central nodes, the intelligence of the system was distributed across its net of equipotent nodes (peers). In the image of the network itself, the organizational structure that presided over the development of the ARPANET was also highly distributed: rather than enforcing contractual obligations, ARPANET administrators relied on collaborative arrangements and technical decisions were commonly arrived at through consensus (Abbate 1999). This organizational approach, and the collegial atmosphere that accompanied it, was acknowledged in a 1972 independent research report as having contributed to the development of ARPANET's innovative concept of network:

> *The configuration control effort has been handled in a rather informal fashion with a great deal of autonomy and an indefinite division of responsibilities among the organizations that address the various elements of this function. . . . This environment is a natural outcome of the progressive R&D atmosphere that was necessary for the development and implementation of the network concept.* (RCA Service Company 1972).

Participation in the ARPANET was available only to universities and firms affiliated with ARPA and, within those organizations, to specific authorized users, but this limited access was not enforced by the technology itself:

> *a. The ARPANET itself (the communications subnet or "backbone") contains no security features for privacy or for the protection of classified defense information transiting the network. Therefore, it is the responsibility of those sponsors and users operating hosts in the network to take steps to protect information resident or*

accessible through their host computers from access by unauthorized users and to provide protection against unauthorized access to classified information which may reside or be accessible via their host computer link to the network.

b. There are no network "login" procedures, all access control is provided by the controls of the computers on the network. (Defense Communications Agency 1978)

In practice, however, once a site was connected to the network, little control was exercised over who accessed it: anyone with an account on an ARPANET-connected computer could use the network's applications (Abbate 1999). Given that the ARPANET was initially underutilized, Janet Abbate argues, there was no incentive to turn away users, particularly those who contributed improvements to the project[25]. For BBN Technologies, the firm ARPA had contracted to the develop the network, this casual access policy played an important role in establishing its unusual style of governance:

. . . despite a deeply ingrained government and Defense Department worry about unauthorized use of government facilities, it was possible to build the ARPANET without complex administrative control over access or complex login procedures or complex accounting of exactly who was using the net for what. (Heart et al. 1978, III-111)

The informal and highly distributed organizational structure that presided over the initial stages of the ARPANET also further encouraged the emergence of inter-organizational collaborations—as described by Joshua Lederberg in an 1978 article exploring the relationship between "Digital Communications and the Conduct of Science:"

Such a resource offers scientists both a significant economic advantage in sharing expensive instrumentation and a greater opportunity to share ideas about their research. This is especially timely in computer science, a field whose

[25] One of the early unofficial activities tolerated by ARPA was Project Gutenberg, an effort led by Michael Hart —who was not an officially authorized user—to make important historical documents available on the network (Abbate 1999)

intellectual and technological complexity tends to nurture relatively isolated research groups. Each group may then tend to pursue its own line of investigation with limited convergence on working programs available to others. The complexity of these programs makes it difficult for one worker to understand and criticize the constructions of others, unless he has direct access to the running programs. (Lederberg 1978, 1318)

Since collaboration between computer scientists necessarily involved the exchange of files, this became common practice—an anonymous file transfer protocol (FTP) was implemented early on to facilitate such exchanges (Edmondson-Yurkanan 2002)—and often took place without the file owner's explicit consent (Abbate 1999). The free sharing of files amongst ARPANET users reflected the collaborative approach that was common in the early days of computing—as practiced at American universities in the 1950s-60s and at the Homebrew Computer Club in the late 1970s—and would eventually become the basis for the free and open source development models. Although the sharing of software and hardware was one of the stated goals of the ARPANET, a parallel and related practice, which would become central in this network's culture, emerged as a surprise: the large volume of electronic mail exchanged by participants. Through these practices, subtly and autonomously, the network was eventually transformed by its producers-users from a system for resource sharing amongst scientists into a distributed communication and collaboration medium.

The informal and collaborative culture that both emerged from and shaped the ARPANET would, however, take a turn when the U.S. Defense Communications Agency (DCA) assumed control over the project and began to shift its focus toward military operations. Under the DCA's management, the formerly decentralized and flexible organizational approach was replaced by a more centralized structure, as signaled by a message issued by Major Joseph Haughney's, the DCA ARPANET manager, to the ARPANET community:

When the network was small, a decentralized management approach was established due to the nature of the network and the small community of users. This promoted flexibility and synergy in network use. Now that the network has grown to *over 66 nodes and an estimated four to five thousand users, flexibility must be tempered with management control to prevent waste and misuse.* (Haughney 1980)

The new system of management control included a curtailment of file-sharing and stricter mechanisms to prevent unauthorized users from accessing the network:

> *The following is in answer to the many requests for guidelines as to who may use the ARPANET: Only military personnel or ARPANET sponsor-validated persons working on government contracts or grants may use the ARPANET.*
>
> *DCA access enforcement policy will consist of the following procedure. If unauthorized users are found on the net because of a weak or nonexistent host access control mechanism, we will review the host's access mechanisms and request improvements. If the host refuses a review or refuses to make the suggested improvements, we will take action to terminate its network access. . . .*
>
> *Files should not be FTPed by anyone unless they are files that have been announced as ARPANET-public or unless permission has been obtained from the owner. Public files on the ARPANET are not to be considered public files outside of the ARPANET, and should not be transferred, or their contents given or sold to the general public without permission of DCA or the ARPANET sponsors. . . .* (Haughney 1981)

This concern with the containment of information and resources had become particularly pressing for the DCA at a time when personal computers were becoming increasingly available outside academic, corporate and military circles. Network administrators also eventually acknowledged that the goals and work methods of scientists were fundamentally incompatible with those of the military. “The research people like open access because it promotes the sharing of ideas,” Robert Bressler, vice president of BBN, noted, “But the down side is that somebody can also launch an attack, which happens every so often” (as cited by Broad 1983). The solution for this problem was to split the community into two separate networks: scientists remained on the ARPANET and military operations were moved to the new MILNET.

The segregation of the military and scientific communities into two distinct networks can been seen as a first step toward the privatization of the Internet. The second step was taken in 1981 when the American National Science Foundation (NSF) funded the CSNET program. CSNET meant to provide network connectivity to computer science institutions (universities, firms, and nonprofit organizations) which were not ARPA contractors and, therefore, did not have access to the ARPANET. This opening of the network to non-military researchers and other civilians was further amplified when universities and firms began spontaneously connecting their own Local Area Networks (LAN) to the wider network. The attachment of LANs, which were the responsibility of local administrators, meant that the network's governance became even more decentralized.

CSNET was soon followed by the National Science Foundation Network (NSFNET)—a project originally created to connect researchers to the NSF's supercomputing centers—which eventually became the backbone of the Internet. By 1996, the privatization of the Internet, spearheaded by the NSF, had been completed.

The privatization of the Internet, in turn, allowed for the interconnection of the several civilian networks that had previously emerged as alternatives to ARPANET—at a time when network access was restricted to ARPA-affiliated organizations. These grassroots efforts to provide networking capabilities—to those who could neither join ARPANET nor afford the costs of commercial networks—were typically user-driven cooperatives, ran with minimal central control.

One of the first of such networks was enabled by a program called Unix-to-Unix Copy (UUCP), which was included in the 1979 version of the Unix operating system and allowed for the exchange of files, emails and other information between computers. This feature was quickly seized by computer users to create the UUCPNET, a highly informal information exchange network made up of the voluntarily linked computer systems of several universities and firms. The UUCP was also adopted as the basis for USENET, an information exchange system that allowed users to read and post messages on a variety of user-defined topics known as newsgroups. Although USENET discussions initially focused mostly on computers and software, topics soon branched into entertainment, humanities, science, social issues, religion, politics, literature, and sex.

The USENET was originally conceived in 1979 by a group of students at Duke University (U.S.) as a "poor man's ARPANET" meant to "give every UNIX system the opportunity to join and benefit from a computer network" (Hauben 1992). Echoing the 1970s personal computer hackers' resentment with the concentration of computational technologies in universities and firms, USENET developers set about creating an alternative network of their own—as explained by Stephen Daniel, one of the students involved in the project:

> *I don't remember when [poor man's ARPANET] was coined, but to me it expressed exactly what was going on. We (or at least I) had little idea of what was really going on on the Arpanet, but we knew we were excluded. Even if we had been allowed to join, there was no way of coming up with the money. It was commonly accepted at the time that to join the Arpanet took political connections and $100,000. I don't know if that assumption was true, but we were so far from having either connections or $$ that we didn't even try. The `Poor man's Arpanet' was our way of joining the CS community (Computer Science -ed), and we made a deliberate attempt to extend it to other not-well-endowed members of the community.* (as cited by Hauben 1992)

In this same spirit, at a time when personal computers were making computation increasingly accessible beyond universities and firms, several projects emerged to provide connectivity to those who lacked access to institutional networks—that was notably the case of FidoNet, a highly popular network that relied on dial-up connections for the private and public exchange of messages amongst users. Soon, this increased access to open networking systems led to the emergence of the first virtual communities—of which the Whole Earth 'Lectronic Link (WELL) is one of the most remarkable examples. Created by Stewart Brand and Larry Brilliant with the goal of providing an alternative communication system, WELL became known as a meeting place for advocates of free speech and countercultural ideas: it was, for example, where the founders of the prominent digital advocacy organization Electronic Frontier Foundation met (EFF 2014), and served as the inspiration for Howard

Rheingold's (2000) *Virtual Communities* book. Through their practices and technical innovations, these open networks contributed both to extending networking systems beyond the walls of academic, corporate and military organizations, and to defining what the Internet would become.

The last step necessary for the transformation of the Internet from a scientific/military network into a worldwide horizontal communication medium was the creation of the World Wide Web, an effort led by Tim Berners-Lee at CERN. Berners-Lee, who was inspired by Ted Nelson's notion that computation should be available to all—rather than controlled solely by the "priesthood" despised by the 1970s hackers—conceived the Web as a free speech - based "pool of human knowledge" (Berners-Lee et al 1994, 76):

> *When I invented the Web, I didn't have to ask anyone's permission. Now, hundreds of millions of people are using it freely. . . . Democracy depends on freedom of speech. Freedom of connection, with any application, to any party, is the fundamental social basis of the Internet, and, now, the society based on it. . . . I want to see the explosion of innovations happening out there on the Web, so diverse and so exciting, continue unabated.* (Berners-Lee 2006)

This emphasis on free speech and unconstrained participation, envisaged by Berners-Lee and built into the horizontal structure of the Web, further contributed to establishing the Internet as an open, distributed and heterogenous system shaped by its participants. Thus, one of the most remarkable aspects of the network of networks—particularly when contrasted with broadcast media—is its lack of separation, or even distinction, between producers and users. From the beginning, the Internet and the Web were built by those who use it—through the creation of new hardware, software, and content; the improvisation of new applications for preexisting features; and the selection through use of those very features that made it so popular. The success of this alternative approach to the development of technologies had profound consequences for the practices and alternative organizational models the Internet enabled and inspired.

Legacy

Less than a century after the advent of broadcast radio, the powerful combination of the personal computer with the Internet and Web brought about a profound shift in the media and communication landscape. Emerging out of military strategies that required a distributed network capable of surviving an attack and further developed by contributors with a multitude of agendas and concerns, the technological architecture of the Internet was designed to resist attempts at restriction and control and, in the process, was itself imbued with values of openness and decentralization. These values, in turn, became a central part of the culture of its users and contributed to shaping their patterns of communication.

Equipped with personal computers, Internet access, and various other digital technologies, the formerly silent mass audience began creating movies, composing music, writing books, producing news, and distributing them to the world without the involvement of movie studios, record labels, publishers, or broadcast media networks. Thus, the traditionally top-down organization of the mediasphere is now increasingly accompanied by and challenged by a participatory culture characterized by highly distributed creativity.

Just as remarkable as the wave of user-generated content was the emergence of what Yochai Benkler (2006) conceptualized as "commons-based peer production." In a comprehensive study of new organizational models for the production and dissemination of information, Benkler describes how the networked environment (propitiated by the distributed architecture of the Internet) enabled "a new modality of organizing production: radically decentralized, collaborative, and nonproprietary; based on sharing resources and outputs among widely distributed, loosely connected individuals who cooperate with each other without relying on either market signals or managerial commands" (Benkler 2006, 60). This unconventional information production model has been most notably implemented and popularized by the open source software Linux and the grassroots encyclopedia Wikipedia.

At the time of writing, Linux's code base is maintained and improved by thousands of developers worldwide, in collaboration with hundreds of firms, who jointly release a new version of the software every three months (Linux Foundation 2011). In 2001, ten years after Torvalds launched Linux, Jimmy Wales and Larry Sanger set out to create an online encyclopedia based on the same principles: Wikipedia would be written and maintained by the public and freely available to all. By the Summer of 2014, Wikipedia included over 32 million articles, written by 47 million contributors worldwide, and distributed across 287 language editions (Wikipedia 2014).

Just as remarkable as the idea that thousands or even millions of individuals can jointly create something as complex as an operating system or an encyclopedia, are the ways in which these processes are organized.

In the firm's typical organizational model, entry into the organization is filtered through formal processes of application and selection. In peer production systems, the decision to participate rests entirely with the individual or group wanting to join the project. For this reason, peer production networks neither require nor rely on credentials such as diplomas, curricula vitae or reference letters. Likewise, there is no formal contract specifying the conditions of entry nor exit—participants are free to enter and leave at any moment and with no stipulations of any kind. Furthermore, open source mass collaboration projects are not only based on voluntary participation, but also on the voluntary selection of tasks. Rather than being subject to centrally determined division of labor and allocation resources, as is often the case in firms, each participant in a peer production project selects what to work on and what to contribute to the collective effort. The coordination of contributions in such an open and complex organizational model would not be possible without the wide distribution and read-write properties of the Internet.

This connection between open source projects and the Internet provides an illustrative example of the reciprocal relationship between technologies and social practices: the Internet was shaped in cultural contexts that valued open collaboration; in turn, the resulting distributed network further encourages decentralized participation. Thus, on the one hand, the distributed network of the Internet is what allows the distributed practices of open source projects; on the other hand, Internet technology itself is largely composed of the very same open source software and protocols it enables.

The cases of Linux and Wikipedia also illustrate how recent changes in the technologies available to society introduced important changes in the ways in which information, knowledge, and culture can be produced and distributed. The emergence of technologies that allow for the peer-to-peer coordination of large groups of loosely connected individuals enabled forms of organization previously considered unlikely, or even impossible. This does not mean that, prior to the emergence of personal computers and the Internet, individuals and groups could not come together to serve a common goal—the collaborative environment of the Homebrew computer club was an example of this. The difference is that now, for the first time, these alternative approaches can assume a central role in the economies and social practices of industrial society, rather than subsisting in its periphery. The shift from primarily centralized to distributive communication and coordination technologies, Benkler argues:

> *. . . allows for an increasing role for nonmarket production in the information and cultural production sector, organized in a radically more decentralized pattern than was true of this sector in the twentieth century. . . . it means that these new patterns of production—nonmarket and radically decentralized—will emerge, if permitted, at the core, rather than the periphery of the most advanced economies. It promises to enable social production and exchange to play a much larger role, alongside property- and market-based production, than they ever have in modern democracies.* (Benkler 2006, 3)

Only two decades ago, the idea of peer production would have sounded utopian or, at the very least, far fetched. Today this alternative mode of organizing production is becoming an economic force. So much so that Don Tapscott and Anthony D. Williams suggest that "The way companies address peer production will shape the future of industry and affect their very chances of survival," and therefore "treating peer production as a curiosity or transient fad is a mistake" (Tapscott and Williams 2008, 1286).

Although several authors—most notably Yochai Benkler (2006), Clay Shirky (2010), Don Tapscott and Anthony D. Williams (2008)—have elaborated comprehensive studies of the democratization of information production and its implications for social and economic practices, the application of the distributed approach to the development of technological artifacts has not yet been sufficiently studied. The remaining chapters will therefore focus specifically on that topic.

III. THE RISE OF DIY HARDWARE

In the early twenty-first century, a powerful combination of design and fabrication technologies, publicly accessible fabrication services, and new DIY hardware practices allowed the distributed approach to expand from the realm of the digital into the realm of the physical. This transformation, fueled by a set of tools capable of converting digital designs into physical objects, was enacted by three interrelated groups: the maker, hackerspaces, and open source hardware communities. Through their ethos and unconventional practices, these communities have, in recent years, challenged the broadcast model by establishing an alternative approach to the development and dissemination of technologies. Together, accessible fabrication technologies and DIY hardware communities promise to bring into the physical world the participatory practices that previously flourished around personal computers and the Internet.

III.1 From Bits to Atoms and Back

Like the earlier transition from mainframes to PCs, the capabilities of machine tools will become accessible to ordinary people in the form of personal fabricators (PFs). This time around, though, the implications are likely to be even greater because what's being personalized is our physical world of atoms rather than the computer's digital world of bits.

—Neil Gershenfeld (2008 , 3)

Today, personal computational devices are everywhere: on desktops, backpacks, and pockets. The Internet, the network of networks, expands across the globe and a Web made up of millions of computers allows the publication, access and exchange of information to anyone with an Internet connection. Powerful software tools and low cost audio and video recording technologies allow those millions of internet users to write their own news and books, record and distribute their own music, shoot, edit and release their own movies, and collectively create large-scale, complex projects such as Wikipedia and Linux. Digital technologies are now playing a fundamental role in the democratization of the production and dissemination of information, software and culture.

Until the mid-2000s, however, the distributed approached was applied almost exclusively to the creation of immaterial goods. Although bits can be duplicated and transmitted at marginally zero cost using only a computer and an Internet connection, the same cannot be done with atoms; therefore, the vast range of objects that make up material culture was beyond the reach of the new participatory practices. This limitation began to lift when digital design and production technologies that allow physical objects to be treated as data became increasingly accessible.

In a world in which most information is digitally encoded, it has become common for physical objects to be modeled using Computer-Aided Design (CAD) software[26]. These applications allow designers to create digital 2D or 3D models and then manipulate, alter or

[26] CAD is currently extensively used in the creation of a vast array of products—from toys and electronic devices to cars, airplanes, buildings and ships.

even simulate their behavior in virtual 3D space. The properties and implications of these technologies were poetically described by science-fiction author Bruce Sterling in a book chapter aptly titled "The Model is the Message:"

> *Sometimes I really want an object, the thing qua thing, the literal entity itself, physically there at hand. At many other times, many crucial times of serious decision, I'm much better served with a representation of that object.*
>
> *Suppose I'm trying to create a new kind of object, to shape a new kind of thing. I don't want to be burdened with the weighty physicality of the old one. I want a virtual 3-D model of the new one, a weightless, conceptual, interactive model that I can rotate inside a screen, using 3-D design software.*
>
> *Then I'm not troubled by the its stubborn materiality; I am much freer to radically alter its form. I can see left, right, front, back, port and starboard. There's no gravity, no friction, no raw materials for making physical models. I'm spared the old exigencies of foamboard and modelling clay, of chickenwire frames and plaster.*
>
> *I can change those immaterial plans as many times as I want. I can restore the changes, save the changes, erase the changes, export the changes. Because it's only data, it's weightless and immaterial. I can research vital information about it without lifting my hands from the keyboard or taking my eyes from the screen. I can show my work to a host of scattered co-workers at very little cost; I can offshore it to India, email it to China, get it back within the day... I've got an object processor! I'm crunching shapes! I'm processing objects! I'm no more likely to return to the older methods than authors are likely to return to typewriters.* (Sterling 2005, 95-96)

Given that CAD models are digital, they exhibit the same properties as all other digital information: they can be created, copied, combined, modified and distributed digitally at marginally zero cost. This is the property that led Chris Anderson, then editor-in-chief of *Wired* magazine, to proclaim:

> *Atoms are the new bits . . . And the more products become information, the more they can be treated as information: collaboratively created by anyone, shared*

globally online, remixed and reimagined, given away for free, or, if you choose, held secret. In short, the reason atoms are the new bits is that they can increasingly be made to act like bits. (Anderson 2012, 72-73)

Digital code is thus the common denominator that enables “objects,” regardless of their medium or material, to be modified, combined and recombined. In this way, it becomes possible to conceive material artifacts as digital data, instances with endless permutations that can be transferred instantaneously across the Internet—and either materialized exactly as downloaded or their building blocks rearranged, recombined and re-shared.

Although the constituent elements of digital files—strings of 0s and 1s—are not human-readable, it is possible to break down models into units to be easily manipulated and rearranged. The modeling software 3DTin, for example, uses virtual building blocks, similar to digital Lego bricks, with which the user can generate a multitude of forms; and OpenSCAD, an open source platform in which the geometry of objects is generated by code, allows users to modify models by altering their textual descriptions. These code-based models also exhibit another significant property: they can be easily parameterized. While with traditional CAD tools making a change to a design requires also altering its linked components, most modeling software now incorporates a parametrization function: a method of linking dimensions and variables to geometry in a such a way that when one value is changed all the other parts change according to a parametric equation. For this reason, parametric designs are not so much a specific object as a series of possible variants around a concept.

The idea of modular objects often evokes a limited vocabulary of basic shapes and thus a limited number of variants that can be created with those units. However, with parametric digital designs, modularity does not require a predefined vocabulary and therefore does not imply a reduction of the number of forms that can be created. On the contrary, as Manovich (2005) points out, if pre-digital modularity leads to repetition and reduction, digital modularity is capable of unlimited diversity.

To further facilitate the generation and transformation of digital models, several applications now enable inexperienced designers to create 2D and 3D models from building blocks and sets of pre-programmed constraints. SketchChair, for example, allows untrained users to control the process of designing and building their own chairs through a simple 2D sketch-based interface and design validation tools—which ensure that the chairs are both fabricable and functional. Similarly, Pop-up Workshop, JavaGami and PePaKuRa offer design environments for generating polyhedral 3D objects to be constructed out of paper: the applications output 2D patterns ready for printing, cutting and folding based on the user's three-dimensional designs.

As CAD software became more accessible and easier to use, publicly-available collections of 2D and 3D models began to appear online. Thingiverse is one of the most prominent examples of this type of repository. Self described as a "universe of things," it consists in a user-populated database of digital designs for physical objects. As of mid-2013, Thingiverse contained over to 100,000 user-contributor designs, including models for toys, machines, sculptures, kitchenware, eyeglass frames, jewelry, and an enormous array of other objects. Since many of these designs are shared under open source licenses, they can be fabricated by anyone with the means to do so, but also modified, remixed and combined in the process. In fact, at Thingiverse, derivative designs are as common as original works: creators not only upload their own designs, but often transform designs by others in order to address problems they might have encountered, extend functionality, or simply adapt them to their own purposes. As an (unwritten) norm, all such derivatives are also publicly shared, often triggering a new round of mutations.

In parallel with CAD software, 3D scanning technologies, which allow for the digitalization of physical objects, have also become more accessible to amateur creators. In recent years, two technologies have greatly contributed to making 3D scanning widely available: the Kinect controller and 3D scanning software for smart phones and tablets. Although the Kinect was initially released by Microsoft as a hands-free game console controller capable of tracking body motion, it was soon adapted by users for numerous other purposes, including 3D scanning. This was achieved by taking advantage of the device’s computer vision capabilities and altering its software to generate 3D models. Even simpler than the Kinect is the freeware software 123D Catch, which runs on smartphones and tablets, and generates 3D models from a series of photographs taken by the user.

These recent advances in CAD software and 3D scanning technologies mean that, as Clay Shirky suggests, "physical activities are becoming so data-centric that the physical aspects are simply executional steps at the end of a chain of digital manipulation" (Shirky 2007). However, the correlation between bits and atoms could not be completed without the ability to effectively convert the former into the latter. The difficulty this involved was highlighted in 1999 by Richard Stallman, who, despite vehemently advocating for free software, suggested that the freedom to copy and modify hardware was not as critical:

> *Because copying hardware is so hard, the question of whether we're allowed to do it is not vitally important. I see no social imperative for free hardware designs like the imperative for free software. Freedom to copy software is an important right because it is easy now—any computer user can do it. Freedom to copy hardware is not as important, because copying hardware is hard to do. Present-day chip and board fabrication technology resembles the printing press. Copying hardware is as difficult as copying books was in the age of the printing press, or more so. So the ethical issue of copying hardware is more like the ethical issue of copying books 50 years ago, than like the issue of copying software today.* (Stallman 1999)

Although this was admittedly true in 1999[27], several years before Stallman expressed this opinion another powerful set of technologies was emerging that would eventually change the relationship between bits and atoms: digital fabrication tools, machines that create physical objects from digital designs, just as document printers materialize digital information on physical sheets of paper.

Digital Fabricators

The first step in digital fabrication processes consists in generating a digital model of an object using a CAD application. The geometric information from the model is then translated by software into toolpaths and instructions, and sent from the computer to the

[27] And, to some extent, still is: board fabrication capabilities have, since then, become accessible to individuals, but not necessarily easier.

manufacturing tool. Finally, the machine builds the object by either cutting, depositing or otherwise manipulating a stock material.

Digital fabrication methods can be generally grouped into two large categories: subtractive and additive. Subtractive fabrication technologies, which build objects by mechanically cutting various stock materials, include milling, routing, and turning machines, laser cutters/engravers, sign cutters, hot-wire foam cutters, plasma cutters, and water jet cutters. Additive fabrication technologies, rather than subtracting by cutting, build objects from the bottom up by depositing successive layers of a stock material. The most common additive technologies—which are commonly referred to as 3D printers—include: selective laser sintering (SLS), which uses a laser to selectively fuse plastic, metal, ceramic or glass powder; fused deposition modeling (FDM), in which a thermosensitive stock material (usually a thermopolymer) is supplied as a filament which the tool then melts and deposits in successive layers to form the object; stereolithography (SLA), which uses a vat of liquid laser-curable photopolymer resin and a laser to build the parts one layer at a time; and electron beam melting (EBM) in which objects are created by melting metal powder layer by layer with an electron beam in a high vacuum.

Initially, additive fabrication tools were used predominantly for rapid prototyping, but today these technologies have found several applications in end-product manufacturing. In 2010, both 3D Systems and Stratasys, two leading manufacturers of 3D printers, reported that 40% of their customers were using additive fabrication tools for direct or indirect manufacturing of end products and parts (Langnau 2010). Currently, these technologies are used in areas as diverse as product design (jewelry, fashion, footwear, industrial design), architecture, engineering, automotive, aerospace, medical, and education.

Despite their range of applications, and although 3D printers have been in use since the 1980s[28], by the mid 2000s they were still large, complex and costly—and therefore adopted primarily by firms and universities. This began to change in 2005 when Adrian Bowyer, an engineering professor at the University of Bath in the U.K., launched the RepRap project: a research effort dedicated to creating a small, self-replicating, personal 3D printer.

[28] 3D printing tools have existed for over 25 years: stereolithography, the first of these technologies, appeared in 1986. Current industry leaders have been in the market for several years: 3D Systems (1986), Stratasys (1988), Z-Corp (1994), Objet (1998), and Solido (1999).

The concept for the RepRap project was announced in an article titled "Wealth Without Money," in which Bowyer (2006) describes an affordable, FDM-based, desktop 3D printer capable of producing several of its own parts (Fig. 2). To facilitate replication, all of the machine's hardware was designed to be either rapid-prototyped or inexpensive and readily available. Bowyer also decided to release the RepRap designs under a GPL license and thus allow anyone to modify, produce and redistribute the machines.

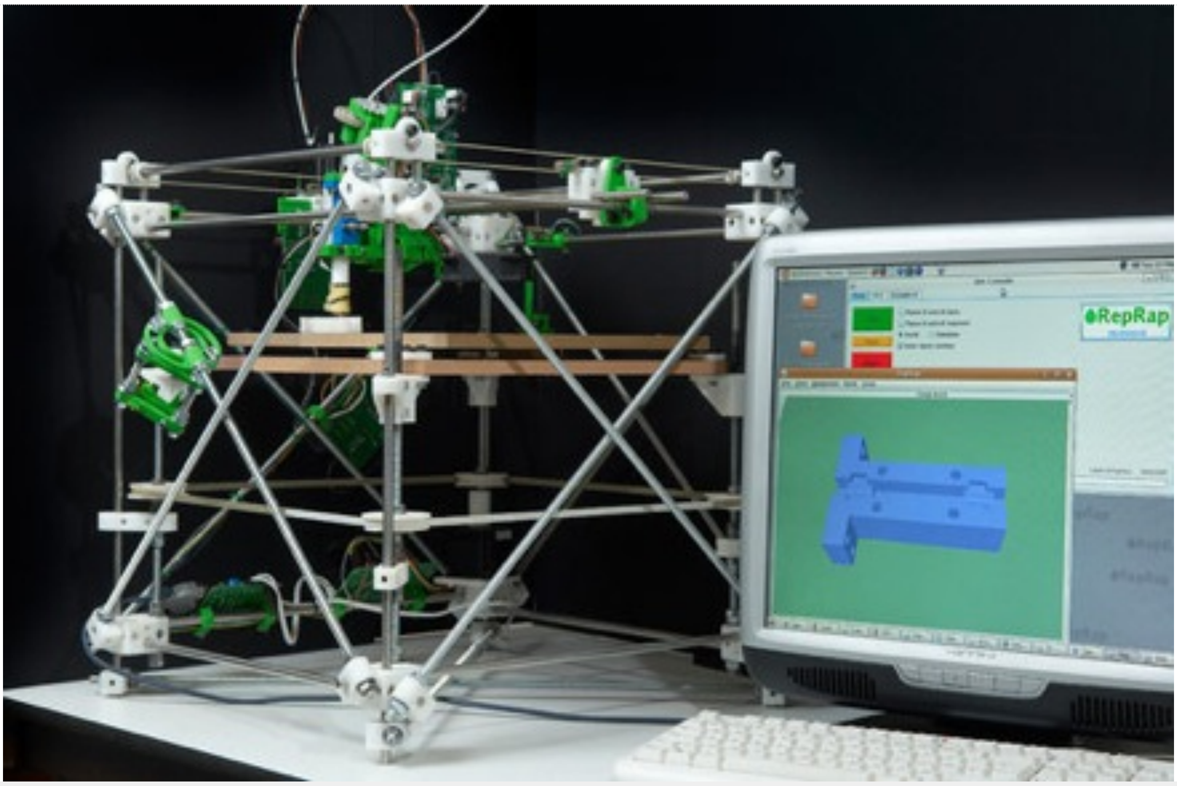


Figure 2: RepRap Darwin

With the RepRap plans available online, an initially small number of hobbyists around the world began building self-replicating machines and using them to produce parts to make more machines[29]. In 2009, hardware hackers Adam Mayer, Zach Smith, and Bre Pettis simplified Bowyer's original design and created another highly affordable machine based on it. Their model cost $850 at a time when the cheapest commercial 3D printer was priced at over $14,000. MakerBot Industries, the company they created to sell these machines as kits, eventually became one of the most successful manufacturers of personal 3D printers.

[29] Around the same time, three other do-it-yourself projects—Fab@Home, Bits from Bytes and CandyFab—publicly published plans and build instructions for personal fabricators.

The grassroots nature of the RepRap project makes it extremely difficult to estimate the number of RepRap machines currently in existence. However, a statistical study conducted by Erik de Bruijn (2010) indicates that by 2010 the number of RepRap users-developers duplicated every six months and grew 10 fold every 20 months. In mid-2013, approximately 470 different RepRap models had been created by the project's user-developer base (RepRap Family Tree 2013). Soon, following in the footsteps of RepRap, plans and prototypes for other digital fabrication technologies—such as the DIY laser cutter Lasersaur and the DIYlilCNC mill—began to appear as well.

In 2005, around the same time Bowyer was designing the first self-replicating personal 3D printer, Neil Gershenfeld (2008) had argued that in a near-future everyone would have a personal fabricator, a machine capable of producing not only physical objects but also other machines. Five years later, this transformation was in full progress.

Digital capture and fabrication tools thus complete the set of personal creation tools now available to both amateur and professional creators. Computers, CAD software and 3D scanners enable the generation of virtual models of objects. The Internet allows these models to be seamlessly transferred to other users or publicly shared. And digital fabrication tools convert the digital information of CAD files into material objects. In turn, these materialized objects can again be scanned, transformed, transferred, and materialized in an endless flow of information between the digital and physical realms.

The New Factories

Despite their relevance, personal fabrication tools are not the only means of production currently available to independent creators. While personal 3D printers were starting to become available to individuals, new types of factories began to emerge in the shape of online fabrication services and public fabrication facilities.

The first online fabrication services appeared in 2007. Bureaus such as Shapeways and Ponoko provide on-demand 3D printing and laser cutting services to the public. In addition to upload-to-make (customers upload a digital design and receive the corresponding physical object in the mail a few days later), these bureaus also offer community marketplaces where creators can sell their designs and fabricated objects directly to the public, web-based platforms for product customization, databases of free designs and, in the case of Ponoko, a request-to-make area where buyers can crowdsource a custom product by asking the community of creators to design and make it: a buyer posts a request with a description and creators submit bids to design/make it. In 2010, Ponoko also began providing services that allow customers to combine electronics with laser-cut or 3D printed parts in diverse materials, thus getting one step closer to becoming a multifunctional public factory.

Also in the mid-2000s, Gershenfeld began teaching the "How to Make Almost Anything" course at MIT with the aim of exploring connections between the digital and physical worlds. From this course emerged a new type of public factory: Fab Labs, an international network of workshops equipped with essential fabrication tools. These public facilities, Gershenfeld explains, were conceived to support a transition towards a society in which fabrication capabilities are highly distributed:

> *We've had a digital revolution, but we don't need to keep having it, we can declare success, we won. What's coming now is the digital revolution in fabrication. . . . Millions of dollars of equipment at MIT are like the mainframes of digital fabrication. We can make anything we want using those tools. In twenty years we'll make it so that you can have them in the home. The Fab Labs are in between. They spread all around the world, letting ordinary people create technology, from South Africa to the north of Norway and from rural India to inner city Boston.* (Gershenfeld 2009).

TechShop, a similar type of public fabrication facility, was launched in 2006 by Jim Newton and Ridge McGhee. This U.S.-based chain of membership-based workshops—equipped with a vast array of design and fabrication tools—seeks to provide inventors, entrepreneurs, hobbyists, artists, engineers and other hardware enthusiasts with access to sophisticated tools with which to "build their dreams" (TechShop 2013). TechShops, which Anderson (2010) describes as incubators for the atoms age, have in recent years become an important resource for budding hardware entrepreneurs—who use it to prototype and even manufacture small batches of their designs. The goal, Hatch says, is to "enable anyone in the middle class to innovate" (O'Connell 2014).

In addition to access to public fabrication facilities, it is also now becoming possible for independent creators to work with more traditional factories. This is facilitated by services such as Alibaba and Maker's Row which act as "matchmakers" between designers at all scales—from a single individual to a large corporation—and factories in China and the U.S., respectively. While Alibaba is mostly focused on interfacing between firms and Chinese factories, Maker's Row is primarily oriented towards individual and small scale producers.

Also catering to single creators and small businesses, online group order services provide still another means for small producers to make use of traditional manufacturing capabilities. BatchPCB, for example, is one of several online services that aggregate small circuit board jobs into larger batches for production and, in this way, allow designers who need a small number of custom printed circuit boards to obtain them at the same price as when ordering a large quantity of a single design. These group order services allow creators to leverage economies of scale by pooling resources (Igoe and Mota 2010).

Thus, in this evolving landscape, the notion of what is a factory is undergoing a profound transformation. Manufacturing equipment and facilities that would once have been prohibitively expensive, and thus available only to capital-intensive operations, are now within the reach of an entirely different sector of the population. Mirroring the creative transformations enabled by digital technologies, these new services and technologies are bringing the participatory practices of the Internet age into the physical world and creating new opportunities for participation in the shaping of technologies. The Web, Chris Anderson argues, "was just the proof-of-concept of what an open, bottom-up, collaborative industrial model could look like. Now the revolution hits the real world" (Anderson 2010).

These new possibilities for do-it-yourself production of physical artifacts were made possible by a confluence of capture, design, communication and fabrication technologies. However, since technologies cannot be separated from their social settings, it is just as important to contextualize these transformations in the parallel and related emergence of three interconnected social phenomena: the maker, hackerspaces and open source hardware communities. In recent years, these overlapping interest groups, through their ethos and practices, have advocated for, enabled, and practiced the distributed approach to the development of technological artifacts.

III.2 Makers

More than consumers of technology, we are makers, adapting technology to our needs and integrating it into our lives.

—Dale Dougherty (2005, 7)

The launch of a new publication in the mid-2000s was amongst the first visible signs of a resurgence of DIY hardware practices in the new millennium. The first issue of *Make*, a combination of website and quarterly book that celebrates "your right to tweak, hack, and bend any technology to your own will" (Make 2013a) came out in January of 2005. On its editorial, Dale Dougherty, the publication's chief editor, wrote: "More than consumers of technology, we are makers, adapting technology to our needs and integrating it into our lives" (Dougherty 2005, 7). This statement would set the tone for the emergence of a community gathered around the identity of the "maker."

The first issue of *Make* described do-it-yourself projects as varied as aerial photography kites, monorails, steam trains, beer kegs, mechano computer machinery, and pattern-generating LED devices. Soon, a growing number of DIY hardware projects began to appear online in websites such as Makezine (Make's online version) and Hackaday, an online publication that "serves up Fresh Hacks Every Day from around the Internet" (Hackaday 2014). By 2013, the print issue of Make magazine had 125,000 paid subscriptions (O'Reilly 2013) and its website, makezine.com, was viewed by 2.8 million unique visitors per month (Make 2013b).

One year after its launch, the publishers of *Make* held the first Maker Faire, a large-scale showcase of DIY projects. This 2006 event counted with 346 exhibitors and was attended by 22,000 people. The exhibitor and attendee numbers continued to grow over the following years and, in 2010, the organizers added a second annual faire to take place in New York City (U.S.), eventually raising the combined number of attendees of both faires to 165,000 (Maker Faire 2013). In 2012, New York's Mayor Michael Bloomberg designated

September 24-30—the week Maker Faire took place in that city—as "Maker Week" (Mohammadi 2012a). In 2013, continuing a trend that had began in 2009, 27 independently-organized Mini Maker Faires took place—mostly in the U.S., but also in Australia, Norway, Canada, Spain, France, and the Netherlands. And in 2014 the U.S. White House hosted its first Maker Faire, announced by President Barack Obama in an official proclamation:

> *Today, more and more Americans are gaining access to 21st century tools, from 3D printers and scanners to design software and laser cutters. Thanks to the democratization of technology, it is easier than ever for inventors to create just about anything. Across our Nation, entrepreneurs, students, and families are getting involved in the Maker Movement. . . .*
>
> *I am proud to host the first-ever White House Maker Faire. This event celebrates every maker — from students learning STEM skills to entrepreneurs launching new businesses to innovators powering the renaissance in American manufacturing. I am calling on people across the country to join us in sparking creativity and encouraging invention in their communities. . . .*
>
> *NOW, THEREFORE, I, BARACK OBAMA, President of the United States of America, by virtue of the authority vested in me by the Constitution and the laws of the United States, do hereby proclaim June 18, 2014, as National Day of Making. I call upon all Americans to observe this day with programs, ceremonies, and activities that encourage a new generation of makers and manufacturers to share their talents and hone their skills.* (Obama 2014)

Although there was nothing radically new about a publication for technology hobbyists, which followed in the footsteps of classics such as *Popular Electronics* and *Popular Mechanics*, *Make's* most significant contribution was the creation of a community and a shared identity out of isolated tinkerers. In a personal interview, Dougherty explained:

> *I never really thought I was creating this audience, I thought they already existed, but they didn't see themselves as a community. They weren't connected to each other, each one of them thought of themselves as either isolated or thought of*

their specific field as what defined them. They didn't see themselves as part of a broader community of makers. (Dougherty 2013)

Make's online presence played an important role in the formation of this multifaceted community. Rather than displaying a digital version of the magazine, *Make's* publishers chose to showcase their readers' projects on the magazine's website. At the time, few magazines covered technological DIY projects, their focus being primarily on the professionally-designed technologies generated by firms. Thus, *Make* not only gave its readers an opportunity to learn about other hobbyists' projects, to showcase their own, but mostly it revealed to lone tinkerers that there were others with similar interests and passions. In a personal interview, Nathan Seidle, the founder of the open source development firm SparkFun, recounts his visit to the first Maker Faire:

> *I got an email from somebody called Dale. I didn't know who he was, but he said he was with O'Reilly and he invited me to this Maker Faire thing. . . . So I ended up flying out to San Francisco with my GPS clock and setting it up behind the stage. And it was mind blowing to see what was going on: all of us, we were all finding each other. We were finally, for the first time, establishing that there were other people like us. And we were kind of this cohesive unit. So I think what Dale did with Make magazine was to show people that there was this thing that had never been before. I mean, it could be argued that people had been making things for decades. . . . What Make did was bring them all together as one core.* (Seidle 2011)

Prior to launching *Make*, Dougherty had developed a book series dedicated to promoting an understanding of hacking as the "finding of non-obvious solutions to interesting problems" (Dougherty 2013). From this work emerged the idea for a "hacks magazine," inspired by contemporary cooking and gardening publications and centered on projects readers could undertake themselves. Dougherty looked to *Popular Mechanics*, *Popular Science* and *Popular Electronics*—the publications favored by technology tinkerers between the 1930s and 70s—which had appealed to a broad audience through a broad range of practical projects: a single issue of *Popular Mechanics* could, for example, contain projects as diverse as how to build a garage, a sailboat, and a bird house. By the 2000s, most technology-centered publications had evolved toward platform specific content (computers, operating systems, applications), and tended to focus on the review of commercial gadgets, the analysis of trends, and the advertisement of new devices. For Dougherty, this emphasis on the consumption of technologies and the specificity of technological platforms meant the loss of the broad appeal of twentieth century DIY publications.

Dougherty's interest in the act of creating something oneself, on the passion of hobbyists—rather than the specificity of projects or technologies—inspired him to create a publication for enthusiasts, for those who, "more than anything, are defined by the enthusiasm for what they are doing, no matter what they are doing" (Dougherty 2013). This focus on DIY, and a perception that activities as diverse as kite building and computer hacking were part of the same phenomenon, led him to turn away from the notion of hacking and towards the broader concept of making. *Make* was thus conceived as a magazine not about any technology or field in particular, but about the act of making.

The publication's coverage of a broad range of fields and pursuits contributed to the creation of a community whose interests and activities are themselves broad and diverse. In a survey of 789 makers[30] (commissioned by *Make* and Intel and conducted by the independent market research firm Karlin Associates), 79% of respondents indicated involvement in hardware/software projects, 40% in gardening, close to 40% in woodworking/furniture, over 35% in cooking/kitchen/food science, and close to 30% in crafts (Karlin Associates 2012). Other categories included learning/discovery, engineering, education, outdoors/nature/camping, robotics/lego, kids projects, life hacking, fine arts, music/musical instruments, alternative/renewable energy, brewing and fermentation, bicycles and other human powered vehicles, rocketry, sewing/weaving/knitting/e-textiles, model airplanes, pets, electric powered vehicles, lapidary and jewelry making, print/book making, citizen science, gas powered vehicles, forging, magic tricks and pranks, and sports (Ibid.).

The mingling of all these practices, Dougherty explains, provides opportunities for information to flow and often results in a hybridization, an intertwining of disciplines stemming from the contact and exchanges between a diverse range of creators. For

[30] The sample was drawn from the random sampling of three Make sources: Maker Faire exhibitors, Make magazine subscribers, and Make newsletter subscribers.

Dougherty (2013), "in a world where everything is very specialized, isolated and siloed, the maker movement is a force around interdisciplinary and integrated activities." While, in the past, activities such as software and hardware hacking, knitting, cooking, DIY science, home improvement, and amateur radio took place within their own specific cultural settings and communities, Dougherty saw the common aspect on which all are founded: a passion for creation and exploration. Thus, the maker community constituted itself as a hybridization of several pre-existing cultural traditions: crafting, amateur radio, DIY home improvement, and hacking.

This diversity is at its most visible in Maker Faires, where crafters, cooks, designers, artists, engineers, scientists, and entrepreneurs exhibit projects side by side, in a colorful palette vividly described by Martin Hemmi, a young Silicon Valley intern, upon his first visit to Maker Faire:

> *There are banana-pianos, singing lobsters, giant metal flowers that shoot fire, and robot dance competitions. . . . The beauty of Maker Faire is that nobody asks why these projects are built. Instead, people ask—and share—how they are made. Maker Faire attendees blur together with exhibitors. There are artists, urban farmers, computer programmers, physicists, engineers, and designers. Or simply: 65,000 nerds and geeks who like to get their hands dirty. Making, it seems, is a sort of religion here, a way of life. And Maker Faire is apparently Mecca. . . .*
>
> *What strikes me the most about the Californian Maker Movement I see around me is that it goes way further than a simple hobby. People are proud of their designs, share them for free on Instructables, GrabCAD, etc. They are willing to spend a little more money and create something unique, rather than buying the new Ikea coffee table, serial number XYZ. A real revolution is taking place, born right here and armed with circuit boards and soldering irons, science and creativity.*
>
> *I just have one question. What should I build first?* (Hemmi 2013)

Thus, with its focus on DIY and diversity, the maker community embraces a distributed approach in which individuals actively and collaboratively participate in the shaping of technologies. In this sense, Dougherty describes the significance of making as being essentially “an affirmation that we are producers, not just consumers” (Dougherty 2013):

> *What we’re trying to do with maker culture is to define it as a participatory culture, made and shaped by the people who participate, who do things. Contemporary culture has this idea that science and technology are produced by an elite for the rest of us, and that we need to find those few brilliant people to create technologies or solve problems for us. I argue, on the other side, that that doesn’t work; what we have to do is engage more and more people so there is a multifaceted approach to solving problems and greater participation in the process. We can do really meaningful things through science and technology that have an impact on the world. We can change it, influence it, repair it. That’s the empowering message behind making. And we really enjoy doing it: it’s fun, it’s satisfying, it creates community. In a sense, the meaning of making is to create meaning.* (Ibid.)

Underlying this desire to appropriate and transform technologies is a perception of corporate manufacturers as misaligned with their customers’ needs. More specifically, the Karlin Associates survey cited above found that 77% of respondents strongly or moderately agree that “Most large scale, ‘corporate’ manufacturers are more interested in making profits than in serving customers,” 70% indicated that “Given the option, I would rather buy a product made by a person I know than by a big company,” and 44% strongly or moderately disagreed that “Large scale, ‘corporate’ manufacturers seldom shirk their responsibility to the consumer” (Karlin Associates 2012).

Maker culture thus constituted itself as a hybrid of several DIY cultural traditions now gathered around both the shared identity of the maker and the collective desire to participate in the shaping of material culture. Although this participation often takes on a playful or educational form, it nevertheless expresses a desire to reclaim technologies at a moment when the technological artifacts used by the majority are predominantly shaped by a comparatively small number of producers.

III.3 Hackerspaces

This is what the worldwide hackerspace movement is all about: learning, teaching, and sharing what we love. We can hack anything! We are limited only by our imaginations, which, of course, are unlimited.

—Mitch Altman and Matthew Borgatti (2011)

Just as the maker community was starting to take shape in the mid-2000s, a new generation of hardware hackers began to gather around the phenomenon of hackerspaces[31]. Hackerspaces, the contemporary descendants of hacker culture and the physical hubs of maker culture, function as clubhouses where people of diverse backgrounds—usually with common interests in science, technology, and art—meet to create, learn, collaborate, experiment, and socialize.

The sharing of workspace and tools is a central feature of these clubs: by pooling resources, members are able to obtain access to machinery—such as laser cutters, 3D printers, CNC mills, wood and metal working tools, as well as bio and chemistry equipment—they may not individually be able to afford. However, even though their physical infrastructure and material resources are important aspects, hackerspaces are above all centers for peer learning and collaborative problem solving. The deep-rooted practices of information sharing and collaboration inherited from the hacker and open source software traditions—and the fact that groups of knowledgeable individuals from various fields are willing to freely share what they know with others—are arguably the most far-reaching characteristics and a critical part of the appeal of hackerspaces.

Despite their roots in hacker culture, hackerspaces are a recent phenomenon. In 2005 there were less than 20 of these clubs (Baichtal 2012), but by 2013 Hackerspaces.org estimated that this number had grown to somewhere between 700 and 1100 (Hackerspaces Wiki 2013). Most of these are membership-based local initiatives, usually founded by small groups of individuals. In fact, in accordance with the hacker culture's tradition of self-

[31] Also referred to as hacklabs or makerspaces.

reliance and autonomy, creating a hackerspace is mostly a matter of self declaration (Troxler 2011): an often small group comes together, acquires a physical space and some basic equipment (which might be bought or donated), and registers on the hackerspaces.org wiki.

Since each hackerspace emerges from a different group of individuals, located in numerous cities around the world, they are all formally independent from each other. The founding, equipping, funding, and managing of a hackerspace rest solely with its founders and members. Thus, hackerspaces come in many shapes and their governance, facilities, and funding vary greatly from one to the other. Some hackerspaces incorporate as non-profit organizations, others as associations, others still as firms, and some are just unofficial coalitions. Most collect membership dues and teach classes as funding strategies, but others are supported by governmental or private subsidies. Some have permanent physical spaces, some squat abandoned buildings, others meet only a few times a week at another organization's space. Some have elected officers and directors, others function as horizontal structures and are managed by all members collectively. Some welcome anyone who wishes to become a member, others have more structured procedures for approval of new members. Some are overtly politically-oriented and others profess themselves apolitical.

Despite this variety, hackerspaces follow a common pattern, built on a global culture and a shared set of values and practices. Ricardo Lobo identifies these common traits and describes hackerspaces as “open, community-driven space[s] with shared resources, where people with common interests, learn, experiment and develop projects, through an organizational model based on peer-learning, collaboration and knowledge sharing” (Lobo 2011). Thus, all hackerspaces have a physical space, where members meet and work, and a pool of shared resources. All are founded on a notion of resource and knowledge sharing and serve to facilitate grassroots experimentation and development of projects at the intersection of technologies, art and science.

Independently of the process through which each one selects and acquires new members, the typical hackerspace also seeks to serve and build ties with other individuals and organizations around it. In fact, this is often an integral part of their mission as described by hackerspace member Robert Ward: “We do exist to serve our members, but we also want to reach out into the community to get people, young people especially, excited about technology and making things" (Ward 2009). This liaison between hackerspaces and their surroundings is usually manifest in weekly "open nights"—in which hackerspaces open their doors to anyone who wants to come by to socialize or work on projects—as well as a variety of activities open to non-members such as classes, social events, residencies, and hackathons (a combination of the words hacking and marathon to characterize events in which creators gather to work on projects for a set period time). Thus, although primarily membership-based, hackerspaces are not closed organizations, they are in fact in permanent contact with their surroundings, showing and publishing projects, inviting locals and visitors to their spaces, and always eager to explain what they do to anyone who asks.

Despite their organizational autonomy, hackerspaces form an informal coalition and regard one another as local nodes of an international network. This sense of shared values and practices is so strong that members often refer to the overall phenomenon as the "hackerspaces movement." Through the collectively maintained hackerspaces.org platform, members communicate with one other, exchange information and advice on how to create, govern and maintain the clubs, and often discuss cultural and political aspects pertinent to their shared culture. Members also frequently visit hackerspaces in other locations and even organize tours of hackerspaces across several cities and countries. This practice is so common that, in 2011, Mitch Altman and Matthew Borgatti created the "Hackerspace Passport," a passport-like booklet that can be stamped at each hackerspace or hacker conference visited. The statement printed on this document is an emblematic assertion of how the hackerspaces network sees itself:

> *There is a world of hackdom out there. Please go out and explore it! By visiting hackerspaces and hack conferences you will find geeks and nerds and dorks of like mind, enthusiastically teaching and sharing what they love. You in turn may find fulfillment in sharing and teaching what you love.*
>
> *. . . . This is what the worldwide hackerspace movement is all about: learning, teaching, and sharing what we love. We can hack anything! We are limited only by our imaginations, which, of course, are unlimited. What you hack is totally up to you: hardware, software, art, craft, science, food, music, society, the planet, and any number of various and sundry areas of possible interest, including your own life!*

What is hacking? You may find this definition a convenient starting place: learning as much as you can about any realm that excites you, improving upon it, and sharing it. Don't know what excites you yet? Exploring hackerspaces and hacker conferences may very well give you the clues you need!

Please spread the joy and pleasures and experiences of you life's hacks. Learn and teach and share as you travel. Get stamps from as many hackerspaces and hacker conferences as you like. And cross-pollinate. We all know something others do not. And we can all learn from one another. And we can always learn more. As we learn, and teach and share, we all benefit. And through the support of the international hackerspace movement, you are making the world a better place merely by living the life you enjoy. So, please, go out into the world and enjoy! Explore what you love! (Altman and Borgatti 2011)

Origins

Although hackerspaces, in their current form, are a recent phenomenon, their roots can be traced to the software hacking practices that begun at MIT several decades earlier. By the mid-1980s, it had become common for hackers to communicate, collaborate and exchange information via computer networks, but there was a growing sense that these virtual exchanges were not enough. Hackers, John Baichtal (2011) argues, longed for physical encounters. Thus, in 1987, Emmanuel Goldstein, editor of the *2600* magazine, organized the first *2600* meeting with the goals of encouraging socialization amongst hackers and countering the image of the hacker as a lone criminal. Also in the late 1980s and early 1990s, the first hacker conventions took place: SummerCon in 1987, HoHoCon in 1990, DEFCON in 1993, and Hackers on Planet Earth (HOPE) in 1994. The success of these events inspired participants to seek ways to make them more permanent. For Nick Farr, founder of two hackerspaces and an important figure in the expansion of the phenomenon, hackerspaces were the answer to that call:

The ability to share tools, resources, work out real-world problems, and have a space for lots of groups to meet has brought the community together in ways I *couldn't have imagined and really answer the question as to why we need hackerspaces.* (as cited by Baichtal 2011)

Farr (2009) identifies three consecutive waves in the evolution of hackerspaces. The first wave began to form in the early 1980's with the creation of the Chaos Computer Club (CCC), an informal organization initially located in Hamburg (Germany). The CCC's first headquarters—two small rooms cluttered with devices, manuals and computer magazines (Pettis, Schneeweisz, and Ohlig 2010)—functioned primarily as a meeting place for computer enthusiasts. In the early 1990s, shortly after the fall of the Berlin Wall, the CCC was relocated to Berlin and eventually moved to its third location—a former carpenter's shop equipped with Internet access. This slow but available connection drew an increasing number of participants whose interests centered as much on digital technologies as on contestational politics:

> *Technical questions were rarely left unanswered and there was a strong urge to follow up on what was going on with society and politics while following the latest trends in technology. It is this strong spirit of responsibility for society that always made the CCC so different from other technology-related groups. It's never just about the toys - it's always about what happens when the toys will be applied to society. Things are always under scrutiny, under discussion, under attack. Nothing is taken for granted and everything needs to be revisited, taken apart, looked closer at.* (Ibid.)

Soon, the acquisition of several tools and machines, as well as improvements on the initially fledgling Internet connection, began to attract visitors from other locations in Germany, Austria and Switzerland::

> *People dropped by, stayed for a couple of days and left the place slightly confused but heavily inspired. For a while, the situation became totally hippiesque. The club rooms became so cozy and comfortable, serving the general geek with everything he or she needed from food to connectivity to music and comfy sofas that people started not to leave the place at all. Or rather: leaving the Club felt as if you*

were leaving a very good party and returning later on felt like "coming home." At one point the club never got deserted at all. It had achieved 24/7 activity. You could come whenever you wanted and there was somebody hacking away. A hacker's dream. (Ibid.)

Eventually, the CCC became an inspiration for other groups in the region who went on to found similar clubs—the most notable being C4 in Cologne, Metalab in Vienna, and C-Base in Berlin. The CCC Berlin also became home to two of the most well-known hacker events: the Chaos Communication Congress and the Chaos Communication Camp. Thirty years after its inception, the CCC Berlin, despite its decentralized approach and unwillingness to become organized, is now a thriving community of 4,000 members that regularly reinvents itself (Ibid.). Today, John Baichtal maintains, the CCC is an "open, anarchic, and wide-ranging" organization whose membership sees itself as "a galactic community of life forms, independent of age, sex, race, or societal orientation, which strives across borders for freedom of information. . . ." (Baichtal 2011, 346).

Meanwhile, the second wave of hackerspaces was forming in the U.S. Theirs was a very different model from the CCC's. As Baichtal describes them, clubs such L0pht, Hasty Pastry, New Hack City, and Walnut Factory were "private affairs where small numbers of programmers could interact in person" (Ibid., 355). Not only did they not admit new members, but endeavored to stay out of sight—Farr (2009), for example, describes New Hack City's location as concealed under a "We Buy Diamonds" awning, evidenced only by a buzzer labelled "SETEC Astronomy" (an anagram for "too many secrets" and a reference to the 1992 movie *Sneakers*). Like the first hackers of the TMRC generation, these organizations were restricted to a small group of initiated. This second wave of hackerspaces, Baichtal argues, existed in "a stifling environment when it came to exposing the hackers to new ideas and new skills" (Baichtal 2011, 358).

While the second wave of hacker clubs remained in the shadows, the number of hackerspaces in Europe—influenced by CCC Berlin, C-Base, C4, and Metalab—continued to steadily grow and eventually inspired what would become the next stage in their expansion.

This third wave of hackerspaces began to take shape in 2006 when American hacker Nick Farr visited C-Base in Berlin:

> *That's really where the whole hackerspace thing hit me. A real community built around a space that had a strong culture, a huge dance floor/meeting area, a bar, and every kind of workshop space imaginable in the basement. A woodworking shop on one end, a recording studio on the other...and the place was full of people hacking in every way imaginable! I saw it and said, "This is what we're missing in the United States!* (quoted by Baichtal 2011)

Farr brought this excitement back to the U.S. and, in 2007, organized a group trip—aptly labeled Hackers on a Plane (HoaP)—from the hacker convention DEFCON in Las Vegas to the CCC in Berlin. Within a few weeks of their return to the U.S., HoaP participants went on to found the first American hackerspaces: NYC Resistor (NYC), Noisebridge (San Francisco), Hacktory (Philadelphia), and HacDC (Washington DC).

The first wave of hackerspaces proved that hackers could create convivial spaces, the second showed them how to make them sustainable (Farr 2009), but the third wave would be the one to reach critical mass. Inspired now by the North American, Austrian, and German clubs, the hackerspace phenomenon rapidly spread across Europe and the U.S., and then expanded to the rest of the world. By 2013, almost all major cities in the world had a hackerspace (Fig. 3)—Tokyo, Shanghai, Hong Kong, Beijing, Bangalore, Saigon, Moscow, Sydney, Buenos Aires, Lagos, Lisbon, New Delhi, Nepal, Singapore, and over 700 other locations (Hackerspaces Wiki 2013).

Figure 3: Hackerspaces.org map

The extrovert attitude of the first and third wave hackerspaces represented an important turn in hacker history by spreading its culture beyond Western academia, software development, and isolated clubhouses. As Farr observes, hackerspaces demonstrated that hackers "could be perfectly open about their work, organize officially, gain recognition from the government and respect from the public by living and applying the Hacker Ethic in their efforts" (Farr 2009).

Identity

In recent years, the hackerspace model has also been increasingly adopted beyond hacker communities. In 2011, for example, the government of Shanghai (China) announced its intention to fund the creation of 100 hackerspaces as part of a larger program to support grassroots science and innovation (Lindtner and Lee 2012). One year before this, the U.S. Defense Advanced Research Projects Agency (DARPA) allocated $10 million in funding to the Makerspaces Initiative, an experimental program to introduce hackerspace-like activities into schools. And, in recent years, a number of American academic and public libraries, as well as museums, has began offering "making" spaces and activities.

This increase in popularity was also accompanied by a semantic split in the identity of the hackerspaces community. While the term hackerspaces clearly associates these clubs with hacker culture, it has also become common to refer to them as "makerspaces" in reference to the maker community. Gui Cavalcanti, founder of Artisan's Asylum—a self-defined makerspace located in Boston, U.S.—suggests that the difference between hacker and makerspaces lies in the type of activities they prioritize. According to Cavalcanti, hackerspaces are "largely focused on repurposing hardware, working on electronic components, and programming," and, even though "some spaces did work with more media and craft than that, the tools and spaces dedicated to those crafts were often seen as secondary to the mission of the space" (Cavalcanti 2013). In makerspaces, on the other hand, "the different types of craft spaces involved weren't considered afterthoughts, they were considered the whole point" (Ibid.). For Cavalcanti, thus, hackerspaces focus on technologies, while makerspaces focus on craft activities. Cavalcanti's assessment points to a central and defining feature of contemporary hacker and maker communities: the convergence of the hacker and craft traditions. This melding of identities, cultures and practices was precisely what Dale Dougherty intended to encourage when he rebranded "hacking" activities with the broader notion of "making."

Cavalcanti's distinction, however, proves too simplistic to explain a grassroots, multifaceted, fluid and hybrid culture that constantly reinvents itself and resists tight definitions. Visits to several hacker/makerspaces, conducted in the context of this research, indicate that this distinction between hackerspaces (focused on technology hacking) and makerspaces (focused on crafts) does not stand in practice. For instance, the activities, culture and layout of the Santiago Makerspace (Chile) are not radically different from the activities, culture and layout of the NYC Resistor (U.S.) hackerspace, where crafts and technology hacking are often engaged in, both as separate and combined activities. And Pumping Station One's space in Chicago (U.S.), for example, is organized around well-equipped areas for crafts and DIY bio, while calling itself a hackerspace and identifying "Make, Hack, Craft" as its defining keywords.

Rather than reflecting different goals or concerns, the choice between the maker or hackerspace labels can more likely be explained by the cultural affiliations of the founders of these collectives. Club founders who identify with the older tradition of hacking tend to adopt the term hacker. Those whose gateway into making and hacking was the more recent maker community are more likely to identify themselves as makers and, therefore, to opt for the makerspaces label. In this sense, the choice between labels seems to reflect primarily the entry point of participants. Thus, although the terms hackerspace and makerspace refer essentially to the same phenomenon (what was described here as a hackerspace), the choice of label indicates a preferred cultural affiliation: while some, particularly the older clubs, draw directly from the hacker culture they emerged from, the more recent clubs may identify with the broader identity of the maker.

This explanation, however, is further complicated by matters related to public perception; more specifically, by the fact that the term hacker has, for several decades, assumed a negative connotation in both the media and popular accounts. For this reason, some clubs in which members identify with the hacker tradition may adopt the public label "makerspace" to avoid negative connotations—as expressed in a recent mailing list discussion by hackerspace member Jens:

> *Here in Kansas (and I'm sure elsewhere), there is a negative connotation to the term "hacker", so to the public we are "makers". Internally we use "hacker" and "maker" (almost) interchangeably and, like others on this list, don't really care what we're called as long as we get to create/make/hack/repurpose/etc and aren't "bad guys" for doing so.* (Jens 2014)

However, while some clubs publicly distance themselves from the politically-charged term hacker, others adopt it intentionally as a means to affirm their cultural identities and recover the original meaning of the word. In response to Jens's (2014) communication transcribed above, Aurélien Desbrières posted the following comment:

> *Jens, completely agree about the point of view of most of people on the words hackers. (here in Corsica). Well, I continue to use that term, getting time to explain them the importance of words and the basic difference. Most of time that interest them and want to know more.* (Desbrières 2014)

The overall consensus appears to be that the adoption of one label or another is more fortuitous and idiosyncratic than definitional. The focus of these communities is on inclusion, hybridization and diversity, rather than exclusion, differentiation and uniformization, as expressed by several hacker/makerspace members:

> *What do you call a space which has machines for making physical objects, which also has computers and wifi, which was founded primarily by software people who wanted a place to use their angle grinders, which is neither about politics nor entirely non-political, which does not have a community of its own but which emerged out of a larger, existing, semi-political-semi-artistic community, which it continues to serve but no longer precisely overlaps, which has no interest in becoming a 501(c)3 style nonprofit and basically doesn't run any educational programs, but also has no intention of ever making any money, which has a group of non-democratically-elected managing members who bear formal political authority, but which in practical terms runs as a good-natured anarchist DIY do-ocracy...? We call it ALTSpace. I don't care whether you call it a hackerspace or a makerspace, it's a cool place either way.* (Saxman 2014)
>
> *To me, "hackers" hack, and "makers" make. I happen to make things with my hands using the pragmatism that most hackers share. Am I a makerhacker? hackermaker? Not sure it matters though, I'm busy doing cool [things] instead of trying to stick a label on what I do ;)* (T. Fischer 2014)
>
> *Define yourself through action. When you are hacking... you are a hacker. When you are cooking... a chef. When you are sleeping... you are dead. When you are watching TV... you are cattle. We are large, we contain multitudes. Embrace them.* (Matt 2014)

Thus, like the maker community, the hackerspaces community emerged from the convergence and intermeshing of a diversity of sub-cultures which, although preserving shifting cultural differences, gathered around the shared idea of communal hands-on creativity.

III.4 Open Source Hardware

Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs.

—Open Source Hardware Definition (2011)

Almost a decade before the launch of *Make* magazine and the creation of the first U.S. hackerspaces, open source software developers began to take an interest in hardware. As the production of open source software expanded, these programmers were also increasingly confronted with the fact that, given that software runs on hardware, the lack of access to the physical architecture of machines effectively limited their ability to write programs.

For this reason, in 1997, Bruce Perens, creator of the "Open Source Definition" and co-founder of the Open Source Initiative, launched the Open Hardware Certification Program (Perens 1997). The goal of the program was to allow hardware manufacturers to self-certify products as open. This required making a set of promises about the availability of documentation for programming device-driver interfaces. In exchange for this commitment, vendors of certified equipment acquired the right to apply the program's open hardware logo to their packaging and to state in advertising that their devices were certified. In turn, those who acquired certified equipment were assured that a change in operating system or even the demise of the manufacturer would not make it impossible to have new software written for their devices. The Open Hardware Certification Program was one of the first attempts at extending software's open source practices to hardware.

Shortly after the launch of the Open Hardware Certification Program, David Freeman (1998) announced the Open Hardware Specification Project, another attempt at licensing hardware components and creating an entirely new platform as an alternative to proprietary computing systems. Also in 1998, Troy Benjegerdes (1998) made public his intention of launching an entrepreneurial venture to apply the principles of open source software to the design and development of hardware. That same year, Reinoud Lamberts (1998) launched

Open Design Circuits, a website dedicated to collaboratively designing low cost and open design circuits. Between 1998 and 1999, Graham Seaman (2001) made several attempts at defining open source hardware. And, in 1999, Damien Lampret launched OpenCores.

The goal of OpenCores, one of the oldest open source hardware development efforts, is the creation of a vast library of freely available hardware designs consisting of elements for processors, memory controllers, peripherals, motherboards and several other components. The principal notion behind the project is that, rather than making large investments in basic and sometimes redundant design work, firms would be able to freely use the library for the know-how, chip designs and other technologies (Spooner 2001). By encouraging device manufacturers to incorporate the blueprints for various OpenCores technologies into their designs, thus saving them time and capital on research and development, OpenCores expected to lower the cost of hardware and boost the development of more open source software (Asaravala 2003). By 2008, the project had over 20,000 registered users and its website was visited by an average of 70,000 engineers every month (Pele 2008). In its first eight years of existence, more than one million developers from over 10,000 organizations had downloaded designs from OpenCores (Lampret 2011).

Despite this initial burst of activity around the nascent concept of open source hardware, most of these first initiatives (with the exception of OpenCores) faded out within a year or two, and only by the mid 2000s would open source hardware become again a hub of activity. Unlike free software—which can be clearly traced back to the moment Richard Stallman (1984) became frustrated with a printer at MIT and decided to "put together a sufficient body of free software" to free him from proprietary software—there is no one defining event that can be identified as the crucial moment open source hardware was born. Rather, it began quietly with several developers around the world making the decision to publish their hardware designs online for others to use. From these early years of open source hardware, three projects emerged that would later play an important role in the maturation and expansion of the practice: SparkFun, Arduino, and RepRap.

In 2002, Nathan Seidle, then an electrical engineering student at the University of Colorado in the U.S., was working on a GPS logger for one of his classes. Realizing just how difficult it was for a single individual to source electronics parts for projects, he decided to start a small online business to sell components to his friends and perhaps a few others in the area. In December 2002, Seidle used his credit cards to acquire the initial inventory and launched SparkFun Electronics in January 2003. As reported on a personal interview, to Seidle's surprise, his small retail business soon showed to have appeal to a larger customer base:

> *I was thinking I was going to sell to my friends and then the third order was from France. So I grossly underestimated where I was going. At first I was doing maybe two or three orders a day, and then it was five orders a day, and when I graduated college about a year and half later it had grown to ten or fifteen orders a day. This was enough to sustain me and I was also looking to hire a friend. So that was my first employment.* (Seidle 2011)

All products designed by Seidle's firm are released under open source licenses, a decision made shortly after the firm's launch. In 2003, Seidle had designed an accelerometer with serial output, but he feared the product would not work properly and thus chose to make its schematic publicly available so customers could repair it. Almost immediately a customer asked him to change the firmware on the device so it could be used on a different system. Instead, Seidle gave the customer the firmware so he could make the change himself.

Ever since, all products created by SparkFun have been accompanied by the public release of their schematics and firmware, as well as detailed descriptions of their layout and functioning. "If people could modify our products to fit what they needed," Seidle explains, "I knew that we would sell more, because if you can modify it, you can make it your own" (Seidle 2011). To facilitate access to and modification of electronics devices, SparkFun also began offering classes and online tutorials with the purpose of enabling "the individual tinkerer/engineer/student/inventor to get the products they need and the information necessary to make their ideas a reality" (BBB 2014). Considering that sourcing parts in small quantities is one of the major hurdles technology hobbyists face, SparkFun would play a fundamental role in the expansion of DIY hardware by making electronics building blocks—components, circuit boards, and kits—accessible to amateur creators.

In the winter of 2005, shortly after the launch of SparkFun, Massimo Banzi, then an associate professor at the Interaction Design Institute Ivrea (IDII) in Italy, was struggling to find an inexpensive and powerful microcontroller (a simple and small "computer" on a single board) to teach electronics to art and design students. The most common product available at the time was the Basic Stamp, which not only did not have enough processing power for some of the projects Banzi's students wanted to create, but was also too costly for their budgets (Kushner 2011).

Several years prior, in 2001, MIT researchers Ben Fry and Casey Reas had created Processing: a designer-friendly and open source programming language that allowed inexperienced programmers to create complex data visualizations. Hernando Barragán, then a student at IDII who had as advisors both Banzi and Reas, took the first steps towards applying the Processing model to electronics. The result was Wiring, a platform geared towards artists and designers, which included both a simple integrated development environment (IDE) and a ready-to-use circuit board. Banzi, however, wished to further simplify Wiring (Gibb 2010) and thus partnered with David Cuartielles, a telecommunications engineer and visiting researcher at IDII, and David Mellis, another of Banzi's students, to create a derivative board and IDE. Shortly after, the team was joined by Gianluca Martino, Nicholas Zambetti, and Tom Igoe, a professor at NYU's Interactive Telecommunications Program.

Within a few days, Banzi and Cuartielles had designed the first Arduino board and Mellis had written the code to drive it (Thompson 2008). It was low cost (under $30), quirky (blue, instead of the traditional green, with a map of Italy on the back), and included several design choices that were considered unconventional at the time (Fig. 4). Martino, who is a formally trained engineer, described the design process as a "new way of thinking about electronics, not in an engineering way, where you have to count electrodes, but a do-it-yourself approach" (Kushner 2011). The board was made of easy to find parts, in case users wanted to build their own, and was for the most part plug-and-play: users just needed to connect it to a computer and begin programming. No extensive knowledge of electronics or programming was required and the system could run on all computer platforms without any special configuration needs.

Figure 4: Arduino Diecimila

The simplicity and ease of use of Arduino made it an instant success amongst IDII students, who soon began using it to read sensors, make lights blink, and control motors. One of the first Arduino projects was a homemade alarm clock that hung from the ceiling by a cable; whenever the user hit the snooze button, the clock would rise higher into the air until he or she had to get up to turn it off (Ibid.).

Given that the goal was to create an accessible platform for learning and experimentation, the creators of Arduino decided to make the project's files available online so that anyone could study, reproduce, modify and manufacture both the software and the boards. Another important factor that influenced this decision was the fact that IDII was about to close. If the school held the intellectual property for the project, it might either be lost or misappropriated once the institute closed (Ibid.). Arduino was, therefore, released as an open source hardware project.

Thus, in 2005, Banzi, Cuartielles, and Mellis published the Arduino schematics online and invested 3,000€ in the first batch of boards. They had 200 boards manufactured and IDII bought 50. Soon, word spread online about the new Arduino platform, despite the absence of marketing or advertising. The first customer was a friend of Banzi's who acquired one board. Within a short period of time, the Arduino team began receiving orders for hundreds more and a distributor offered to sell the boards (Kushner 2011, Thompson 2008). By 2011, Arduino had sold over 300,000 boards (Igoe and Mota 2011) and was distributed by over 200 retailers around the world, from large firms, such as SparkFun, to small one or two person businesses—like the Portuguese man who told Banzi he had quit his job to sell Arduino products from his home (Kushner 2011). In late 2011, RadioShack, a wireless devices and consumer electronics retailer with over 7,000 stores across the United States, began carrying Arduino products.

Most electronics projects require microcontrollers to process the devices' logic. Given Arduino's low cost, availability, and flexibility (manifest not just on the multipurpose system itself, but also on the ability to replicate and customize it), the platform eventually became a staple for electronics enthusiasts and one of the principal building blocks of open source hardware creations.

At the same time that SparkFun and Arduino were beginning to take shape, Adrian Bowyer was releasing the first plans for the open source 3D printer RepRap. In a personal interview, Bowyer described the two principal motivations for releasing the machine under an open source license:

> *1. The moral dimension . . . - it seemed to me that RepRap might become a world-changing and powerful technology. If world-changing and powerful technologies are controlled by a few people, then the few advance and the rest (to a greater or lesser extent) go hungry. The only way to avoid that was to give RepRap away for free, and to ensure that future developments stayed free. . . .*
>
> *2. A more powerful reason - if you have a machine that copies itself and you try to restrict it, you are saying to the world that you want to spend the rest of your life in court trying to stop people doing with the machine the one thing it was designed to do. I have better things to do with my time…* (Bowyer 2009)

Together, these early open source hardware projects played a pivotal role in the expansion of open source hardware by acting as catalysts for new DIY projects: SparkFun provided access to components, Arduino contributed the computational platform, and RepRap the capability to generate parts for other machines.

By 2010, the practice of publishing digital plans for physical objects had caught the attention of the media. Prominent articles in wide-reaching publications—such as *The New York Times* (Vance 2010), *The Wall Street Journal* (Lahart 2009), and *Wired* magazine (Thompson 2008; Anderson 2010)—further contributed to fuel interest in and expand the practice. Encouraged by the media attention and the growth of what was by then being referred to as a movement, but also wary of possible abuses, a group of open source hardware practitioners realized the need to formalize the practice and wrote the first draft of the "Open Source Hardware Definition"[32]. This document, which was subsequently endorsed by 319 individuals and organizations, defines open source hardware as:

> *. . . hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design. The hardware's source, the design from which it is made, is available in the preferred format for making modifications to it. Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open source design tools to maximize the ability of individuals to make and use hardware. Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs.* (Open Source Hardware Definition 2011)

Although the term open source hardware initially referred mostly to electronic devices (such as computers and microcontrollers), it eventually turned into an umbrella term for a variety of physical goods that are designed and distributed according to open source principles. By early 2013, open source plans and recipes for automobiles, 3D printers, laser cutters, aerial drones, sailing drones, sub-aquatic drones, book scanners, toys, houses, agricultural and construction machinery, raw materials and chemical compounds, reactive

[32] This definition, which was heavily based on Bruce Perens's (1997) "Open Source Definition," serves as a filter to determine whether or not a hardware design can be labeled open source hardware.

garments, biomedical devices, brain wave monitoring tools, and radiation monitors for civilian use could be found online.

A Great Babbling Bazaar

If in proprietary hardware there is a hard distinction between producer/designer and consumer/user, in open source hardware the two roles tend to overlap in varying degrees. One may be the originator of a new open source project or one may simply acquire an open source device, assemble it (if obtained as a kit), and use it. But in between the two there are several other forms of involvement that blur the roles of consumer and producer/designer. One may acquire an open source hardware device and modify it to either fit personal or organizational needs, or to improve it in some way. Or one may create an entirely new version of a device based on preexisting designs.

As such, an open source hardware project is an eternal work-in-progress, a standing invitation for improvements and modifications: anyone can modify, add to, or build upon it without asking permission to do so. Naturally, designing, altering and producing hardware requires knowledge and skills. Nevertheless, this does not mean that only professional engineers or product designers are qualified to develop hardware. The conjunction of well documented open source projects with the wealth of technical knowledge now available online and the support of fellow developers often lowers the barriers to entry to such a point that individuals with no formal training in engineering or product design can make meaningful contributions to a project, or even originate a new one. In fact, one of the most salient characteristics of open source development is precisely the fact that no formal credentials are required. This has been informally called a do-ocracy, a system in which the only necessary credential is the ability to do.

The most prominent open source software projects count with thousands of developers who collaborate to create a single release of the project. However, there is nothing to prevent any one developer from "forking" it—that is, from using the collectively developed code base to create a new project. Open-source code and the licenses under which it is distributed downright empower this possibility. In practice though, open source software forks do not happen very often since they may lead to incompatible versions of a system (forcing developers to choose which version to base their future work on), resulting in a loss of synergies and dilution of the project. Therefore, open source software developers tend to consider forking as legitimate only in particular circumstances (such as cases in which the primary developer has abandoned the project) (Weber 2004).

In open source hardware, however, mass collaboration is usually absent and forking is extremely common. As David Mellis suggests, this marks an important distinction between the ways in which open source software and hardware are developed. While open source software is collaborative, Mellis (2008) argues, open source hardware is primarily derivative. To illustrate this point, he describes the evolution of the YBox, a small electronic device for generating textual TV channels. The YBox was created in 2006 by Uncommon Projects at Yahoo's annual Hack Day event, after which Yahoo financed the production of 80 kits to be given away at Maker Faire in 2007. Subsequently, the YBox was redesigned by Robert Quattlebaum whose version dramatically lowered the cost of the device. Finally, the design was further refined by Adafruit, which then began selling it as kit. Thus, the open source nature of the YBox allowed several creators to work on, improve and redistribute the device. However, unlike open source software, these contributions were not collected into a single and official version of the project—instead each iteration remained as an independent product (Ibid.).

Thus, derivatives—understood here as independent designs based on one or more preexisting works and distinct from contributions bundled into a single work—are extremely common in open source hardware. Mellis (Ibid.) attributes this to the entrepreneurial nature of open source hardware, which fundamentally distinguishes it from its software counterpart. Although several firms have emerged around large software projects, such as Linux and Apache, and numerous programmers are paid by firms to contribute to their development, open source software's quintessential developer is the volunteer, someone who contributes to the project with no direct monetary gain. The figure of the volunteer developer is still present in open source hardware, but while no one can profit from the sale of open source software (its business models are based on selling related services and products, not the software itself), it is possible to profit from the sale of open source hardware. Although there are still many developers who contribute to hardware projects for non-monetary reasons, the fact that this possibility exists also attracts the more entrepreneurial developers who see in it a possibility to not only satisfy personal motivations, but also earn a living doing it. Such developers often opt to create and commercialize new products based on pre-existing open source works, rather than contributing modifications or additions directly to those projects.

The predominance of derivatives must also be accounted for by the repurposing and adaptation that open source hardware is meant to encourage. Developers often re-design devices not to improve them but to adapt them to a different purpose or specificity, in which case the creation of a derivative is the only option. The Arduino designs, for example, have spawned dozens of derivatives in which the original schematics were built upon, transformed and adapted to serve functions not contemplated by the original designs. Examples of these derivatives include the LilyPad, a washable board designed to be used on wearables and e-textiles; the Sanguino, a microcontroller created to drive open source 3D printers; the ArduPilot, an autopilot for autonomous vehicles; and the Blipduino, a robotic blimp controller board. The project also gave origin to hundreds of compatible devices known as shields: boards that can be connected to an Arduino to extend its capabilities with functions ranging from enabling internet and GPS connectivity to controlling motors and LCD displays.

In open source hardware small groups of developers or, just as often, a single individual work on a version of a device at a time. However, these efforts are surrounded and in constant communication with the array of parallel endeavors that form a project's ecology. The complex network of parallel and iterative endeavors that characterizes open source hardware projects, especially the most successful ones, can be glimpsed in an anecdote concerning the Arduino-brand boards. On one of the initial designs, Massimo Banzi made a mistake on the spacing between two of the board's pins. Later on, when Banzi sought to correct it, he realized that even though this was a simple design alteration, it would have vast implications for the overall project (Banzi et al. 2011). By then, an array of devices had already been created around the Arduino platform (devices that communicate, expand or modify the Arduino), so the removal of that extra space on a new version of the board would render all those other parallel products incompatible and possibly useless. For this reason, several years after the mistake was discovered, the standard Arduino boards were still shipped with the original spacing error.

The RepRap project is another excellent example of the wealth of contributions and agendas that characterize open source hardware projects. RepRap has since the beginning been developed by a core team of approximately twenty geographically-disperse volunteers —who are coordinated by Adrian Bowyer, the original creator of the device. However, in addition to the official RepRap design branches—Darwin, Huxley, Mendel, and Prusa—designed by the core team, several derivative versions of the machine have been created by other contributors. These variants are generally meant to improve the machines, but in specific ways. For example, the MendelMax derivative, a full-sized RepRap, focuses on structural rigidity and ease of assembly; the Wallace, a smaller RepRap, was designed specifically to reduce part count and minimize complexity of build; and the Makergear Prusa Mendel, a variation of the Prusa Mendel, seeks to minimize frame flex and improve ease of assembly. These RepRap derivatives seek to address specific issues—ease of assembly, part count, size, flexibility, etc.—and therefore reflect the particular concerns and priorities of their creators.

The RepRap project has also served as the inspiration for other open source machines different enough from the original to be considered new projects—that is the case of Lulzbot, MakerBot and Ultimaker 3D printers. It is also common for user-developers to combine parts from different machines to create hybrids that mix and match the extrusion head of one project with the body and electronics of others. To add further complexity, several businesses have sprung up around the RepRap project dedicated to retailing complete machines or parts to build one, which are usually slightly modified in the process.

By definition, an open source hardware project has no set structure nor rules governing who can contribute, when or how—except for the broader ones dictated by the Open Source Hardware Definition and the distribution licenses adopted by each project. Individuals and firms self-assign tasks, sometimes taking into account the project's needs and goals, sometimes guided by their own agendas. As a result, the shape and state of an open source hardware project at any given moment are defined only by what the constantly evolving network of participating individuals and organizations are doing of their own accord. The result is in fact very similar to the "great babbling bazaar of differing agendas and approaches" Raymond (2005) speaks of. Nevertheless, as Steven Weber argues, this seeming anarchy results in an evolutionary approach to complex problem-solving in which diversity serves to accelerate the discovery and resolution of problems:

> *(...) If it is an important problem, it will probably attract many different people or perhaps teams of people to work on it. They will work in many different places at the same time, and hence in parallel. They will experiment with different routes to a resolution. And they will produce a number of potential solutions. At some point a selection mechanism (which is messy and anything but "natural selection") weeds out some paths and concentrates on others. This evolutionary archetype works through voluntary parallel processing. No central authority decides how many paths ought to be tested, how many people ought to be placed on each path, or which people have the most appropriate skills for which tasks.* (Weber 2004)

Open For Business

The distributed approach of open source hardware is not, however, incompatible with business. In fact, several of the most prominent open source hardware projects either originated from firms or were the basis for the launch of new firms. In the broadcast approach firms typically patent their products in order to prevent competitors from recreating and redistributing their designs, and thus safeguard investments in research and development, manufacturing, and distribution. While the commercial production of open source hardware still entails a financial investment, it operates on a very different logic.

The principal open source hardware business model can be summarized in one short sentence often cited by its commercial developers: “give away the bits, sell the atoms.” With the designs available under licenses that allow anyone to copy, make and commercialize an open source product, competitors are free to manufacture another firm’s products. Thus, the most successful businesses are the ones that offer the highest quality products at the lowest prices, whether that is the product's original creator or not. Based on this logic, open source hardware businesses strive to stay ahead of the competition by focusing on increasing quality and lowering costs.

However, even if any individual or firm can legally clone and distribute an open source product—which is perceived by traditional business models as a competitive disadvantage—open source hardware manufacturers focus on a different advantage: the hacker culture's notion that distributed development enables faster technological innovation. Given that many open source hardware designs are released under copyleft licenses—which ensure that their clones and derivatives are also distributed as open source—firms are allowed to fold back into their products any improvements devised by users or competitors, and therefore new developments benefit the entire ecosystem.

Economist Eric von Hippel (2005), one of the leading proponents of open development processes, maintains that products are best designed and modified by those who actually use them. In *Democratizing Innovation,* he argues that user-centered innovation offers great advantages over the manufacturer-centric development system that has been the cornerstone of commerce for the last hundred years:

> *The user-centered innovation process . . . is in sharp contrast to the traditional model, in which products and services are developed by manufacturers using patents, copyrights, and other protections to prevent imitators from free riding on their innovation investments. . . . However, a growing body of empirical work shows that users are the first to develop many and perhaps most new industrial and consumer products. Further, the contribution of users is growing steadily larger as a result of continuing advances in computer and communications capabilities.* (Hippel 2005)

In a study comparing business and household sector innovation in consumer products, Hippel, Jong and Flowers (2010) found that 2.9 million users—6.2% of U.K. consumers—engaged in consumer product innovation between 2007 and 2010. In aggregate, the annual product development expenditures of these consumers was 2.3 times larger than the combined annual consumer product R&D expenditures of all firms in the UK. In this same study, the researchers suggest that—while it would be extremely costly for manufacturers to design, prototype and test-market every design adjustment their customers may desire—motivated users can take on these tasks themselves and create exactly what they want. Moreover, these users can benefit from innovations developed and freely shared by other users. This participatory process is precisely what open source firms seek to encourage.

Thus, like open source software, open source hardware combines commercial goals with a belief that technologies are better developed by those who use them. This notion was clearly conveyed by Chris Anderson, leader of the DIY Drones project, when a Chinese manufacturer began selling copies of the DIY Drones ArduPilot Mega at less than half its original price, and in the process translated the project's documentation into Chinese:

> *Personally, I'm delighted to see this development, for four reasons. I think it's great that people have translated the wiki into Chinese, which makes it accessible to more people. It's a sign of success--you only get cloned if you're making something people want. Competition is good. What starts as clones may eventually become real innovation and improvements. Remember that our license requires that any derivative designs must also be open source. Think how great would it be if a Chinese team created a better design than ours. Then we could turn the tables and produce their design, translating the documentation into English and making them available to a market outside China.*
>
> *This is the classic open source hardware model. Software, which costs nothing to distribute, is free. Hardware, which is expensive to make, is priced at the minimum necessary to ensure the healthy growth of a sustainable business to ensure quality, support and availability of the products. All intellectual property is given away, so the community can use it, improve it, make their own variants, etc. The possibility that others would clone the products is built into the model. It's specifically allowed by our open source license. Ideally, people would change/improve the products ("derivative designs") to address market needs that they perceive and we have not addressed. That's the sort of innovation that open source is designed to promote. But if they only clone the products and sell them at lower prices, that's okay, too. The marketplace will decide. (...) Arduino has gone through exactly the same situation, with many Chinese cloners. The clones were sometimes of lower quality, but even when they were good most people continued to support the official Arduino products and the developers that created them. Today, clones have a small share of the market, mostly in very price sensitive markets such as China. And frankly, being able to reach a lower-price market is a form of innovation, too, and that is no bad thing.* (Anderson 2011)

For Nathan Seidle—whose open source firm currently employs 136 people and recently reported $25 million in revenue (Inc 2013)—competition between open source products also contributes to accelerating development by encouraging firms to continually improve their products:

> *Whenever we release a product as open-source hardware, it allows our competitors to download those files and potentially produce the exact same thing. But there is a little bit of lag time. So we design a product, it takes us multiple weeks, and when we post that product with all the files, it's going to take our competitors probably 6 to 10 weeks in order to replicate it and get the components in place. So we have 6 to 10 weeks to sell the heck out of that product. At the end of that period our competitor comes online and now we have true competition. And it just comes down to price and support. So at SparkFun the reason why we open source is because it keeps us sharp. Every 6 to 10 weeks we say "do we need to revise it, do we need to make it better, how are we going to keep this product better than our competitor's?" While with intellectual property, if you just locked it down with a patent, you get very lazy and say "okay, I've got this product for the next 7 years, I don't have to change anything for 7 years." You can get very lazy like that. So we like it because it keeps us sharp, it makes it so that we're always driving to make the product incrementally better.* (Seidle 2011)

Thus, in open source hardware, the belief that users can and should be able to modify their technologies is combined with the notion that open development processes lead to faster and better engineering. This is, in fact, the main argument made by advocates of open source software and hardware: the greater the number of testers and developers, the better the technologies will become. The evolution of open source 3D printers is a case in point.

Since the launch of the RepRap project, a number of individuals and organizations took an interest in and, directly or indirectly, contributed to the project. Between the project's launch date in 2004 and late 2008, progress was somewhat slow, with only a few developers contributing directly to it. At that point, RepRap machines were still difficult to build and operate, and most of the resulting prints of poor quality. Between early 2009 and 2011, several new commercial and non-commercial developers of RepRap-related devices emerged, resulting not only in more research and development but also in an increasing number of 3D printers in the hands of users. As Erik De Bruijn (2010) points out, since each user of an open source 3D printer is also a potential developer, the growth in the number of users also translates into improvements in the technology. In turn, cheaper, better and easier to operate 3D printers tend to draw new users and developers. Because of this, in less than two years, these machines evolved from producing mostly small, simple, and often mangled plastic objects to being operated by individuals with limited technical skills and becoming capable of generating extremely complex prints. Thus, amidst the tangle of activities and agendas that characterizes the development of open source 3D printers, the quality and performance of the technology took a remarkable leap and greatly extended its user-developer base. In turn, this greater dissemination of the technology continues to attract additional developers and new variants.

III.5 Self-Determination

Revolution doesn't happen when society adopts new technology—it happens when society adopts new behaviors.

—Clay Shirky (2009, 160)

The identities, ethos, and cultural backgrounds of the maker, hackerspaces and open source hardware communities are somewhat different. It can be said that the maker community's greatest emphasis is on the act of making something/anything. Hackerspaces are centered on facilitating access to production capabilities through tool and space sharing, as well as the establishment and maintenance of local communities sedimented by collective technological exploration. And open source hardware focuses on information sharing and the collaborative development of technologies. However, in practice, the cultural distinctions between them are difficult to pinpoint, so fluid and overlapping are their memberships and so numerous and important their shared traits and goals: community building is just as relevant in maker culture and open source hardware as in hackerspaces; information sharing is valued and practiced across the board, even if not as consistently as within the open source hardware community; and the act of making is the cornerstone of all three identities and practices. They represent three facets of the phenomenon that concerns this dissertation: citizen participation in the production of material culture and the shaping of technologies through collaborative practices. Thus, rather than seeking to pinpoint the shifting and blurry differences between their identities, the emphasis here is on the ways in which they collectively apply the distributed approach and challenge the broadcast model. In this context, the maker, hackerspaces and open source hardware communities will be jointly referred to as DIY hardware communities.

At the core of the ethos and practices of these DIY hardware communities lies the act of doing something one self, individually or in voluntary collaboration with others. The term do-it-yourself commonly describes the act of creating, producing, modifying or repairing something that lies outside of one's professional expertise. It is thus based on notions of self-reliance and self-improvement through the acquisition of new knowledge and skills. This focus on self-reliance and proactive creativity, however, appears jarring against a backdrop in which pure consumption plays such a central role.

In *Cognitive Surplus*, Clay Shirky notes that citizens of developed societies, now having more leisure time than ever before, have predominantly chosen to spend most of this "surplus" time watching television:

> *For most of the time when we've had a truly large-scale surplus of free time—billions and then trillions of hours per year—we've spent it consuming television, because we judged that use of time to be better than the available alternatives. Sure, we could have played outdoors or read books or made music with our friends, but we mostly didn't, because the thresholds to those activities were high, compared to just sitting and watching. Life in the developed world includes a lot of passive participation: at work we're office drones, at home we're couch potatoes. The pattern is easy enough to explain by assuming we've wanted to be passive participants more than we wanted other things. This story has been, in the last several decades, pretty plausible; a lot of evidence certainly supported this view, and not a lot contradicted it.* (Shirky 2010, 173)

Given that television watching is essentially an act of passive consumption—in the sense that the audience is neither participating in nor producing the content broadcast by television networks—the behavior of mass audiences seems to indicate that consumption is most individuals' preferred use of leisure time. Thus, at first sight, the emergence of participatory practices may appear surprising. In fact, Shirky suggests, "The atomization of social life in the twentieth century left us so far removed from participatory culture that when it came back, we needed the phrase 'participatory culture' to describe it" (Ibid., 288). How then can the proliferation of user-created content on the Internet, the rise and growth of mass collaboration projects, and the making activities of DIY hardware communities be explained?

Part of the answer lies in the opportunities opened by digital technologies which made do-it-yourself creativity and sharing not only possible, but also easy, instantaneous, and low cost. "Evidence accumulates daily that if you offer people the opportunity to produce and share," Shirky argues, "they'll sometimes take you up on it, even if they've never behaved that way before and even if they're not as good as the pros" (Ibid., 331). This radical lowering of barriers makes participatory behaviors accessible and therefore more likely to occur. However, that the possibility exists does not mean that it will be acted upon if there is no motivation. In other words: technologies enable behaviors, but they do not necessarily cause them. Thus, the second part of the answer can only be found in human motivations, more specifically in intrinsic motivations.

Intrinsic motivations are at play when individuals engage in an activity because it is interesting and satisfying—as opposed to extrinsic motivations in which activities are engaged in to achieve an external reward. In the field of psychology, studies of this type of self-motivation evolved into Self-Determination Theory (SDT). The central premise of this theory—initially proposed by psychologists Edward L. Deci and Richard M. Ryan (1985) and subsequently investigated and applied by several others—is that all individuals' have an innate propensity towards personal growth and vitality, which can be either satisfied or frustrated by their environment (Hill 2011). Self-Determination Theory focuses on three universal needs said to be inherent to all human beings: competence—the need to experience mastery; relatedness—the need to be socially connected; and autonomy—the need to be "self-initiating and self-regulating" (Deci et al 1991, 327). While the satisfaction of these needs promotes mental health and enhanced motivation, Ryan and Deci (2000) argue, their thwarting conversely leads to a deficit in both well-being and motivation. Given its focus on ability, connectedness and choice, self-determination theory and the three universal needs it identified provide a useful lens through which to analyze the activities and ethos of DIY hardware communities.

Competence

In self-determination theory, competence refers to an individual's need to take on challenges and experience mastery. This concept is closely related to Robert White's (2011) theory of "effectance motivation." In White's conception, effectance refers to the desire to interact with, explore, manipulate and produce changes in one's environment. This type of motivation is essentially creative, playful and exploratory and, therefore, engaged in for the “joy of being a cause” (White 2011, 465). For Ives Hendrick, the need of individuals to control their environment reflects an “instinct to master,” “an inborn drive to do and to learn how to do” (Laplanche and Pontalis 1988, 219). Richard de Charms, in turn, understands “personal causation” as “the initiation by an individual of behavior intended to produce a change in his environment” (Charms 2013, 6). Broeck et al further refine the concept by suggesting that competence also includes the “propensity to . . . engage in challenging tasks to test and extend one’s skill” (Broeck et al et 2010, 982). Thus, as noted by Alloy et al, “Even a cursory examination of the literature on control suggests that individuals are motivated to effect their environment in instrumental ways” (Alloy, Clements, and Koenig 1993, 1).

Three recent studies of the maker, hackerspaces and open source hardware communities demonstrated that the desire to take on challenges and experience mastery in relationship to technologies is a pivotal motivation for engaging in DIY hardware practices. The most recent survey of hackerspace members, conducted by Martin Charter and Scott Keiller (2014), found that two of the primary motivations for participating in a hackerspace are “To be intellectually stimulated” and “To learn new skills.” In another survey of the maker community, conducted by Karlin Associates on behalf of Make and Intel in 2012, 94% of respondents strongly agreed or agreed with the statement “Making things makes me feel resourceful,” and 81% strongly agreed or agreed that “Making things makes me feel like I can do things I didn’t know I could do” (Karlin Associates 2012). Lastly, in a 2013 survey of the open source hardware community, distributed by the Open Source Hardware Association, 80% of respondents indicated “To develop my skills and learn” as a motivation for creating or otherwise contributing to open source hardware projects (Mota and Mellis 2013).

An analysis of several DIY hardware communities projects and initiatives further showed that, in these communities, the desire to manipulate and explore one’s environment and extending one’s skills by engaging in challenging tasks is often expressed in the exploration and repurposing of machines, the construction of technologies to explore the environment, and the promotion of technological literacy to encourage and enable feelings of competence in others.

Experiencing Competence Through the Playful Exploration of Technology

Early twentieth century amateur radio operators saw the technology as a means to escape the deskilling of work by experiencing technical mastery in their leisure hours (Abbate 1999). Similarly, both the 1950s-60s MIT programmers and the 1970s personal computer hobbyists wished to gain access to computers in order to understand and master them. They did not see computers as mere tools for data processing; the machines themselves were the object of research. Their curiosity went beyond mere knowledge and included the desire to master the technology, to improve it, to push it further. In this sense, these hackers' relationship with computers hinged on curiosity and a passionate desire for exploration and mastery. As noted by Levy (2010) and Taylor (1999), the playful shape this exploration took, the hacks themselves, allowed these hackers to not only achieve personal satisfaction, but also to demonstrate mastery and obtain the recognition of their peers.

This perspective persists in contemporary DIY hardware communities in which the exploration of technology for its own sake is still an unquestionable motivation for opening, reviving, and repurposing machines. This type of exploration—in which preexisting machines are transformed to perform tasks they were not originally designed for—can be illustrated by a few emblematic technological experiments undertaken by members of the NYC Resistor hackerspace, namely: Barbot, a slot-machined turned cocktail mixing robot (Fig. 5); Mr. Stabby, an industrial robotic arm reprogrammed to hit a piñata (Fig. 6); and Teletype, a 1930s teletype repurposed to print messages from the social network Twitter (Fig. 7). In these projects, which serve no practical purpose or need, the act of subverting and imprinting one's own imagination in industrially produced technologies by breathing a new (and different) life into obsolete machines—and thus act upon one's technological environment—is the only goal.

Figure 5: Barbot by NYC Resistor

Figure 6: Mr. Stabby by NYC Resistor

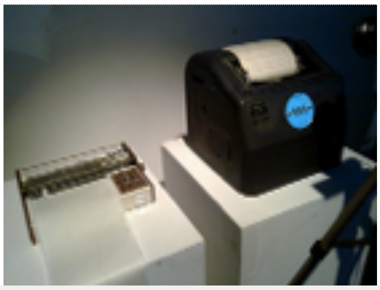


Figure 7: Teletype by NYC Resistor

The exploration of technologies through activities that allow individuals to take on challenges, test and extend their skills, and manipulate the environment does not necessarily need to begin with a pre-existing machine. It is also often expressed in whimsical projects such as the Nuclear Taco Sensor Helmet Gameshow created by the Portuguese hackerspace AltLab—a helmet device with humidity, temperature and fluid intake sensors, used to record and measure the biological reactions of the wearer while eating spicy tacos (Fig. 8); or the Karate Champ Game, created by members of the hackerspace Hack Factory, in which players control kung-fu fighting robots (Fig. 9). Projects such as these neither possess any particularly useful applications, nor were conceived as artistic objects. They are, rather, the product of a playful approach to the exploration of technologies in which the main purpose is to devise and execute clever and previously unattempted technological feats as an expression of one's creativity and technical prowess.

Figure 8: Nuclear Taco Sensor Helmet Gameshow by AltLab

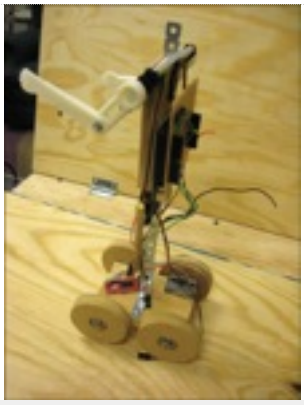


Figure 9: Robot Karate Champ Game by Hack Factory

This interest in exploring technologies beyond their practical applications is aptly epitomized by *New York Time's* reporter J. Jacobs attempt to 3D print a meal for his wife, which required several days of preparation and a host of devices. Although the end goal itself—to cook a meal—would have been more efficiently achieved through traditional means, the objective here was to explore the technology itself and, in the process, Jacobs experienced the sense of mastery that so often fuels explorers of technologies in DIY hardware communities:

> *In my defense, 3-D printing is surprisingly hard—a fact its advocates don't dwell upon. So much can go wrong: The nozzle clogs, the machine overheats, the print pad tilts. . . .*

> *It's also mind-numbingly slow. A teacup takes about four hours to print, accompanied by nonstop whirring. When I tried to design and print a replacement die for my son's Monopoly game, it was a daylong project. My son helpfully pointed out that Amazon has one-click ordering.*
>
> *That said, I did improve with practice. I was particularly proud of my wineglass, with its tapered cone. I became obsessed with the design software, spending hours squashing spheres and hollowing out cylinders. I downloaded some of the hundreds of free, publicly shared designs (though my wife nixed the Tetris-themed earrings).*
>
> *I found myself almost giddy after every successful print: Yes, I created this napkin ring! I can make anything. I am a god and bright blue plastic is my universe!* (Jacobs 2013)

In other instances, however, the exploration of technology is carried out as an art form. In the 1960s, MIT hacker Peter Samson wrote a compiler that allowed the DEC mainframe to play music, a novel application at a time when computers were thought of as mere calculation tools. However, for those hackers, "the art of the program did not reside in the pleasing sounds emanating from the online speaker," Levy explains, "The code of the program held a beauty of its own" (Levy 2010, 31). This notion that the act of exploring technologies can be thought of as an art form, that beauty can be found in technical prowess, still informs contemporary technological explorations.

Today, it is not uncommon for artists to use technologies in the creation of their work, or even to incorporate software and hardware in the art itself—examples of this practice are numerous and varied. However, there is one type of artistic exploration that is particularly relevant in this context: artworks that use technologies as aesthetics, that deconstruct technologies, that are themselves an invitation to technological exploration. This approach is particularly visible in the works of Jie Qi and Hannah Perner-Wilson, both MIT graduates and artists working at the intersection of technologies and crafts.

Jie Qi's work "investigates materials and techniques for blending electronics with traditional arts and crafts media to create personally meaningful technology" (Qi 2013). Qi is interested in the questions that arise from the use of circuits and programming as a form of expression: “What magical experiences can these techniques and materials enable? What new stories can we tell? And how does this change our aesthetic understanding of modern technology?” (Ibid.). Her Electronic Popables book—an interactive pop-up book that lights-up, plays sounds, and moves (Fig. 10)—results from a combination of traditional pop-up mechanisms with thin, flexible, paper-based electronics. In this piece, Qi assembled a series of tableaus in which the circuitry (the electronic system that makes the book react) plays both a functional and an aesthetic role. Using smart materials, Qi replaced the typical motors, wires and etched traces of circuit boards with muscle wire, conductive ink and copper tape. Rather than hiding the functional mechanism, Qi displayed it on the pages of the book. In this sense, the circuits themselves became the artwork, as the circuitry that triggers lights, sound and motion reveals its logic through the painted traces.

Figure 10: Electronic Popables by Jie Qi

Figure 11: TeleScrapbook by Jie Qi, Natalie Freed, and Adam Setapen

On another project, Telecrapbook (Fig. 11), Qi partnered with Natalie Freed and Adam Setapen to create a set of two scrapbooks capable of communicating remotely with each other. Here, once again, the artists opted for leaving all the circuitry exposed, the cover of the book featuring prominently the two open source circuit boards that process the core logic of the books’ communication protocols. Each page of the books contains specific areas for handmade, stick-on sensors and actuators to be placed, and displays next to them the electric circuit that allows them to communicate.

Working along the same lines of revealing and subverting the inner workings of technologies, in Kit-of-No-Parts, Hannah Perner-Wilson sought to reinvent the concept of electronics kits:

> *Conventionally electronics that are built from a kit-of-parts have been optimized for speed, efficiency and repeatability of assembly. While this approach demonstrates the power of modular systems that have made many of the technologies we rely on possible, it also constrains us to particular styles of building, influencing what we build as well as impacting how we come to think about electronics. In order to promote a different approach I have developed a series of techniques that allow us to build electronics using a variety of craft materials and tools.* (Perner-Wilson 2013)

For this purpose, Perner-Wilson deconstructed the logic of several electrical components and devices, and then recreated them using crafts techniques and smart materials. Thus, the Kit-of-No-Parts contains a variety of handmade devices, from gold-gilded or calligraphed traces to paper audio speakers and graphite resistors (Fig. 12). In this piece, Perner-Wilson reveals the workings of electronic components—motors, potentiometers, resistors, audio speakers, microphones, switches, sensors—and uses their functional aspects as material for artistic exploration. Through her work, users are not only invited to explore the inner workings and beauty of machines, but are also encouraged to recreate and reinvent them. On the Kit-of-No-Parts website, Perner-Wilson documented her work in the form of "recipes," which contain detailed instructions on how to build each of these pieces, as a means to "promote further exploration and material investigation, instead of straightforward replication" (Ibid.).

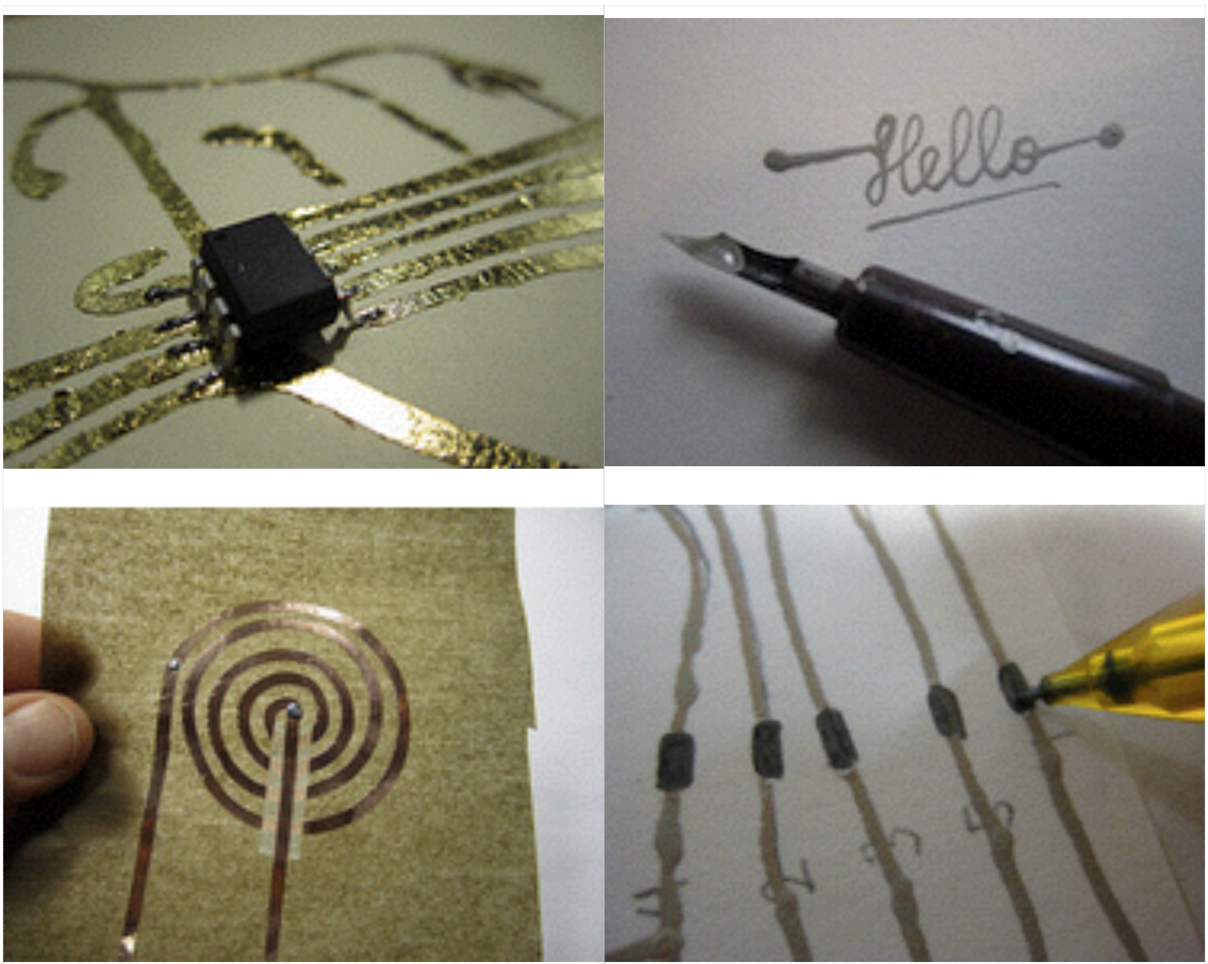


Figure 12: Gilded Electrical Traces, Caligraphed Electrical Traces, Paper Speaker, and Pencil Resistors by Hannah Perner-Wilson

Experiencing Competence by Exploring the World and Creating Technologies to Explore the World

While the exploration and manipulation of the inner workings of machines play a central role in DIY hardware practices, a significant number of projects focus on developing technologies in the service of other explorations. This is the case of devices created for DIY biology experimentation, environmental sensing, and aerial and space exploration.

An interest in DIY biology (DIYbio) experimentation became apparent in contemporary DIY communities as early as 2005, when technologist and writer Meredith Patterson demonstrated at the hacker conference CodeCon how to purify DNA using common household items. Four years later, the 2009 edition of CodeCon dedicated one third of its program to a biohack track. Subsequently, biohacking became a common topic for conferences, having been the theme of the 2010 Humanity+ Summit at Harvard (subtitled "Rise of the Citizen Scientist"), of the Outlaw Biology Summit at UCLA, and included in the programs of the 2010 Open Science Summit and the 2012 Open Hardware Summit.

More permanent DIYbio groups began to emerge in the late 2000s. In 2008, amateur biologist Mackenzie Cowell and Personal Genome Project community director Jason Bobe launched Diybio.org with the goal of establishing "a vibrant, productive and safe community of DIY biologists," based on the "belief that biotechnology and greater public understanding about it has the potential to benefit everyone" (DIY Bio 2013). Hackteria, a web platform and collection of open source biological art projects, was founded the following year by Andy Gracie, Marc Dusseiller and Yashas Shetty—in the sequence of the Interactivos?09 Garage Science workshop which took place earlier that year at Medialab Prado in Madrid. As a community platform, hackteria seeks to "encourage the collaboration of scientists, hackers and artists to combine their expertise, write critical and theoretical reflections, [and] share simple instructions to work with lifescience technologies . . .." (Hackteria 2013). One year later, BioCurious, a biotech hackerspace, was established in the U.S. with the mission of providing DIYers with low-cost laboratory space and classes. Based on the notion that "innovations in biology should be accessible, affordable, and open to everyone" (BioCurious 2013), BioCurious provides a complete working laboratory and technical library that includes access to equipment and materials, a co-working space, a training center for biotechniques, and a meeting place for citizen scientists, hobbyists, activists, and students.

As the interest in DIYbio grew amongst DIY communities, more experiments and classes began to appear at hackerspaces, several of which now offer meeting and laboratory space to DIYbio groups. From one of these groups, hosted by the hackerspace NYC Resistor, emerged GenSpace, a nonprofit organization focused on the promotion of citizen science and access to biotechnology, which now runs the first community biotechnology laboratory in New York City (U.S.).

Given that DIYbio activities require low-cost, accessible, and hackable devices, several open source hardware projects were created in recent years to address that need. That is the case, for example, of SpikerBox, an EMG system to detect the electrical activity of human muscles using simple skin surface electrodes (Fig. 13); Roboroach, a minuscule electronics backpack that can be attached to a cockroach and then used to control the animal's movements (Fig. 14); a DIY algae incubator (Fig. 15); an open source and inexpensive centrifuge (Fig. 16); a DIY algae microscope and cell-picker (Fig. 17); an open source spectrometer (Fig. 18); an open source orbital shaker (Fig. 19); and a 3D printer capable of creating forms from biological materials (Fig. 20).

Figure 13: SpikerBox by Backyard Brains

Figure 14: Roboroach by Backyard Brains

Figure 15: DIY Algae Incubator by Hackteria

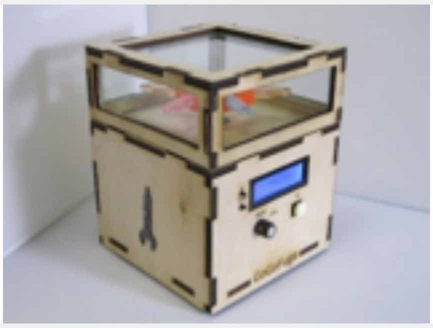


Figure 16: GoGoFudge by Keegan Cooke

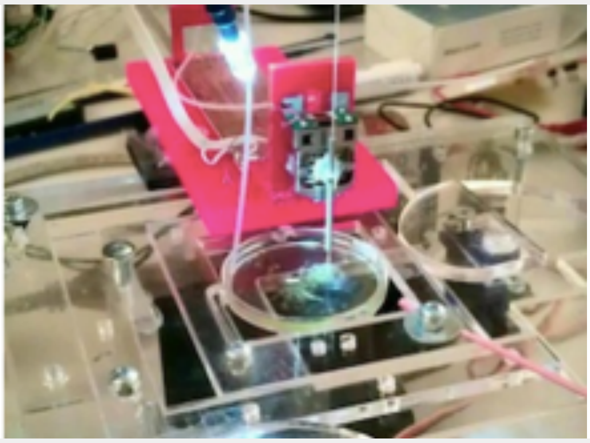


Figure 17: DIY algae microscope and cell-picker by Urs Gaudenz

Figure 18: Open Source Spectrometer by Public Lab

Figure 19: Open Source Orbital Shaker by Jordan Miller

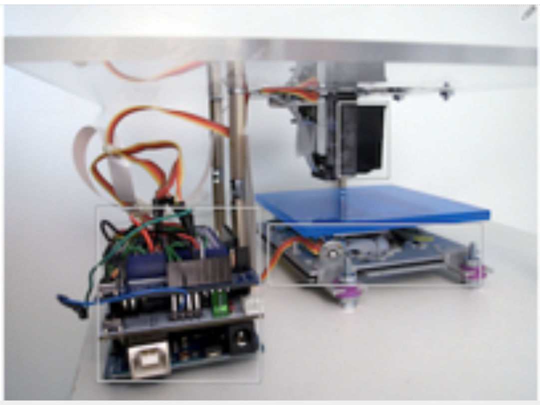


Figure 20: DIY Bio Printer by BioCurious

Alongside an interest in citizen science, DIY hardware creators have also focused on developing technologies to explore the skies and the oceans. One of the most remarkable projects in this area is Protei, an open source vessel for ocean exploration and oil spill cleaning (Fig. 21). The concept for the project emerged in 2010, shortly after the BP Oil spill in the Gulf of Mexico, when Cesar Harada resigned his position at MIT in order to develop a simple and low cost way to absorb oil from the ocean. The result was a remote-controlled, shape-shifting vessel that blends and flexes, capturing the wind in both directions, and is thus capable of sailing through oil-covered waters. Although not necessarily sharing the environmental mission of Protei, other projects emerged in recent years that seek to disseminate exploratory capabilities. That is the case, for example, of Cubesat, a small, DIY satellite (Fig. 22); OpenROV, a project dedicated to the development of underwater robots (Fig. 23); and DIY Drones, a network of developers of open source unmanned aerial vehicles (UAV) for civilian use and scientific data collection (Fig. 24).

Figure 21: Protei

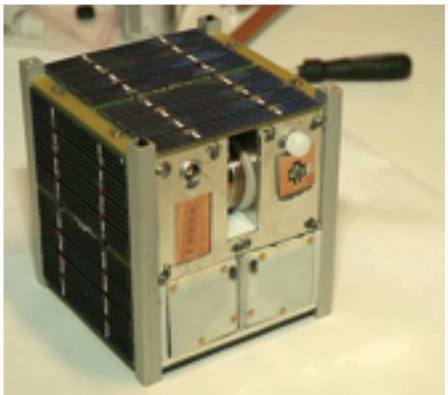


Figure 22: CubeSat

Figure 23: OpenROV

Figure 24: DIY Drones

Experiencing Competence Through Technological Literacy

Given DIY hardware communities' desire to reclaim the shaping of technologies for its users, the pursuit of technological explorations also assumed an educational mantle in their practices. In these communities, it is believed that teaching children and adults how machines work can be a means to shape a more empowered, conscious, and active generation of users of technologies. Since most contemporary technological devices actively or passively prevent exploration, DIY hardware communities have, in the last few years, created several projects with the main purpose of educating users (particularly children) about technologies, and encouraging experimentation and exploration. Examples of these projects include: Squishy Circuits, a set of tools and activities that allow children to create circuits and explore electronics using homemade conductive dough (Fig. 25); SparkFun Kits, a series of playful kits designed to teach the basics of electronics (Fig. 26); LittleBits, a library of electronic modules that snap together with magnets and seek to "break down the barriers between the products we consume and the things we make" (Littlebits 2013) (Fig. 27); and Makey Makey, a touch circuit board that turns everyday items with conductive properties (such as food, plants, and metal utensils) into touchpads and thus encourages playful explorations of electric phenomena (Fig. 28).

Figure 25: Squishy Circuits

Figure 26: SparkFun Kits

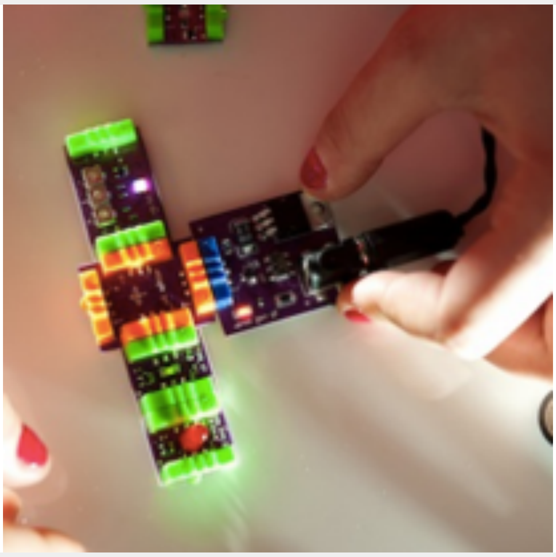


Figure 27: LittleBits

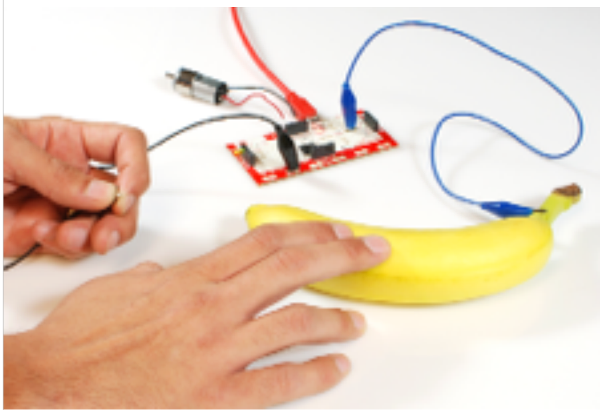


Figure 28: Makey Makey

This focus on technological literacy also led to the emergence of educational programs. One of such programs is The Makery, a pop-up makerspace offering hands-on workshops in programming, electronics, game design, and 3D printing with the goal of providing a place "where communities can gather to play with the creative power of digital design and fabrication, physical computing, and computer programming" (The Makery 2013). Another prominent initiative in this area is the Maker Education Initiative, a program established to foster "more opportunities for young people to make, and, by making, build confidence, foster creativity, and spark interest in science, technology, engineering, math, the arts—and learning as a whole" (Maker Education Initiative 2013). The program's stated goal is to build "community networks of families, leaders, educators, mentors, and organizations to nurture young makers" (Ibid.).

The Raspberry Pi Foundation, a UK-based non-profit with an educational mission, is still another prominent organization dedicated to the promotion of technological literacy. This foundation's main product is the Raspberry Pi, a low cost computer on a single circuit board designed to plug into a television set and a USB keyboard (Fig. 29). The board runs Linux and can be used for word processing, spreadsheets, games, or to play high-definition video. However, the principal goal of the project is not just to provide a low cost device to run common computer utilities, but to encourage the same kind of tinkering that 1970s and 80s computers inspired.

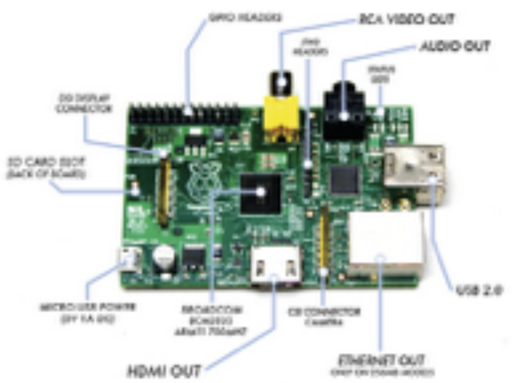


Figure 29: Raspberry Pi

The idea for the Raspberry Pi first emerged in 2006 when researchers at the University of Cambridge's Computer Laboratory became concerned with the progressive decline in the number and skills of top students applying for computer science programs at the university:

> *From a situation in the 1990s where most of the kids applying were coming to interview as experienced hobbyist programmers, the landscape in the 2000s was very different; a typical applicant might only have done a little web design.*
>
> *Something had changed in the way kids were interacting with computers. A number of problems were identified: the colonisation of the ICT curriculum with lessons on using Word and Excel, or writing webpages; the end of the dot-com boom; and the rise of the home PC and games console to replace the Amigas, BBC Micros, Spectrum ZX and Commodore 64 machines that people of an earlier generation learned to program on. (*Raspberry Pi Foundation 2012a)

This phenomenon became noticeable when Eben Upton, an academic at Cambridge University, was interviewing candidates for the university's computer sciences program and realized that "None of them seemed to know enough about what a computer really was or how it worked" (as cited by Moorhead 2012). Upton attributes this generalized lack of understanding to the fact that most schools no longer teach the basics of computation:

> *Children were learning about applications, which are pretty low-value skills. They weren't being properly equipped to think about how computers are programmed, about how they're built and how we make them work . . . What was needed was a return to an exciting, programmable machine like the old BBC Micro; and it had to be affordable, say around £20, so every child could potentially have one.* (Ibid.).

One of Raspberry Pi's stated goals is, therefore, to make available a very low cost computational device to children who lack access to computers outside of school. In this, Raspberry Pi echoes the One Laptop Per Child (OLPC) program: an initiative dedicated to providing children in the developing world with low-cost laptops as a means to encourage “collaborative, joyful, and self-empowered learning” (One Laptop Per Child 2012). Thus, both OLPC and Raspberry Pi demonstrate that, despite the pervasiveness of computational devices at the beginning of the twenty-first century, their distribution is still uneven.

Several years later, when the Raspberry Pi Foundation announced that the boards were finally available for purchase, an unexpected level of interest was demonstrated not just by the education sector but also by a variety of other organizations and individuals: developing countries interested in affordable replacements for traditional desktop computers; hospitals and museums seeking low cost devices to run displays; parents of children with disabilities looking for monitoring and accessibility applications; and “a million and one people out there with hot soldering irons who want to make a robot” (Raspberry Pi Foundation 2012b). Premier Farnell, one of the two hardware distributors used by the foundation, sold out its entire stock of Raspberry Pi boards within a few minutes.

In the 1970s, hobbyists did not have access to professionally-produced computers and therefore had no choice but to build their own. But why would twenty-first century citizens—

so many of whom own laptops, smart phones and tablets—want a "naked" computer? The success of Raspberry Pi can be largely explained by its low cost (approx. $35/22€), which makes it appropriate for applications too specific to justify the use of a standard computer. That is not, however, the entire explanation. For the Raspberry Pi Foundation, the goal is not just to make computers more affordable and accessible, but also to provide children—even those who may already have computers—with a device designed specifically to encourage the type of tinkering other computers no longer incite.

Like the Altair kits of the 1970s, a simple and "naked" computer shifts focus from its instrumental nature to an understanding and exploration of the device's own logic. It is not surprising, therefore, that BBC reporter Peter Price—in an analogy that echoes Turkle's (2005) notion of looking "under the hood" of a computer—compared the Raspberry Pi with early automobiles. "Cars, like computers," he notes, "were simpler back then and a lot of early adopters took an interest in how they worked. Today computers are more complex than ever and we're happy just to do the driving, leaving the maintenance and development to the specialists" (Price 2011).

The result of a system that focuses on "consumption hardware and not production hardware," Upton argues, is "a generation of consumers not producers" (as cited by Solon 2013). To counteract this, it is thus necessary to "generate a group of people who see computing as an open environment, see it as a platform for creating their own destiny" (Ibid.). This notion is further reinforced by Ian Livingston who highlights the difference between using and programming a computer as two fundamental aspects of technological literacy:

> *[Children] learn about Word and Powerpoint and Excel. They learn how to use the applications but don't have the skills to make them. . . . It's the difference between reading and writing. We're teaching them how to read, we're not teaching them how to write. The narrowness of how we teach children about computers risks creating a generation of digital illiterates.* (as cited by Hudson 2011)

Early personal computers and radio devices were typically acquired in the form of kits which the user had to put together. Given that the process of assembling a device from a series of parts necessarily opens its mechanisms and logic to discovery, the kits that were so popular in the 1950s-70s tended to facilitate technological literacy. Conversely, the fully assembled and tightly encased devices that subsequently replaced them reveal nothing of their inner workings. To counter this, DIY hardware communities have also focused on the design and creation of assemble-yourself devices. These kits serve both to facilitate learning and encourage exploration: while creating a new device from raw materials can be daunting, kits are typically just difficult enough to provide beginners with the sense of accomplishment —of competence—that comes from having built something one self. As Goli Mohammadi suggests: "If you don't know how to make it from scratch, then the kit is your path into the unknown, to new knowledge that's empowering" (Mohammadi 2012b).

The abundance of technological literacy -oriented initiatives and tactics in DIY hardware communities distinctly reveals a desire to encourage widespread participation in the shaping of technologies—a practice often described as "making makers." In a 2012 speech, AnneMarie Thomas (2012), an educator, academic and (at the time) executive director of the Maker Education Initiative, echoed the personal computer hackers' desire to bring computing power to the people by suggesting that it is time the "one laptop per child" initiative was matched by a "one screwdriver per child" program. For Thomas, encouraging hands-on creativity and fostering resourcefulness at an early age serves to provide children with the "confidence and the knowledge to understand how their world works" (A. M. Thomas 2012). In a similar fashion, Dustyn Roberts, an electronics and mechanical engineering professor at NYU's Interactive Telecommunications Program, suggests to her students that when "they make their first LED blink, a veil lifts from the world around them, and it feels like they have a particular kind of superpower" (D. Roberts 2013). Roberts's veil analogy playfully encapsulates the mystery that shrouds contemporary technologies, and her reference to a superpower suggests the sense of empowerment individuals can derive from the ability to shape and reshape technological artifacts.

Thus, "creating something personal, even of moderate quality," Shirky argues, "has a different kind of appeal than consuming something made by others, even something of high quality" (Shirky 2010, 1014). However, experiencing mastery and effectance does not serve only to satisfy individuals' innate needs; it also changes one's relationship with the resulting artifacts. In an article titled "The IKEA Effect," researchers Michael Norton, Daniel Mochon and Dan Ariely (2011) presented the results of a series of tests designed to investigate whether consumers would be willing pay more for products that require self-assembly. In these experiments, participants assembled IKEA boxes or made origamis, and were then asked to bid on both the objects they had put together and other identical but pre-assembled goods. The experiments revealed that participants were consistently willing to pay more for the objects they had assembled themselves, leading the researchers to conclude that "labor leads to love" (Norton, Mochon and Ariel 2011)—that is, individuals tend to attribute a higher value to objects that include their own labor than to similar professionally-produced goods.

Relatedness

In DIY hardware communities, the need to be socially connected (Deci and Ryan 2000) is perhaps best observed in hackerspaces—which Andrew Schrock (2011), Jarkko Moilanen (2012b) and Ricardo Lobo (2011) identify as "third places"[33] according to the concept defined by Ray Oldenburg (1989). For Oldenburg, public gathering spaces—such as cafes, pubs and bookstores—where citizens can gather in leisurely and informal ways, serve an important function as centers of social life where citizens "find and create their common interests and realize the collective abilities essential to community and democracy" (Oldenburg 1999, xii).

Although, at their most basic level, hackerspaces can be seen simply as shared workshops, relatedness is in fact a central motivational factor for these communities, as demonstrated by the findings of several recent studies. According to a survey, conducted by Jarkko Moilanen (2012a), of 138 members of 56 DIY communities located in 16 countries, the most important motivations for participating in a hackerspace are: "to help people without getting something in return" (71%), "commitment to the community" (68%), and "meeting other hackers and hacker-minded people" (59%). In another survey of hackerspaces conducted two years later by Charter and Keiller (2014), the relatedness motivation ranked even higher with over 90% of respondents indicating (strongly agreeing or agreeing) that they participate in hackerspaces to meet others who share their interests. Additional related

[33] Home being the "first place" and work the second.

motivations uncovered by this survey included: “To share my knowledge and skills with others” (over 80%), “To make new friends” (over 80%), “To meet people in the local community” (over 70%), “To be a part of a movement that challenges wider societal norms” (close to 60%), “To provide a valuable service to the community” (close to 60%), “To educate others outside of the Hackerspace” (over 50%), and “To develop a product(s) for benefit to society” (approximately 50%) (Ibid.).

While, according to Robert Putnam’s controversial book *Bowling Alone* (2000), participation in neighboring associations has greatly decreased with dire consequences for the political life of democracies, contemporary hackerspaces offer informal and communal settings where DIY communities can exchange knowledge and strengthen social ties. In this sense, Lobo suggests, hackerspaces “serve to satisfy essential needs of socialization that are felt strongly and increasingly in contemporary societies” (Lobo 2011).

This emphasis on community and relatedness is not exclusive to hackerspaces, however, and can be found across the several groups that compose DIY hardware communities. A 2012 survey of Maker Faire exhibitors, Make magazine subscribers, and Make newsletter subscribers found that 50% of respondents “make things with others” and 72% agreed with the statement: “It is important to me to share my knowledge and skills with other makers” (Karlin Associates 2012). Another international survey of 1007 members of the open source hardware community, revealed that the two highest ranked motivations for openly sharing hardware plans are to “contribute to the community” and to “allow others to learn from the design” (Mota and Mellis 2013).

If the term do-it-yourself implies a solitary activity, DIY Hardware communities’ emphasis on connectedness and sharing activities makes the derivative expression “do-it-together” more appropriate to describe their practices and values. Going beyond the act of simply doing something oneself, makers, hackerspace members and open source hardware developers frequently participate in gatherings (such as Maker Faires, hacker conferences, and open source hardware summits), share their work publicly, and often encourage others to replicate and transform it. These constant social exchanges not only improve the dissemination of information and knowledge, but also promote greater collective engagement and social cohesion amongst the members of these communities.

Autonomy

The pursuit of autonomy—understood as self-determination but distinct from individualism, independence and separateness (Chirkov et al 2003)—is arguably the most fundamental aspect of DIY hardware culture. Not only is it the central theme of the hacker ethic, but also the recurring motivational factor underlying the cultural antecedents of contemporary DIY hardware communities: the 1950s MIT hackers sought the autonomy to experiment with computers; the personal computer activists wished to provide individuals with the autonomy to create their own information, to communicate, and to shape the technology; the free and open source software programmers advocate for the autonomy to adapt software to one's own needs; and the early Internet developers reasoned that the autonomy to join, participate in and shape the network were essential to its formation.

Likewise, the theme of autonomy can be observed in practically all activities and discourses of contemporary DIY hardware communities. Although tools to explore the world, for example, serve to satisfy a need for competence—that is, to explore the environment and experience efficacy—they are just as much an expression of a desire to autonomously "read and write," to independently and freely explore, learn, create, and control one's own destiny. The series of events leading to the creation of the Civilian Radiation Monitor project provide a useful example to illustrate this.

In the aftermath of the Fukushima nuclear accident, the Japanese government, one of the few entities in the country with access to radiation monitors, declared all areas outside the evacuation zone as safe to inhabit. Despite this, a group of farmers located 30 km beyond the evacuation zone was still concerned with the safety of their area of residence (Akiba 2012). When Akiba—a Tokyo hackerspace founder and United Nations consultant—became aware of this, he donated to the farmers one of the two geiger counters he had been able to obtain from an American surplus outlet. This geiger counter, brought by the farmers to their locality, accused radiation levels above those typically deemed safe.

Concerned with these events, the members of the Tokyo hackerspace partnered with the RDTN group to create Safecast, "a global sensor network for collecting and sharing radiation measurements to empower people with data about their environments" (Safecast 2014), and began performing radiation monitoring all over Japan. The group detected concerning radiation levels in several other areas previously deemed safe by Japan's authorities—including a kindergarten playground. The residents of Koriyama—a city approximately 100 km outside the evacuation zone, and the area where the playground is located—self-organized to decontaminate the city and pressure the government to provide support.

As Safecast attempted to collect more radiation readings around Tokyo, Akiba and his colleagues began working on coupling the geiger counter with the open source Arduino platform, an SD card reader, and a GPS reader to create a geo-tagging geiger counter. After mounting this DIY device onto a car, which they then drove all over Japan, the group was able to collect—and publish online as open data—the most comprehensive non-governmental radiation dataset in Japan. The plans and instructions to build this simple device were also published on the Web for others to reproduce and improve upon. A few months after these events took place, Bunnie Huang, an open source hardware developer based in Singapore, partnered with Safecast to design a reliable, open source radiation monitor for civilian use. As a result of these independent activities by hackerspace members and open source hardware developers, radiation monitoring capabilities, which had previously been accessible only to the Japanese authorities, became available to Japanese citizens—thus providing them with greater autonomy to assess environmental conditions in the aftermath of a nuclear accident.

This focus on providing individuals with autonomous capabilities to read environmental factors has become increasingly common in DIY hardware communities. One of the most active initiatives in this area is the Public Laboratory for Open Technology and Science (Public Lab), a community dedicated to developing and applying open source tools to environmental investigation and exploration, with the stated goal of providing communities with the means to address matters of environmental health:

> *The core Public Lab program is focused on "civic science" in which we research open source hardware and software tools and methods to generate knowledge and share data about community environmental health. Our goal is to increase the ability of underserved communities to identify, redress, remediate, and create awareness and accountability around environmental concerns. Public Lab achieves this by providing online and offline training, education and support, and by*

focusing on locally-relevant outcomes that emphasize human capacity and understanding. (Public Lab 2013)

Some of the most interesting projects created by this "collaborative network of practitioners who actively re-imagine the human relationship with the environment" (Ibid.) include an indoor air-quality mapping device, a hydrogen sulphide sensor, a home test for endocrine disruptors, and a DIY water quality sensor.

In DIY hardware communities, the pursuit of an autonomous and more empowered relationship with technologies is not, however, limited to data collecting tools. It also concerns the autonomy to repair one's own technological artifacts. This is evident, for example, in the Platform21 = Repairing campaign:

> *Platform21 = Repairing started with the idea that repair is underestimated as a creative, cultural and economic force. If we don't consider repair a contemporary activity we will lose an incredibly rich body of knowledge – one that contributes to human independence and pleasure. . . .*
>
> *In the hope of spurring a reappraisal of repair, Platform21 wrote and published a manifesto describing the benefits of fixing things and calling upon designers and consumers to break the chain of throwaway thinking.*
>
> *Throwaway thinking, a culture in itself almost, is designed to cater to short term needs of both industry, politics and society. But by being very successful at short term effects it has lost track of the innumerable and rich possibilities that lie ahead if durable notions of design in general, and repair especially, are reconsidered and implemented.* (Platform 21 2009a)

As part of this effort, Platform21 created the "Repair Manifesto" (Fig. 30) in which the notions of creativity, discovery, and independence are associated with the ability to repair one's own goods and expressed in statements such as "Repairing is a creative challenge," "To repair is to discover," "Repairing is about independence," and "Don't be a slave to technology – be its master. If it's broken, fix it and make it better. And if you're a master, empower others" (Platform 21 2009b). Similarly, iFixit, a firm that produces free repair guides, drew up the a "Self-Repair Manifesto" (Fig. 31) in which it proclaims: "If you can't fix it, you don't own it" (iFixit 2010).

Figure 30: Repair Manifesto by Platform21

Figure 31: Repair Manifesto by iFixit

Although Richard Stallman currently advocates for free software as a moral imperative, the initial trigger for his refusal of proprietary software was propelled by practical frustration with a technology that did not respond to his needs and which he was not allowed to modify or repair. Several years later, a similar episode led to the creation of the Global Village Construction Set project.

After completing a Ph.D. in physics and becoming disenchanted with the lack of practical applications of his academic research, Marcin Jakubowski decided to become a farmer. He acquired a plot of land in a rural area and a tractor. When this tractor broke down repeatedly, and was repeatedly repaired by professionals, Jakubowski became frustrated with the inconvenience and cost of these constant repairs. Fueled also by indignation at the lack of durability of contemporary technologies and at a system that did not provide him with the tools and information that would allow him to repair and improve the machine, he eventually opted for designing and building his own tractor—one that could be easily repaired—which he then published online so other farmers could replicate and adapt.

Just as Stallman's campaign to free software arose from a small and practical incident, Jakubowski's frustration with the lack of resilience and costly repairs of his tractor soon took on an ethical stance. Jakubowski had spent the first ten years of his life in Iron Curtain Poland. His childhood memories were filled with images of military tanks driving down the streets of his home town, and recollections of waiting in long lines for meat and butter (Jakubowski 2013). He would later associate these early memories with the misery caused by material scarcity. It seemed to him that material scarcity made no sense in a world where nature provides everything humans need to survive and thrive. As the broken tractor episode demonstrated, what stood between individuals and material security were technologies capable of converting natural resources into usable goods. Fueled by this realization of the importance of technologies for human well-being and self-determination, Jakubowski identified the 50 machines required to rebuild civilization from the ground up, which he labeled the Global Village Construction Set (GVCS), and set out to design and release them to the world:

> *Growing up in Poland and having a grandparent [who was] in the concentration camps, I was aware even at an early age what happens when materials*

are scarce and when people fight over opportunity. It's what drove me to identify the 50 machines, from cement mixers to 3D printers to moving vehicles, that will allow a working society to be created. My goal, and my daily life, is dedicated to open source these tools, so that anyone—from the remote villages in Third World countries to small enterprise in the developed world—can have access to these meaningful tools to create a better life for themselves. EVERYONE needs access to these tools—it's why we're creating them with an open source model, and with the most advanced digital and physical technology known to us today. (Thomson and Jakubowski 2012, 55)

So deeply ingrained is the desire for autonomy in DIY hardware communities that it is not viewed as just something one individual reclaims for him or herself. As expressed in DIY hardware's practice of promoting technological literacy and "making makers," autonomy is regarded as something one should both encourage and provide to others, thus conferring it a social mission mantle. This desire to provide others, particularly those in a position of greater dependency, with self-reliance capabilities was distinctly articulated by Adrian Bowyer's student and RepRap co-designer Ed Sells upon accepting a prize from the Bath University's postgraduate conference:

Currently we ship consumer items from the other side of the planet because we do not have the ability to make things for ourselves. The RepRap project seeks to put manufacturing power into the hands of the people by delivering a manufacturing technology which can self-replicate. (Sells 2009)

Thus, in DIY hardware communities, the autonomy to shape technologies serves also a practical need for self-reliance, as corroborated by the surveys of the maker, hackerspaces and open source hardware communities previously cited. The Make survey found that 79% of respondents agreed with the statement "it is important to me to be able to modify, repair, extend, or repurpose products that are made by large scale, 'corporate' manufacturers;" 75% agreed with the statement "I would prefer to assemble a product myself so that I know how to fix it if it breaks"; and 77% disagreed with the statement "It is no longer important that people like me are able to fix our own devices with our own tools" (Karlin Associates 2012). In the 2014 hackerspaces survey, over 80% of respondents indicated that they participate in hackerspaces "To make things that suit my specific needs/requirements" and 60% "To learn how to fix my own possessions" (Charter and Keiller, 2014). Finally, in the OSHWA survey, the highest ranked motivation for using open source hardware, rather than proprietary hardware, was the "ability to personalize, repurpose and customize products" (Mota and Mellis 2013).

Just as significant, however, are the less practical intrinsic motivations that underlie DIY hardware culture, which William Byrd, a computer science researcher, hackerspace member and open source advocate, poignantly encapsulated in a personal statement:

> *I want to be in control of my own destiny and feel part of a community. Unlike the 1960s with its priesthood of computer users—peons were not allowed to even see the computer—today I don't even need an engineering degree or other formal credentials, I don't need anyone's permission, I can do something for the love of it.*
>
> *Open source hardware, hackerspaces and the maker movement are all about grassroots empowerment, about doing something you never thought you'd be able to do. They're about feeling that you belong to a community and about doing something new, pushing boundaries. And the great thing about working with great people is that they make you feel you can be great too—you too can do this awesome stuff. This is how people are gaining expertise, sharing, pushing technology.*
>
> *This makes me happy and optimistic about the future—even though I belong to a generation known for apathy and cynicism, the dystopian "me" generation. Here's a chance to help create a better world, using technology and community at the same time, the opposite of the lone geek in his basement. This is radically more fun and interesting than working at a company and comes with the reward and joy of doing it with other people. It's liberating, idealistic, democratic, geeky and fun.* (Byrd 2013)

In this short but passionate statement, Byrd encapsulates and summarizes the most fundamental motivations driving DIY hardware communities: the satisfaction of self-determination, of being in control of one's destiny; the autonomy to do something without asking for permission or requiring formal credentials; the sense of empowerment derived from pushing boundaries and surpassing one's own expectations; the comfort and encouragement of belonging to a community; the enthusiasm of defying societal norms to "create a better world;" and the enjoyment and hope derived from all these things.

While projects such as RepRap and the Global Village Construction Set are remarkable for their potential impact on issues as significant as the distribution of resources and economic justice, many other DIY hardware projects are essentially playful, engaged in mostly to experience competence, relatedness and autonomy. However, the feelings of enjoyment and empowerment derived from these activities may go beyond just benefitting individuals—and thus also play a role in a broader transformation of the technosphere.

In DIY hardware communities problem solving and enjoyment go hand in hand. This was aptly expressed by Dale Dougherty's assertion that "We can do really meaningful things through science and technology that have an impact on the world . . . And we really enjoy doing it: it's fun, it's satisfying, it creates community" (Dougherty 2013). The Power Racing Series is an illustrative example of this melding of playfulness with problem solving. In this project, members of hackerspaces transform children's electric cars and then race them against each other in one of several annual competitions. At first sight, a race of modified children's' cars appears to be purely about entertainment, but the organizers of the project have loftier goals:

> *Engineering, technology, diversity, and above all imagination are at the core of what we represent. We believe that sharing open source knowledge, tools, and tech among inspired makers of all ages and abilities will unlock the solutions to some of the most difficult challenges we face today. The challenge of creating a working electric vehicle for under $500 encourages progressive use of available technology and inspires our teams to help each other, even in the spirit of competition. Above all else, we believe that anyone with the passion and drive to learn will help lead us into the future.*
>
> *Never welded before? No problem. Not sure which one is the wrench and which one is the screwdriver? We can help you with that. Electronics a mysterious*

> *jumble of lights and sounds? Well, it's time to learn what those lights and sounds do. This is a series made for the motivated beginner. . . .*
>
> *. . . Have a literal blast. And do it all while learning, sharing tools and technology with your competitors, and pleasing a crowd full of cheering, adoring fans.* (Power Racing Series 2014)

Even those projects that do not overtly seek to address wider challenges may, in fact, be more meaningful than they appear. As Shirky reasons:

> *The stupidest possible creative act is still a creative act . . . On the spectrum of creative work, the difference between the mediocre and the good is vast. Mediocrity is, however, still on the spectrum; you can move from mediocre to good in increments. The real gap is between doing nothing and doing something . . .* (Shirky 2010, 278)

In other words: even the simplest or least useful contraption created by an amateur still bridges the gap between strictly consuming and shaping technologies. Furthermore, Shirky suggests, these creative acts, particular the simplest ones, carry the message "You can play this game too" (Ibid.), and thus challenge others to join in. In this sense, the enjoyment derived from experiencing competence, relatedness, and autonomy in the creation and recreation of technological artifacts is also a means to encourage a more direct participation in the shaping of technologies. The resulting technologies, in turn, tend to reflect the values and goals of the cultural settings in which they are shaped. This relationship between the ethos of DIY hardware communities and the technologies they generate is addressed in greater detail on the next chapter.

IV. SHAPING TECHNOLOGIES

The social construction of technology theory hinges on the notion that there is no one best way to design artifacts (Pinch and Bijker 1984). Rather than following an autonomous and purely technical logic of their own, technologies are primarily shaped by the individuals and social groups involved in their development. In turn, the resulting artifacts and systems facilitate some behaviors, modes of organization, and relations, but not others—and in this way play an important role in the social dynamics that emerge or perish around them.

This understanding of technologies as both the results and enablers of social phenomena elicits several important questions about the shaping of technologies: Who participates in this process? How do the assumptions and goals of creators and developers influence the particular configurations of the technologies they create? And how, in turn, do these configurations influence the realm of possible actions they foster or discourage? Moreover, if technologies are now inextricably intertwined with individual and social experience, how and by whom should technological artifacts be shaped in democratic societies?

The preceding chapters focused on the ethos and practices of the broadcast and distributed approaches. The following section will now look into the ways in which the goals and assumptions underlying each of these models influence the technologies they originate and how, in turn, these technologies define the realm of possible actions they enable. Based on this analysis, it becomes possible to see how the distributed model challenges the assumptions of the broadcast approach and offers a more democratic and participatory approach to the development of technological artifacts.

IV.1 The Shape of Technologies

To an increasing extent the qualities of technical artifacts reflect the possibilities of human living, what human beings are and aspire to be. At the same time, people mirror the technologies which surround them.

—Langdon Winner (2003, 5692)

The assumptions and objectives of those involved in the development of technologies influence their design choices and become imprinted in the technical characteristics and affordances of the artifacts. Moreover, the contexts in which technologies are developed not only determine the cultural values that shape technological artifacts, but also who is involved in this process. This is first apparent in the ways through which, in both the broadcast and distributed models, the identification of intended users—those for whom a technology is meant—shape the resulting technologies.

Tools of Production

In the broadcast approach artifacts tend to be targeted at two main classes of users: professionals and end-consumers. A large part of the technological artifacts aimed at professionals consists in tools and components. The assumption, in the broadcast approach, is that such tools and components will be used primarily by firms and other professional organizations to explore the environment, to collect data, or to design, produce and distribute large batches of goods as efficiently as possible. Since these tools are meant specifically to accommodate the needs and capabilities of organizations, they are designed and priced accordingly, which often results in large, costly, and complex machinery. Examples of this ethos abound but, to illustrate this point, it is useful to recall the case of the radiation monitor previously described: up until the moment Japanese citizens began to question their government's radiation readings and members of DIY hardware communities intervened by creating small, affordable and easy to operate radiation monitors for civilian use, only officials had access to these types of devices.

Unlike the broadcast approach, DIY hardware communities assume that individuals too are producers of both goods and knowledge—in this divergent notion of who is a producer lies one of the most important differences between the two models. While the tools of production generated by the broadcast model are aimed primarily at professional producers, DIY hardware communities tend to generate tools meant to provide individuals with autonomous capabilities to explore the environment, collect data, conduct scientific research, and produce both material goods and more machines. This can be glimpsed in the number of distributed approach projects that seek to extend exploration and material production beyond traditional research and development organizations.

In DIY hardware practices, tools and components can be further subdivided into three subcategories: tools for exploration and data collection, tools for production, and building blocks (Table 1). Under tools for exploration and data collection are projects such as DIY Drones, Protei, OpenROV, CubeSat, Civilian Radiation Monitor, and a variety of measuring instruments. The tools for production category includes 3D printers, CNC mills, laser cutters, and the GVCS tools. Building blocks—sub-assemblies to build projects from—include Arduino microcontrollers, derivatives and shields, as well as a wide range of electronics sensors and boards.

Category	Tools for Exploration and Data Collection	Tools for Production	Building Blocks
Technologies	Aerial, sailing, and underwater drones; Satellites Measuring instruments; Ambient data collection devices	3D printers, CNC mills, laser cutters, agricultural machinery, other production machinery	Microcontrollers, shields, electronics modules

Projects	DIY Drones OpenROV Protei CubeSat Civilian Radiation Monitor Smart Citizen Kit Open Energy Monitor Public Laboratory's Measurement Instruments	RepRap (includes RepRap derivatives) Shapeoko DIYLilCNC Lasersaur GVCS Multimachine	Arduino (includes Arduino derivatives and shields) Raspberry Pi BeagleBone SparkFun's electronic boards Adafruit's electronics boards

Table 1: Tools and Components

Most of these technologies are not new. In fact, drones, digital fabrication tools, and microcontrollers precede the emergence of contemporary DIY hardware practices by several decades: the milling machine dates back to the early 1800s, the first aerial drone was designed by Archibald Montgomery Low in 1916, the first laser cutter was created by the Western Electric Engineering Research Center in 1965, the first microcontroller was created by Texas Instruments in 1971, and the first 3D printer was design by Charles Hull in 1984. However, until recently, drones, 3D printers, laser cutters, CNC mills, and microcontrollers were targeted mainly at professional applications by professional engineers, scientists, architects, designers, and the military. Thus, although the large majority of these technologies were previously in existence, they were beyond the reach of most individuals due to the cost, size or complexity of the devices.

Rather than focusing on professional use, DIY hardware tools and components typically consist in variants of preexisting technologies redesigned for low cost, size and ease of use; in other words, redesigned to make them accessible to and usable outside of traditional professional contexts. In this sense, DIY hardware's tools are essentially reconfigurations of preexisting technologies transformed to serve a different purpose.

For this reason, DIY hardware tools and components tend to exhibit different characteristics from their broadcast counterparts. They are often considerably smaller than industrial manufacturing technologies, in order to fit in homes and offices, and lower cost, in order to be accessible to smaller budgets. Just as significant as size and cost, is also the complexity of these devices. While professional engineers are equipped to, for example, assemble electronic components, such as chips, into new complex circuit boards, amateurs often lack both the depth of expertise and the sophisticated tools this requires. One way in which DIY hardware addresses this is through the design and dissemination of simple to use building blocks: multi-purpose sub-assemblies such as breakout boards and microcontrollers (Arduino and Raspberry Pi being the most popular) that provide simple input and output channels. Even though these microcontrollers and breakout boards might themselves be complex, they enable amateurs to make use of sub-assemblies without the need to go down to the complexity of the component level.

The abundance of DIY tools and components distinctly reveals the value these communities attribute to autonomy and participation. Tools for exploration and data collection provide individuals with the autonomous ability to explore and collect data from the skies, outer space, land, oceans, and bodies. Building blocks provide amateur creators with simplified components from which to build new technological artifacts. And production tools such as 3D printers, laser cutters, CNC mills and other similar machinery provide individuals with small scale prototyping and manufacturing capabilities. These tools not only allow users to fabricate objects but also to create new tools; that is, 3D printers, laser cutters and CNC mills can be used to create new 3D printers, laser cutters and CNC mills. Thus, while the broadcast approach assumes that exploration, data collection and production are activities primarily conducted by firms and other professional organizations, DIY hardware communities suggest that these activities are the prerogative of all citizens.

For this reason, as Tom Igoe (2013) suggests, DIY hardware tools tend to fall halfway on the spectrum between industrial/professional technologies and end-user technologies: they provide individuals with the ability to create and transform technologies without requiring deep technical knowledge or access to traditional factories. While the broadcast approach caters to either consumers understood as mere users of devices, or producers understood as firms or other professional organizations, the distributed approach of DIY hardware communities caters to a hybrid user-producer. In this sense, what distinguishes DIY hardware tools and components from their predecessors are their applications, target audiences and distribution—which are then reflected in the characteristics of the resulting technologies.

Concatenations

Andrew Feenberg (2002) compares technical components with a vocabulary from which different sentences—and, therefore, different meanings—can be created. Drawing from this analogy, it can be said that both the broadcast and distributed approaches make use of the same vocabulary of technical elements—the same constitutive mechanisms and techniques—but the ways in which such elements are assembled into devices can differ significantly between these models.

In the broadcast approach users are discouraged from tinkering with technological artifacts. This is based on the assumption of a clear separation between producers and consumers, in which the former create and the latter consume. Therefore, broadcast approach devices tend to be conceived to be easily used but not transformed: they are often composed of miniaturized, custom parts fabricated with highly specialized equipment—designed for producers to manufacture cheaply and efficiently, and for consumers to use with no need to understand or even see their inner workings. As Norman (1999) notes, this greater exterior simplicity is often achieved at the cost of greater inner complexity; in other words, as these devices are made increasingly simple to use, their technical complexity also tends to increase. Furthermore, broadcast approach devices are typically enclosed in sealed cases, which conceal their inner mechanisms, and it has become common for broadcast producers to resort to tamper-proof mechanisms such non-standard screws or seals that void a device's warranty if broken.

Conversely, in the distributed approach of DIY hardware communities, given their goal of enabling and encouraging public participation in the shaping of the technologies, different design constraints are at play. Although cost and efficiency of both manufacturing and performance are still important considerations, it also becomes necessary to facilitate replication, appropriation and transformation of the technological artifacts. For this reason, open source hardware technologies are often designed specifically to enable easy access to mechanisms and code—in order to facilitate understanding and modification—and composed of ubiquitous parts that can be assembled, as much as possible, with inexpensive or otherwise accessible tools—to facilitate replication.

As illustrated by the examples in Table 2, the notion of transparency is also interpreted differently in these two contexts. While in the broadcast approach, transparent technologies are those that disappear from view and consciousness and can, therefore, be used unthinkingly, in DIY hardware practices transparency is commonly understood as access to a technology's inner mechanisms and the ability to understand them. In other words, transparency here consists in making evident and accessible the functioning of technologies.

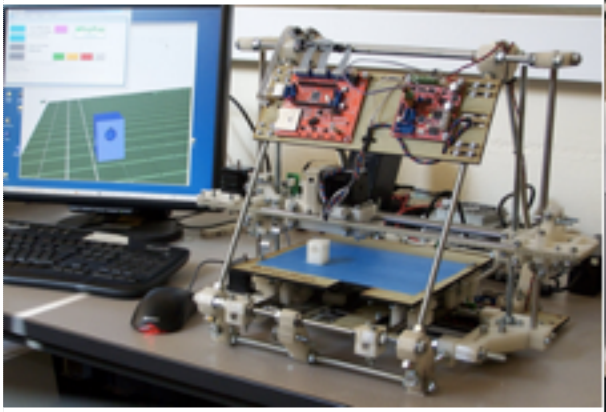
Distributed Approach	**Broadcast Approach**
	
Mendel RepRap 3D printer, by RepRap Team: open source, exposed mechanisms, structure made from standard aluminum extrusions and 3D printed plastic parts (printed by the machine itself).	Mojo 3D printer, by Stratasys: enclosed in a custom injection-molded case, inner mechanisms concealed.
	
LifeTrac Tractor, by Open Source Ecology: exposed mechanisms, modular design, lego-like components.	6M Series Tractor, by John Deere: enclosed engine, composed of custom parts.

Table 2: Distributed vs. Broadcast Technologies

PhoneBloks (Fig 32) is a useful example to illustrate this alternative approach to design. The project arose from its founder's desire to "end or reduce the various ethical and environmental problems existing in the consumer electronic market today" (PhoneBloks

2014), starting with electronic waste. The miniaturization, compaction and overall design approach of most contemporary smartphones makes them difficult to repair (Fig. 33). As a result, once one of the components stops functioning, the whole device is usually discarded, leading to a growing amount of electronic waste. The PhoneBloks project proposes a modular approach to address this problem. If phones were composed of several detachable blocks, the project's team argues, this would allow users to replace deficient blocks rather than discarding the entire device.

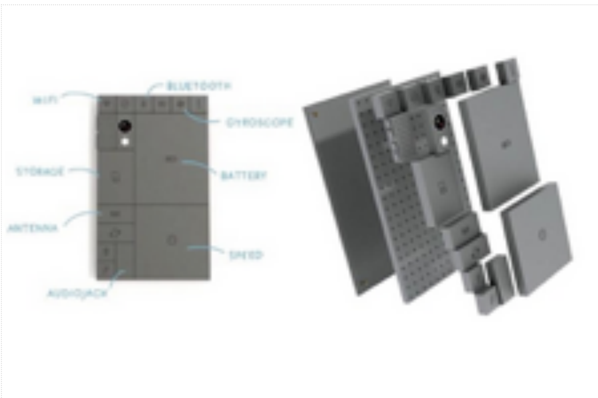


Figure 32: PhoneBloks

Figure 33: iPhone by Apple

A modular design such as the one proposed by this project has another important implication: it allows users to configure their phones according to their own specific needs. An individual who uses the device primarily for photography, for example, may choose a more sophisticated camera block, or a user who does not store information in the device may choose to replace the storage block with a larger battery pack. PhoneBloks also proposes an open approach to the creation and commercialization of each block: rather than being limited to selecting from the options made available by the original producer of the phone, users would be able to obtain modules from different producers or even make their own. This is a significant departure from the standard practices of the broadcast approach—in which all hardware configuration decisions are made by the originating firms and hardwired into the devices.

The idea that technological artifacts should be designed to allow users to re-shape them is aptly illustrated by the "Maker's Bill of Rights" (Fig. 34), written by Internet user Mister Jalopy (2005), and subsequently published by *Make*. Through a brief survey of common design practices and the suggestion of alternatives—from easy to open cases to easy to replace and repair components—Mister Jalopy offers a simple critique of the broadcast approach while reclaiming "ownership" of devices back to their users.

Figure 34: The Maker's Bill of Rights

Politico-Technological Formations

The concern of DIY hardware communities with access to and distribution of technologies often crystallizes in what Jordan and Taylor (2004) conceptualized as "politico-technological formations:" technologies in which the political values of their creators are deliberately embedded in the very mechanisms of the devices and shape the range and nature of the possibilities they offer to users. The RepRap and GVCS projects, in which the relation between politics and design are declared and ostensible, offer two useful cases to illustrate this.

RepRap

In "Wealth Without Money," the 2004 article that set the political and technical agenda for the RepRap project, Adrian Bowyer wrote:

> *Karl Marx and Frederick Engels wrote in the Communist Manifesto that, "By proletariat is meant the class of modern wage labourers who, having no means of production of their own, are reduced to selling their labour power in order to live." This diagnosis is essentially correct; it is a commonplace that people with resources can quite easily use them to acquire more, but people without have to try exceptionally hard to get anywhere, and most of them never do. Marxism then goes on to say that the way to fix this problem is for the proletariat to seize the means of production by revolution, which is a good candidate for the all-time worst-idea in human history. Whenever it is applied, the main things produced are corpses, and in the last hundred years the body count from this idea's application was even worse than that from Nazism. So the Marxist prescription, unlike its diagnosis, is plain wrong. . . .*
>
> *In the mid twentieth century John von Neumann proposed a Universal Constructor - a machine that could copy itself. Since then a number of people have realized his idea, both in simulation, and physically. However, in the case of physical implementations, all current systems require a supply of very complicated and intricate building blocks. The purpose of this short web-page is to persuade you that there is one development in direct writing and rapid prototyping technology that is*

not only the most important, but that is more important than all the others put together. That development would be a direct writing or rapid prototyping machine that can make a copy of itself. I contend that this is the first useful version of von Neumann's Universal Constructor that we can have. . . .

The three most important aspects of such a self-copying rapid-prototyping machine are that:

1. The number of them in existence and the wealth they produce can grow exponentially,

2. The machine becomes subject to evolution by artificial selection, and

3. The machine creates wealth with a minimal need for industrial manufacturing. . . .

So the replicating rapid prototyping machine will allow the revolutionary ownership, by the proletariat, of the means of production. But it will do so without all that messy and dangerous revolution stuff, and even without all that messy and dangerous industrial stuff. Therefore I have decided to call this process Darwinian Marxism… (Bowyer 2004)

In order to achieve self-replication, Bowyer based the concept for the RepRap 3D printer on John von Neumann's 1950's universal constructor: a self-replicating machine on a cellular automata environment. Although Neumann's focus was mostly on the mathematical and computational aspects of self-replication, he realized that such a machine would eventually be able to produce anything that is physically possible. The goal for the RepRap project is thus to create a machine capable of producing all of its own metal and plastic parts. However, at the time of writing, RepRap machines were mostly used to produce plastic objects as its metal printing capabilities were not yet sufficiently advanced. For this reason, RepRap machines are currently designed to use as many 3D printed plastic parts as possible which are then combined with low cost, off-the-shelf metal parts (Fig. 35).

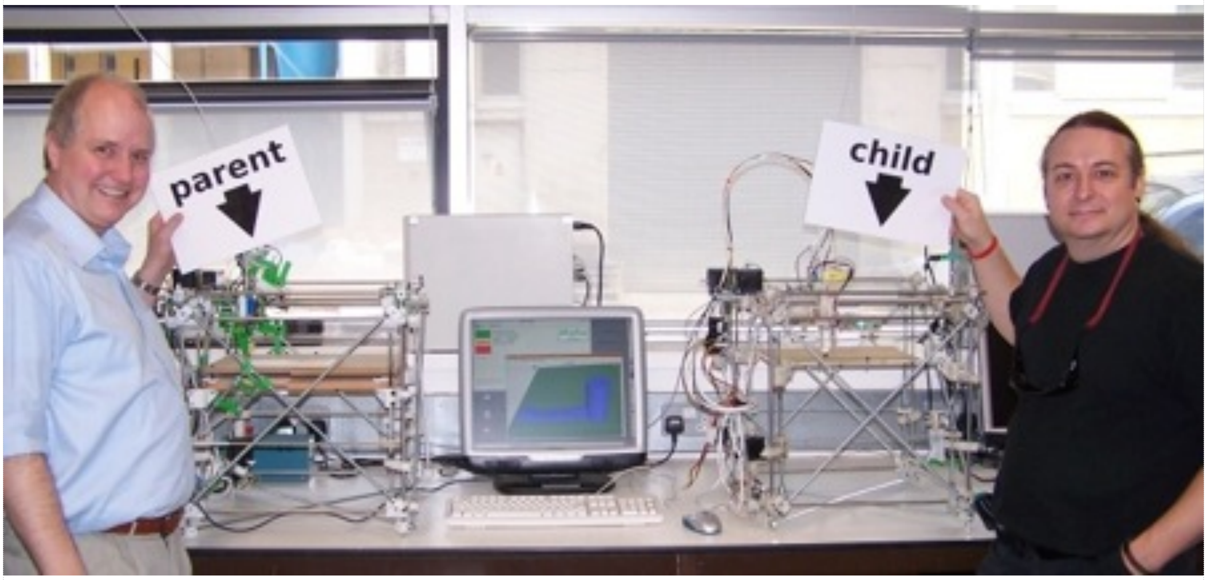


Figure 35: Adrian Bowyer (left) and Vik Olliver (right) with a parent RepRap Darwin machine and its first working child

Another level of complexity is added by the need to not only self-replicate but also self-assemble (Bowyer 2007). Thus, in conceiving the RepRap machine, Bowyer took cues from biomimetics and, in addition to the notion of cell-like reproduction integral to the concept of universal constructor, was inspired by the phenomenon of symbiosis. Given the added difficulty of conceiving a machine capable of both self-copying and self-assembling, Bowyer turned to man-machine symbiosis and opted for a design capable of manufacturing its own components but that left assembly to humans. The idea here being that both humans and machines would benefit from such a relationship:

> *If the universal constructor gave those people something useful in return, then the result would be a symbiosis between the two, such as that between the flowers and the insects. In particular, if this universal constructor could make other industrial goods, those would constitute a reward for helping it to reproduce*. (Ibid.)

In order to facilitate assembly by humans, RepRap machines are designed to be built with simple, low-cost tools such as screwdrivers and soldering irons. As Bowyer (Ibid.) notes, anything that can copy itself becomes subject to Darwinian evolution. In this aspect, the main difference between RepRap and nature, Bowyer argues, is that natural organisms suffer random mutations, while machine mutations are the result of human analytical thought.

Thus, users may choose to simply copy the machine or to modify and improve it by using the parent to create a derivative child machine. In this order of progression, the RepRap design improves with each new generation, as less functional models are abandoned in detriment of more appropriate ones.

Thus, in order to achieve the goal of making production capabilities available to a greater number of people, RepRap machines are designed to enable and foster the distribution of the technology through self-replication, low cost, and ease of transformation. In this sense, the political goals of the project are embodied in the technical characteristics of the technology and translated into affordances. While in the broadcast approach 3D printers are designed to be easily manufacturable and used, RepRap is subject to a greater number of design constraints: it must use as many parent-machine-generated plastic parts as possible; all its other parts must be low-cost and easily acquirable; it must be assembled with simple, inexpensive tools; and this assembly process cannot require specialized technical knowledge.

Bowyer's politics are thus deeply embedded in the architecture of the machine. Had his objective been only to create a 3D printer, this machine would not need to self-replicate. However his goals were that the technology spread fast, that it does this without the need for central coordination, and that it grants individuals productive autonomy. Given that he wanted the technology to be grassroots and to spread from one user to another, he designed it so that not only new machines could be created without the interference of a central producer, but further encouraged the symbiotic relationship between humans—by allowing one producer to create parts for another.

Global Village Construction Set

With a similar mission as RepRap, Open Source Ecology's Global Village Construction Set (GVCS) is designed to facilitate transformation and replication with the goal of providing individuals with autonomous production capabilities:

> *At Open Source Ecology we design and manufacture, and help others design and manufacture, devices like tractors, bread ovens, and circuit makers. Much as Wikipedia has sought to democratize access to knowledge and the open source software movement has attempted to democratize computing, Open Source Ecology*

(OSE) seeks to democratize human well being and the industrial tools that help to create it. . . . We design our tools in a nontraditional way with nontraditional goals in mind, and we design them to work with each other.

We call our interconnected set of devices the Global Village Construction Set (GVCS), which, upon completion, will include 50 simple modular open source tools that are designed to provide modern comforts and basic material self-sufficiency. The GVCS tools are designed simply so they can be used to replicate themselves and are easy to modify and customize. Much like the Erector sets we used in our childhoods, the tools have interchangeable Lego-like modular components and quick-connect couplers. The open, collaborative nature of the GVCS project means that the toolset can, in principle, be independently adapted for the American farmer, the African technologist, or the pioneering lunar colonist.

If the plans for the iPhone were open sourced, the average consumer, innovator, or manufacturer would still be helpless to replicate one, let alone participate in its design, because to make an iPhone, everything has to fall into place. Governments need to function effectively, ships must sail and trains need to leave the station on time, workers need to show up on the job, the weather needs to cooperate, and all the materials in the supply chain must be on hand. At that point, the highly proprietary equipment and manufacturing processes are put in motion. The robust image of our modern economy in fact depends on a small miracle taking place each day within our labyrinthine supply chain. In contrast to the iPhone's design—which uses African minerals that are assembled in China with parts from Japan—contributors all over the world have designed the GVCS so that its supply chain is no farther than the backyard and the local scrap heap. Its subcomponents range from basic manual manufacturing to highly automated, software-based precision tools. . . .

Our moral aim is to work globally to stop material constraints from determining the well-being of humans, thereby eliminating production as an issue of control and power. The goal is to address the issue of artificial scarcity and disparity *of wealth as related to peoples' lifestyles, global geopolitics, and corrupt leadership.* (Thomson and Jakubowski 2012)

The goal of the GVCS project is thus to provide individuals with accessible, low cost, DIY tools for economic and creative autonomy. For this reason, the GVCS's interchangeable and compatible modules are designed to allow the recombination of elements to create different machines for varied purposes (Fig. 36) and, in this way, extend the range of possible applications available to its users while reducing redundancy and waste—for example, most of the GVCS machines, from the tractor to the brick press, are driven by a common power module which can be switched from one machine to the other, thus avoiding the added cost of having one engine per machine. To achieve this flexibility, the GVCS modules use standard connectors and function similarly to large lego-like bricks that can be recombined according to the needs of their users.

Figure 36: Global Village Construction Set by Open Source Ecology

In order to further facilitate appropriation and transformation, the GVCS modules are "naked" in the sense meant by Sherry Turkle (2005), their mechanisms completely exposed and their parts easily accessible. The goal of distributing production capabilities also requires these tools to be low cost, easily replicable, and designed to work with accessible stock parts. For this reason, the toolset is stripped down to essential components for cost and simplicity of replication; planned to use local, low cost materials—as is the case of the Liberator, which fabricates bricks from soil; and designed to enable parallel builds in order to allow several people to collaborate on a given machine. These design characteristics embody their creator's politics in their simplicity, accessibility, flexibility, and malleability, conceived specifically "to democratize human well being and the industrial tools that help to create it" (Thomson and Jakubowski 2012).

Thus, in the RepRap and GVCS projects, the goal of making production capabilities available to a greater number of people is not only pursued through the free distribution of open source plans—which allow anyone to replicate and transform the machines—but also embedded in the designs of the technologies themselves, resulting in what Jordan and Taylor describe as the "clear intermingling, the inextricable intertwining, of politics and technology," as the technologies themselves become their creators' "political imaginations brought to life" (Jordan and Taylor 2004).

The Biases of Technologies

The preceding analysis illustrates how the assumptions and goals of each context become embedded in the devices they generate. The technical characteristics of technological devices are thus powerful statements about their producers' assumptions about the world, of what behaviors they intend to encourage and discourage, and how they intend devices to be used.

The cases of the Minitel and Kinect described in the first chapter show how unplanned and voluntary uses of technologies can at times transform the meanings of and dictate new paths for the development of technologies. However, in both cases this was achieved on the margins of the systems, not through intentional liberties afforded by the technologies or their producers. Thus, despite their grassroots character, these stories nevertheless concern what Blauvelt (2003) called a battle between "repression and expression," between structure—understood here as constraint on human activity—and agency—independent, intentional and undetermined action. If technologies can be conceived as structural constraints, in the cases of the Minitel and Kinect, agency was affirmed *despite* these constraints—users took advantage of obscure technical characteristics of the technologies to independently transform their purposes and meanings. In this understanding of technologies as structures—defining what uses are expected and allowed—lies a fundamental difference between the broadcast and distributed models.

While in the broadcast approach technologies are sometimes appropriated and subverted by users, despite the intentions of producers, in the distributed approach practiced by DIY hardware communities the possibility of appropriation and transformation is built into both the development model and the technologies themselves. This is more clearly seen in open source technologies which are not designed just for replication, but also conceived to further encourage exploration and transformation.

Given that exploration and transformation require pliable technologies, the malleability of the devices, the extent to which they open themselves up to reappropriation and transformation, the ways in which they can be adapted to different uses and purposes, play a very important role in this approach. This is evident in DIY hardware communities' appreciation of and emphasis on flexible production tools and components; that is, in technologies, such as digital fabrication tools and microcontrollers, which allow for the creation of a wide range of other artifacts.

The goal of providing everyone with the agency to create whatever they wish often leads to what Jordan and Taylor (2004) conceptualized as "digitally correct technologies:" application-agnostic devices that, rather than serving solely the uses conceived by their creators, are adaptable to a greater range of applications and contexts. RepRap is, once again, a case in point. Although the main development team releases standard RepRap models, which are configured to print plastic objects, several users have adapted the machines to address applications not contemplated by the original designs. RepRaps have been designed or repurposed to, for example, work with low melting point metals, bio materials, inks, and edibles, and thus enabled engineers, biologists, chefs, and artists to print electronic circuits, fabricate blood vessels, create two-dimensional drawings, and erect chocolate sculptures.

Thus, although the broadcast and distributed approaches draw from the same set of technical elements, in the first they are configured in specific, immutable constellations, in the second they are combined in ways that allow reconfiguration and appropriation. The resulting technologies are very different, even if they stem from the same basic technical concepts, and therefore offer different possibilities to their users. These differences between broadcast and distributed approach technologies cannot be dismissed simply as technical details.

The affordances of technologies greatly contribute to defining the realm of possible behaviors available to individuals and groups. The technical system of television broadcasting, for example, effectively establishes a one-way communication system and therefore stimulates listening rather than speaking, receiving rather than emitting, consuming rather than producing. The technical architecture of the Internet, on the contrary, not only allows but positively encourages point-to-point and many-to-many communication amongst those whom Jay Rosen labels "the people formerly known as the audience" (Rosen 2011).

Therefore, the affordances of technologies—the realm of possible behaviors they enable—play a fundamental role in the shaping of individual and social practices. In the broadcast approach these affordances are not only defined a priori but are further constrained by circumscribing what technologies are available to each category of user—production and exploration technologies for firms and other organizations, and appliances, gadgets and other similar devices for individual consumers—and limiting the range of what can be done with these devices. Conversely, distributed approach technologies—although also reflecting the biases and assumptions of their creators—are designed to open, rather than close, possibilities. Open technologies emerge from the notion that producers cannot know and should not constrain what devices will be used for and how they will be used. Thus, while broadcast approach technologies limit the range of actions available to users, distributed approach technologies seek to provide users with greater agency.

IV.2 Democratizing the Technosphere

While any new technical device may increase the range of human freedom, it does so only if the human beneficiaries are at liberty to accept it, modify it, or reject it: to use it where and when and how it suits their own purposes, in quantities that conform to those purposes.

—Lewis Mumford (1964, 129)

The distributed approach practiced by DIY hardware communities offers a practical path towards a participatory democratization of the technosphere by 1) demystifying technologies, 2) providing the public with the means necessary to understand and shape technologies on both an individual and a collective level, and 3) stimulating citizen participation in the development of technologies.

1) Demystifying Technologies

Today, most technologies are developed in closed settings—primarily those of firms, but also academic institutions and governmental agencies—and the resulting finished devices are then "broadcast" to consumers. These "well-behaved appliances . . . whose use was fully specified at the factory floor", as Benkler (2006) incisively describes them, permeate most realms of individual and social life, but reveal nothing about themselves—their mechanisms concealed inside tamper-proof casings and the human choices they embody removed from public scrutiny. Thus, technological artifacts are now both highly familiar and utterly mysterious.

The obscurity in which technological devices are shrouded stems in part from the closed settings in which they are developed and the desire of producers to shield proprietary knowledge, but also from a main current in design which strives to make technologies invisible. "The ideal system," Donald Norman argues, "so buries the technology that the user is not aware of its presence" (Norman 1999, 75). Hidden mechanisms, it is thought, make devices aesthetically pleasing, inviting, accessible and friendly to users. This drive to make technologies invisible stems from a conception of these artifacts as mere tools one uses to accomplish other ends. Technologies cannot, however, be conceived a mere neutral instruments. Prior to any use, the affordances of technologies shape the realm of actions available to users by facilitating some behaviors while hindering others and thus influence individual and social practices. Since these affordances are primarily defined by those involved in the development process of technologies, their biases become—intentionally or unintentionally—imprinted in the distinct shapes of technological artifacts and, in turn, play an important role in defining the range of possibilities they offer. Given the central role assumed by technologies in contemporary life, it has become increasingly important for citizens to understand the social dynamics that underlie the particular configurations of each technology.

However, the familiarity with the presence of technological artifacts, on the one hand, and the efforts to render them invisible, on the other hand, tend to place both the affordances of technologies and the biases that shape them beyond critical thinking. Furthermore, the combination of the first hand experience of the power of technologies to transform human experience with the invisibility of the processes through which they are shaped has contributed to the widespread belief that technologies evolve according to an asocial logic of their own. As claimed by this view (known as technological determinism), the relationship between society and technologies is unidirectional: technical necessity and the path towards efficiency dictate the evolution of technologies, which in turn have profound impacts on human affairs. In this conception, technologies are beyond social influence and therefore individuals and societies have a binary choice: to accept both the positive and the negative "impacts" of technologies, or to reject them altogether. The belief in technological determinism thus promotes a passive attitude towards technological development. It removes technologies from the sphere of public influence and debate—the very space in which, as Habermas argues, "something approaching public opinion can be formed" (Habermas 1974b, 49).

The open source hardware model does just the inverse. In this approach, the specificities of technological artifacts are made publicly known so that anyone can study, replicate, modify or otherwise appropriate them. This availability of information not only reveals the inner workings of technological artifacts, but results in a greater number of variants as each design is transformed, remixed and mashed-up—according to idiosyncratic priorities, applications, and contexts. In turn, the proliferation of derivatives deconstructs the notion that technologies evolve along a path defined solely by technical necessity, as each variant of a device necessarily reveals the choices and alternative approaches of each creator.

Through this open process of shaping technologies, open source hardware practices both disclose the inner workings of technologies and reveal the ways in which technological artifacts are shaped by human agendas. These practices contribute to shattering the predominantly unchallenging acceptance—or, as Winner (1986) calls it, "somnambulism"—that now characterizes most individuals' relationship with technologies, and to replace it with a more critical and participatory culture. Once technological artifacts are demystified and the biases they embody brought to the forefront, it becomes possible to collectively interrogate the shape of contemporary technologies, and begin to conceive of alternatives that reflect a greater diversity of agendas and contexts.

2) Providing the Means

Making evident the functioning of technologies and the human choices that shape them is not, however, the only way in which the distributed model practiced by DIY hardware communities contributes to a democratization of the technosphere. DIY hardware's approach is in fact essentially practical, focused on providing citizens with the means to directly shape technologies. This is achieved by distributing information about the makeup of devices, facilitating access to tools with which to create and recreate technologies, and designing technologies that open themselves up to appropriation and transformation.

In the broadcast approach it is common for firms to rely heavily on exclusive rights - based business models: these firms invest in the development and manufacturing of technologies, and in return are granted, via intellectual property laws, exclusive rights over the use and commercialization of their innovations. This means that both the particular implementation and the knowledge behind a given technology are not only closely guarded—so much so that Pekka Himanen (2009) has compared contemporary information firms with maximum-security prisons—but effectively monopolized by these firms. Given the barriers posed by the lack of access to information and the legal constraints that shield it, it becomes extremely difficult for adopters of these technologies to use them in any way not specified by the original producers.

Conversely, open source hardware producers freely distributed the plans for their devices under licenses that allow anyone to copy, reproduce, and modify them. Rather than relying on exclusive rights, open source -based businesses rely on the free flow of information as a means to achieve faster technical development by harnessing collective creativity. These firms base their business practices on the notion that public and collective creation of technological artifacts contributes to faster development processes and better technologies. In other words, allowing everyone who wishes to do so to contribute modifications and additions to a project fosters a quick identification of a technology's weaknesses, rapid development in virtue of a greater number of contributions, and devices that reflect and respond to a greater number of use cases.

With the software code and hardware plans publicly available it is expected that both users and competitors will make improvements to the technologies. Given that many open source hardware designs are released under "copyleft" licenses—which ensure that both copies and derivatives are also distributed as open source—firms are then allowed to fold back into their products any improvements devised by others. Thus, new developments benefit the entire ecosystem of users and competing producers. In this model, adopters of technologies, rather than just using the devices according to predefined parameters, are positively encouraged to transform them.

In addition to providing the public with the information and legal rights necessary to shape technologies, DIY communities also strive to make prototyping and production capabilities accessible to individuals. This has been notably achieved through the development of low cost, open source, do-it-yourself tools such as digital fabrication technologies, and building blocks such as microcontrollers and breakout boards. However, despite their importance, the development of open source tools and building blocks is not the only way in which DIY communities contribute to making production capabilities available to independent creators. Other equally important efforts include: hackerspaces, where otherwise prohibitively expensive tools are collective acquired and shared; "maker" stores, where components and machines once reserved for industrial and professional use are made available to the public; and platforms for group orders, which allow independent creators to harness economies of scale by combining job orders. Additional initiatives that have significantly contributed to distributing productive capabilities beyond firms include chains of workshops, such as FabLabs and TechShops, where prototyping and production tools are made publicly available, and online fabrication bureaus that offer on-demand fabrication services.

This complex mosaic of new initiatives, businesses, forms of organization, and technologies has increasingly made the ability to prototype and fabricate technological artifacts accessible to small scale creators—ranging from start-up firms to a single individual building a device for fun. The wider availability of productive capabilities means that it is now possible for amateurs and other independent creators to modify and even create new technological artifacts.

In order to facilitate the distributed design and production of technologies, it is also common in open source hardware practices to design technologies specifically to facilitate independent replication and modification. While technological artifacts produced according to the broadcast approach are based on the assumption that users cannot, need not and want not to understand or modify technologies—and therefore are designed for use, not replication or modification—open source hardware devices are based on the inverse assumption that users can, need and want to shape the technologies they use. RepRap 3D printers are one of the most emblematic examples of this, as they are designed to be built with low-cost, easy to acquire components, and to produce as many of their own parts as possible. Another relevant example of this approach is PhoneBloks, in which the goal is to allow each user to shape their own phone according to individual priorities, applications and contexts, and therefore transfer to users choices that are typically made by firms.

The combination of the availability of information about the makeup of devices, access to tools, and technologies designed to facilitate replication and modification provides individuals with the practical means to (re)shape their own technologies. However, the application of the distributed approach to the development of technological artifacts also has a broader effect. Given that, in open source hardware projects, most alterations and improvements devised by users and firms alike are publicly shared, all other creators are able to incorporate these new approaches and concepts into their own versions. There is thus a constant flow of information between producers-users who build upon each other's work to generate both divergent and convergent versions of the technologies. This means that distributed approach technologies are not only individually transformed, but also collectively shaped.

3) Stimulating Participation

While in the broadcast approach the role of users is to have needs (Hippel 2005)—which producers strive to fulfill—and select from the solutions firms make available in the marketplace, DIY hardware communities propose an alternative model, one in which users of technologies are empowered to directly and actively shape them. In addition to demystifying technologies and making available the means necessary to practically transform and create artifacts, these communities also actively seek to excite a greater and more direct public engagement with the process of shaping technologies.

Technological artifacts have been rendered opaque both by the practice of blackboxing devices—although one can see the inputs and outputs, the inner workings of devices are for the most part invisible and unknowable—and by changes in how technological knowledge is understood. In the 1980s leaning how to use a computer meant, at the very least, learning how to program it. Today, given that the role of users is not to shape but to operate, computer literacy consists mostly in being capable of using common utilities such as word processing and spreadsheet programs. Although it is not uncommon for schools to teach the use of computer applications, programming and engineering are mostly reserved for professional engineers and programmers. This notion that technical knowledge is the purview of specialists—coupled with the monopolies of knowledge held by firms and the assumption that users neither need nor want to understand how technologies function—has led to widespread technological illiteracy. Thus, although technologies are now deeply interwoven with everyday live, they are for the most part unknown by those whose experience they affect.

To counter this trend, DIY hardware communities have created several outreach programs and activities designed to "make makers," that is, to facilitate the distribution of technological literacy and incite interest in the making of technologies. Programs such as the Maker Education Initiative and The Makery actively seek to provide technical education to children and adults, as well as encourage do-it-yourself experimentation and exploration. Hackerspaces, in which members collaborate and teach one other, are another way in which those with no formal training in science and technology can acquire both basic and advanced technical expertise. It is also very common for hackerspaces to offer public classes on technical subject matters—which allows them to raise funds for the collectives, recruit new members, and promote technological literacy beyond their own confines. All these efforts are further supported by a host of online tutorials and online discussion venues (mailing lists, forums, and other similar platforms) where individuals and organizations share information, experiments, and advice. Together, open source code and plans, online information sharing platforms, and hackerspaces enable quick peer-to-peer transfer of information and knowledge.

Just as important as the distribution of technical knowledge, are the alternative approaches to design commonly implemented by these communities with the goal of facilitating the understanding—and therefore the replication, modification, and (re)creation—of technologies. These tactics to make technologies more accessible commonly involve modular systems, kits, and building blocks. Building blocks—multi-purpose sub-assemblies such as breakout boards and microcontrollers—concentrate technical complexity in small electronics boards, while providing simplified means of input and output, and thus considerably lower the the barriers to building simple electronics projects. Kits help users understand the functioning of technologies, as the process of assembling them necessarily reveals how the different parts interact and contribute to the overall system. Similarly to kits, modular devices, such as the GVCS machines and the LittleBits system, expose and teach about the technical relationships between a technological artifacts' constitutive elements.

Thus, contrary to broadcast approach technologies, which tend to evolve towards greater simplicity of use at the cost of greater technical complexity (Norman 1999), many proponents of the distributed approach focus on simplifying the mechanisms themselves so they can become more accessible to those with no formal training in science and technology.

Technologies designed to be understandable and modifiable by non-professionals, coupled with educational programs and activities, play a fundamental role in the distribution of technological literacy and the incitement of greater involvement in the technosphere.

Finally, in DIY hardware communities, participation in the shaping of technologies is also encouraged in indirect ways. For these communities, shaping technologies is enjoyable per se. The acts of creating and recreating machines satisfy the universal and innate needs to experience competence and autonomy, and the community settings in which this takes place facilitate feelings of relatedness. The satisfaction of each of these needs in an interconnected creative process further reinforces and amplifies these practices. While sharing, and the feeling of relatedness that comes with it, provides satisfaction by itself, it can also further enable competence and autonomy through the sharing of knowledge—that is, the learnings enabled by knowledge sharing allow individuals to become increasingly more competent and autonomous. Thus, the enjoyment derived from tinkering with technologies also provides a pathway towards technological literacy and greater involvement in the shaping of technologies.

Challenging the Broadcast Approach

The preceding analysis now makes evident the ways in which the distributed approach practiced by DIY hardware communities challenge each of the assumptions of the broadcast approach.

1) While the broadcast approach is based on the assumption that the complexity of technological development requires firms, a wealth of resources, and dedicated teams of professionals, a wider access to production technologies and technical knowledge are making sophisticated development and production capabilities increasingly available to individuals and independent groups. This means that amateurs, not just professionals, can not only participate in the development of technologies, but also make significant contributions to the resolution of both technical and social problems.

Moreover, new distributed models for the organization of production—such as the ones adopted by the open source operating system Linux, the grassroots encyclopedia Wikipedia, and the myriad of open source hardware projects—challenge the notion that the complexity of technologies requires the centralization of resources in firms and their traditional approach to the division of labor. Together, digital technologies and distributed production practices are enabling the locus of technological innovation to become once again distributed across the population, rather than centralized in firms.

2) Open source hardware challenges the assumption that exclusive intellectual property rights are essential for commerce, and therefore for technological advancement, in two ways: by implementing alternative business models that do not rely on exclusive intellectual property rights, and by contradicting the basic tenet behind intellectual property laws—that, without these exclusive rights, individuals and organizations would have no incentive to innovate.

The first challenge comes from open source -based firms which, although giving away for free the source code and hardware plans for their products, have continued to thrive and expand by pursuing business practices that not only eschew exclusive rights, but in fact benefit from their absence. The second challenge can be observed everywhere: in the creative commons -licensed works that populate content sharing platforms across the Web, in the success of projects like Wikipedia, and in the proliferation of free and open source software and hardware projects. This boom of creativity—be it for the sake of self-expression or for more practical purposes—has shown that not only exclusive rights over one's creation are not essential to business, but also that profit is far from being the only motivation driving creativity and innovation.

3) Finally, DIY hardware communities dispute the assumption that users of technologies cannot, want not, and need not know how technologies work. It is useful here to break down this statement into its three components in order to understand how DIY hardware communities challenge each one:

a) *Users cannot understand how technologies work*. It is undeniable that contemporary technologies have become extremely complex. The lack of understanding of the functioning of technologies, however, has been further enhanced by the design practices of the broadcast approach—in which the inner workings of technologies are concealed—and the insistence that users do not need to know how they work, only how to use them. The distributed model of DIY hardware defies and seeks to reverse this trend by promoting technological literacy. This is achieved through open information sharing about the makeup of technologies, a focus on technical education and DIY experimentation, and a different approach to the design of technologies which focuses on simplifying the mechanisms themselves—so they become more accessible to those with no formal training in science and technology.

b) *Users do not need to understand how technologies work*. This assumption of the broadcast approach is based on the notion that producers can provide users with everything they may want while freeing them from the burden of having to comprehend the technical complexity of devices.

Understanding technical complexity is not always viewed as a burden, however. For many proponents of the distributed approach, and in particular for DIY hardware communities, technologies are not simply tools with which to compose reports, perform calculations or exchange emails, as Norman (1999) suggests. They are, in and of themselves, objects of interest and means of creative expression. This was evident in the culture of the 1950s and 60s MIT hackers who, unlike other students at the university, saw computers not just as powerful research aids but as the objects of research themselves. This interest in the makeup of technologies and a drive to push them further, to make them do new things, is still present in contemporary DIY hardware practices. Today, in addition to creating new devices, it is still common in these communities to repair and repurpose preexisting machinery. Technologies are also increasingly a means of creative expression which can take on several forms, from artistic objects in which mechanisms serve both as functionality and aesthetics, to expressions of technical prowess and playful exploration, engaged in for the simple pleasure of tackling a new challenge.

There are also, however, more practical reasons why users may need to understand how technologies work. As Eric von Hippel (2005) notes, it is impossible for producers of technologies to know what are the exact needs and wants of each of their technology's users. Marketing studies and user research can only uncover commonalities, not the idiosyncrasies of each individual user, context, and particular situation. Even if it were possible to obtain information about each and every single use case for a particular technology, given that in the broadcast approach devices are typically mass produced, it would still be extremely difficult to address each one on a single design. It is for this reason that Hippel suggests that users, who know exactly what they want, are, therefore, in a better position to obtain it by designing it themselves. Thus, rather than being dependent on professional producers and having to settle for what is provided by them, the ability to create and recreate technologies can enable individuals and groups to fulfill needs and aspirations not addressed by the products produced by firms.

c) *Users do not want to understand how technologies work*. Over the last few years, several common assumptions about what individuals want, or do not want, have been challenged by the emergence of participatory behaviors. These behaviors may, at first sight, seem aberrant and incongruent with what has thus far been the norm: passive consumption of professionally created content and goods. However, the technological explorations engaged in by DIY hardware communities can be seen as expressions of deeply rooted needs and social patterns. The broadcast approach's notion that users do not want to understand how technologies work regards technologies as simple tools, to be consumed in the most efficient and least inconvenient way possible. The practices and ethos of DIY hardware communities, on the other hand, are a reminder that technologies are a fundamental part of culture and that individuals are often motivated by much more than efficiency and convenience. Once the barriers to participation are low enough, and new opportunities are presented, it becomes possible for these behaviors to emerge.

While the ethos of the broadcast approach could be easily summarized by the motto adopted by the 1933 World's Fair in Chicago—"Science Finds, Industry Applies, Man Conforms"—the distributed approach promises a radical shift not only in the ways technologies are designed, but also in the social dynamics underlying that process. Under the broadcast approach, the technosphere is a polarized system with producers on one side and consumers on the other. Although the functioning of the marketplace has been likened to a democratic process, the participation of most citizens in the shaping of technologies is nevertheless limited to consuming what producers produce. Conversely, the distributed approach proposed by DIY hardware communities offers a practical path towards a democratization of the technosphere—one in which each user is viewed as a potential producer, and citizens are enabled to more directly and actively participate in the shaping of technologies.

CONCLUSION

The acknowledgement that the affordances and characteristics of technologies greatly influence both everyday experience and broader social practices has led a few concerned critics to call for a democratization of technological development through a greater involvement of citizens in these processes. MacKenzie and Wajcman (1999), for example, have attempted to encourage a more engaged politics, "seeking consciously to shape technology," by deconstructing technological determinism (MacKenzie and Wajcman 1999, xv). More notably, Langdon Winner, one of the leading proponents of the application of a "decentralized democratic politics" to the technosphere, has suggested "building institutions in which the claims of technical expertise and those of a democratic citizenry would regularly meet face to face" (Winner 1986, 55). And Andrew Feenberg has suggested that a more democratic technosphere could be achieved through "extensive (if not universal) public ownership, the democratization of management, the spread of lifetime learning beyond the immediate needs of the economy, and the transformation of techniques and professional training to incorporate an ever wider range of human needs into the technical code" (Feenberg 2002, 3). Thus, the proposals for democratizing the technosphere have so far fallen into either the category of advocacy and awareness, or into the category of the deliberate reorganization of political and economic institutions.

The distributed approach practiced by DIY hardware communities, on the other hand, offers an alternative path that is both more practical and grassroots: to provide citizens with the knowledge and practical means to both interrogate techno-social choices and directly participate in the shaping of technologies. Neither being strictly an advocacy project nor requiring the intervention of the state, the model proposed and developed by DIY hardware communities suggests that a democratization of the technosphere may be practically implemented, spontaneously and from the bottom up.

Implications

A democratization of the technosphere means that a greater number of individuals and groups can be involved in the process of shaping technologies. This has several and possibly profound implications.

Centralized design and production of technologies require that all decisions about the technical characteristics and affordances of technological artifacts be made by their producers. Once these batches of identical items leave the factories all that is left to the user is a choice between the devices available on the market. Although contemporary technological artifacts tend to offer multiple configuration and personalization options, these are still finite and cannot account for all possible use cases. Therefore, users must often adapt to what is given and what is given tends to cater to an averaging of uses and needs.

Thus, despite a recent focus on customizable goods, industrial production today still reflects the drive towards sameness Horkheimer and Adorno (1997) critiqued seven decades ago. The illusory differences between the products of industrial economies serve mostly, in the words of these authors, to "perpetuate the appearance of competition and choice" and "to assist in the classification, organization, and identification of consumers." In the broadcast approach, thus, "Everyone is supposed to behave spontaneously according to a 'level' determined by indices and to select the category of mass product manufactured for their type" (Adorno and Horkheimer 1997).

Technologies that are collectively shaped, on the contrary, tend to reflect a greater number of priorities, applications and contexts—and thus better reflect and serve a diversity of requirements. The differences between, for example, a 3D printer originating from the distributed model and one emerging from the broadcast model are not just technical trivialities, they are expressions of fundamentally different views of how the world works and how it should work.

Under the broadcast model, technologies have been primarily shaped by firms and the marketplace. Although users play a role in this process, by indicating their preferences through purchases, the choices that determine the characteristics and affordances of technologies are primarily driven by the dynamics of firms and markets. A greater and more participatory involvement of citizens in the technosphere, on the other hand, allows noneconomic concerns to surface and take on a more central role. These concerns range from niche needs, which the mass market does not address, to broader social problems such as economic justice and environmental degradation. Technologies such as RepRap, GVCS, Protei, and the Civilian Radiation Monitor arose not from the logic of offer and demand that governs firms, but from citizens' concerns with the distribution of productive capabilities and the ability to cope with environmental disasters. A democratization of the technosphere promises to bring to the forefront challenges that firms and markets currently have no incentive to address.

The implications of allowing a greater number of citizens to participate in the shaping of technologies, however, go beyond more immediate practical applications. By facilitating some actions and not others, technologies help define the realm of options available to their users and, in this way, influence individual and collective behaviors. The configurations and affordances of technologies, in turn, are the result of intentional or unintentional choices made by those involved in their development. Therefore, the question of how and by whom these choices are made is of great importance to both individuals and societies. While in the broadcast approach the shaping of technologies rests primarily with a relatively small number of producers, a democratization of the technosphere would allow a greater number of citizens to be involved in decisions that so influence both social dynamics and the quality of lived experience. If, as Winner suggests, "the qualities of technical artifacts reflect the possibilities of human living, what human beings are and aspire to be" (Winner 2003, 5692), it follows that, in democratic societies at least, the definition of these qualities should be subject to participatory processes.

The opportunity to shape one's material culture and to participate in the construction of the collective environment also has important implications for the more general condition of the human experience. An environment in which consumers are not mere receptacles but co-authors, in which individuals have greater agency to build what they want—rather than adapting to what others provide—allows a fundamental shift in outlook. This shift, Benkler argues, "[enables] us to look at the world as potential participants in discourse, rather than as potential viewers only" (Benkler 2006, 140).

Thus, a democratization of the technosphere, if allowed to flourish, has the potential to give rise to technologies that better reflect a democratic society's citizenry, address a broader range of social and individual concerns, and enrich the experience of humans as authors of their own lives and vital social beings. In other words, it enables the transformation of the technosphere into a public sphere.

Limits, Challenges, and Opportunities

Even though the distributed approach practiced by DIY hardware communities shows remarkable potential for a transformation of the technosphere, it has been argued here that it provides *a path towards* a democratization of the technosphere, rather than a full democratization. This is mostly due to the fact that, although promising, this model exhibits some limitations and open questions that present both challenges and opportunities.

Does It Scale?

The distributed approach enables the collective shaping of technologies and can potentially give rise to technological artifacts that better reflect the diversity of concerns, priorities and needs of a greater number of people. However, this shaping of technologies through the direct creation, appropriation and transformation of goods is limited to those artifacts which can be individually produced and transformed. Large technological systems—such as power grids, transportation systems, or the technologies developed and employed by national defense systems—are beyond the direct sphere of influence of average citizens and, therefore, cannot be collectively shaped in the same way. The distributed approach thus meets its limits on those discrete artifacts that can be individually transformed and, for this reason, cannot completely address a call for the democratization of technology.

However, albeit in indirect ways, the distributed approach as practiced by DIY hardware communities introduces cognitive and behavioral changes that may extend beyond the shaping of discrete technological artifacts. As Clay Shirky suggests, "switching from paying professionals to create something to having communities do it for the love of the thing may be technically trivial but socially wrenching" (Shirky 2010, 1419).

It may be argued that many of the digital creations that flourished around digital media are essentially trivial and therefore cannot have any possible impact beyond providing their creators with the satisfaction of bringing them to life—and the same could be said of a number of technological artifacts created by DIY hardware communities. Although many DIY hardware projects are indeed playful and engaged in simply for personal or collective enjoyment, the significance of these acts should not be altogether dismissed. As Shirky has pointed out, even the least remarkable creative act is still a creative act (Ibid.). There may be a significant difference between a mediocre project and a great one, but the largest gap is between creating and not creating, participating and not participating, producing and consuming. Once this gap is bridged, it becomes possible to progress towards greater levels of involvement in the shaping of technologies.

More importantly, going against the notion that technologies should disappear from the user's consciousness, the practices of DIY hardware communities draw attention to the technical characteristics of technologies and the processes through which these are socially defined. They thus call for a different kind of transparency: a transparency that reveals technologies' inner workings and biases to the public. These practices suggest that the construction—both technical and social—of technologies should be put front and center as an object of analysis, discussion and participation. Furthermore, through its efforts to distribute technological literacy, these communities also seek to equip citizens with the basic knowledge necessary to participate in debates about technological development and its social ramifications. In this sense, the practices of DIY hardware communities contribute to creating a public sphere in which technological choices can at least be interrogated and debated.

Thus, although their realm of action is indeed limited, the ability to take on a more active role in the shaping of one's own material culture and a greater technological literacy can also help foster a participative culture that encourages the involvement of citizens in debates about those large technological systems that cannot be individually shaped. The recent SOPA, PIPA and ACTA protests—in which dispersed individuals and organizations self-organized to oppose legislations that threatened to curtail the new digital freedoms—illustrates the increased awareness of the interplay between the social and technological realms, and exemplifies how citizens can and do mobilize to intervene in the technosphere.

Do Individuals Want to Shape Technologies?

The degree to which watching television displaced other more social and dynamic pursuits seems to indicate that the majority of individuals prefer to spend their leisure time involved in activities that do not require creativity or effort. Likewise, Norman's claim that "the bulk of the market consists of people who just want to get on with life, people who think technology should be invisible, hidden behind the scenes, providing its benefits without pain, anguish or stress" (Norman 1999, 52) is not unfounded. Thus, although DIY hardware communities practice and advocate for a more hands-on approach to the development of technologies, they may simply be in the minority. If so, the ability to participate in the shaping of technologies may never progress beyond the stage of potentiality.

DIY hardware communities are relatively recent and it is too soon to know whether their practices and ethos will continue to expand or what shape they will assume in the future. The participatory practices that emerged around digital media, although not displacing broadcast media, were a surprising development. The previously accepted understanding of what individuals want to do and will do with their time is now increasingly being questioned as technologies open new opportunities for behavior and scholars strive to analyze and explain emerging practices and phenomena (see, for example, Weber 2004, Shirky 2010, Benkler 2006, and Himanen 2009).

On the one hand, the pure consumption of media and goods is still a predominant part of individual and collective experience in industrialized societies. On the other hand, the identification of competence, relatedness and autonomy as universal human needs (Deci and Ryan 1985) seems to indicate that participatory behaviors are deeply rooted in human nature and will continue to manifest themselves as more opportunities arise. Both Benkler (2006) and Shirky (2010) argue that this powerful combination of motive and opportunity indicates that participatory practices will play an increasing central role in the production and distribution of information. There is no reason to believe that this cannot be applied to the production of technologies as well. In fact, as shown by the spontaneous transformation by users of both the Minitel and Kinect technologies, it appears that users are indeed interested in adapting technologies to their own purposes and contexts. According to this logic, as barriers to participation decrease—as obstacles are removed, less effort is required and more opportunities are presented—the likelihood of participative behaviors also increases.

The expansion or demise of these participatory practices depends largely on individual choices but also, like other social phenomena, on how they are collectively perceived. In 2008, when this research work was initiated, the practices of DIY hardware communities were still an essentially niche phenomena. By 2014, however, they had been featured in numerous mainstream media articles around the world, and personal 3D printers along with hacker/makerspaces had become part of the collective vocabulary.

For the most part, the practices of makers, hackerspace members and open source hardware developers have been cast by the media as solutions to accelerate the development of technologies and revitalize manufacturing industries. This idea that technological innovation and a revitalization of manufacturing might be tied to amateurs' activities soon drew the attention of governments. In 2011, the government of Shanghai announced its intention to fund the creation of 100 hackerspaces as part of a larger program to support grassroots science and innovation (Lindtner and Li 2012). In 2012, NYC's Mayor Michael Bloomberg designated September 24-30, the week when the annual Maker Faire took place in that city, as "Maker Week." In 2014, the U.S. White House hosted its first Maker Faire and U.S. President Barack Obama declared June 18 "National Day of Making" in a proclamation that highlighted the inventive and economic potential of a "democratization of technology" (Obama 2014). The pedagogical component of DIY hardware practices also captured the attention of educational institutions: in 2012, the U.S. Defense Advanced Research Projects Agency (DARPA) allocated $10 million to the Makerspaces initiative and, over the last few years, a number of American libraries and museums established makerspaces and began offering making activities.

Thus far, the attention of the media, the endorsement of governments, and the interest of educational institutions have contributed to spreading the practices and ethos of DIY hardware communities. The public perception of DIY hardware activities as positive in both economic and educational terms may, therefore, further contribute to the incorporation of these practices into mainstream culture.

Is it Economically Sustainable?

The distributed approach played an important role in the shaping of the radio and personal computer technologies, but it was eventually prevailed over by the broadcast model as these then new technologies gave rise to industries. This indicates that the distributed model has, in the past, tended to thrive in the early days of a technology when it is not yet clear what it will be used for and how successful it will be. Once the shapes of technologies crystallize and economic interests take precedence, distributed practices may become no more than tinkering around the edges of more powerful industrial forces. Thus, a sustained democratization of the technosphere may also depend on its economic viability.

The principal difference between radio in the 1910s-20s, or the personal computer in the 1970s, and the contemporary distributed approach lies in that fact that in neither of those periods was it possible to publicly share technical information or to coordinate contributions from many disperse sources. As Benkler (2006) suggests, the communication and coordination possibilities opened by digital technologies are what enables the distributed approach to move from the periphery of the industrial system to its economic center. Thus, the Internet's distributed network and the distributed production model it enables are also creating opportunities for new production models to emerge.

Although open source hardware firms forgo exclusive rights over the use and commercialization of their products, their reliance on the quality of their goods, fast technical advancement fueled by open development, and the loyalty of their customers has allowed most to survive and thrive. SparkFun—which was founded in 2003, currently has 136 employees, and reported a revenue of $25 million for 2012 (Inc 2013)—is one of the success stories. It therefore appears that the distributed approach is not incompatible with commerce and may actually provide firms with advantages. In fact, analysts Don Tapscott and Anthony D. Williams argue that this model will play an increasingly important role in the business world and, therefore, "treating peer production as a curiosity or transient fad is a mistake" (Tapscott and Williams 2008, 1286). Open source software businesses—such as Red Hat, a 21 year old firm that reported a revenue of $1.5 billion for 2013 (Red Hat 2014)—confirm this perspective. Although the approach of open source -based firms may appear counterintuitive against a backdrop of over a century of exclusive rights -based business models, the distributed model has thus far proven to be a practical alternative.

Future Work

This dissertation centered specifically on the ways in which, as practiced by DIY hardware communities, the distributed model enables public participation in the shaping of technologies. However, to avoid dispersion, several other relevant aspects were left unexplored that are worthy of future research across several disciplines.

Mechanized Craft Production

At the turn of the twentieth century, mass production pioneer Henry Ford sought to lower costs of production by implementing technologies and organizational strategies that allowed for the manufacturing of a greater quantity of goods in a shorter period of time—the introduction of the assembly line, for example, lowered the time it took to assemble a Ford automobile from twenty-one to one and a half hours (Colt 2013). However, given the rigidity of the machinery developed for this purpose, mass production systems cannot easily switch from one good to another—for this reason, the industrial system that rose around these processes specialized in manufacturing large quantities of a single design. Conversely, the dynamic artisanal system displaced by mass production had focused on the use of flexible tools to produce a wide variety of goods for large but constantly changing markets (Piore and Sabel 1984). The triumph of the mass model and its one-size-fits-all approach eventually relegated these craft industries and their variety of goods to the margins of the system.

Contemporary digital fabrication tools share two important characteristics with mass production machinery: precision and speed (although digital fabricators are typically not as fast as large scale factory equipment, they are, nevertheless, significantly faster than manual production). More importantly—unlike mass production technologies—laser cutters, 3D printers and CNC mills are extremely versatile. They can produce a wide range goods out of diverse materials. One single fabricator can, for example, make products as diverse as jewelry, toys, and furniture. For this reason, digital fabrication tools allow for the automation of small to medium batches of a variety goods. Similarly, the new production ecosystem made up of online factories, public fabrication facilities, hackerspaces, group orders, and factory-designer matchmaking services is making production at all scales both possible and accessible: a mouse click can either send a product design to a local fabrication tool or to a professional factory elsewhere. Just as significant is the fact that, while small producers were once confined to local markets—due to the high cost involved in setting up outlets in additional physical locations—the worldwide dissemination of the Internet now allows them to distribute goods on a global scale.

Thus, the combination of access to flexible and sophisticated production and distribution tools with the public dissemination of designs and technical know-how is making manufacturing increasingly accessible to a larger number of small firms and single individuals, who can produce a greater variety of goods. This lowering of barriers promises to enable a revival of the craft-industry system previously displaced by mass production. If allowed to flourish, this could indeed be a radically different industrial system.

The democratization of the production of information enabled by digital media has already introduced several transformations and destabilizing factors into the culture, media, and software industries. If a parallel transformation is taking place in the realm of manufacturing it is, therefore, important to study its implications for both local and national economies.

The System Within the System

Some of the most remarkable aspects of DIY hardware practices are the processes through which these communities implement and maintain an alternative production system within the mainstream system it challenges. This is accomplished by making use of several preexisting institutions and mechanisms—and, in some cases, turning them upside down—through processes that resemble Michel de Certeau's (1988) concept of tactics. Copyleft, for example, takes advantage of intellectual property laws—which state that all creative works are automatically protected by copyrights—to invert their logic and protect the right to distribute, rather than the right to exclude. Similarly, open source firms, while challenging the dominant exclusive rights -based business models of broadcast companies, compete with them in capitalist markets by relying on quality, price and fast development. Equally significant is the fact that the large majority of open source hardware technologies are not new technologies, but reinterpretations of preexisting broadcast approach devices appropriated and redesigned to facilitate the distributed approach.

This implementation of an alternative system within another system, which it both co-opts and subverts, reflects the older hacker traditions of hacking systems and acting without asking for permission—practices that are still central in DIY hardware communities. To illustrate this point, it is worthwhile recalling Adrian Bowyer's "Wealth Without Money" (2004) statement in which he asserted that, rather than seeking economic justice through a revolution, his approach focused on creating means of production that can self-replicate—that is, technologies that can spread from one adopter to another without the need for abrupt political transformation or top-down intervention.

Conversely, some DIY hardware technologies and organizations have also been co-opted by the broadcast approach. Notably, MakerBot Industries, a firm that played a fundamental role in the dissemination of RepRap-based personal fabricators, initially distributed all its products under open source licenses. Although this firm started small, it soon received venture capital investments—and was later acquired by another large corporate producer of 3D printers—and abandoned the distributed approach. Information about the makeup of MakerBot's products is no longer publicly available, several of its parts are protected by patents, and the initially exposed mechanisms of these machines are now firmly concealed inside black boxes.

Thus, the coexistence of the distributed and broadcast approaches within the same settings gives rise to a series of co-optation, appropriation, and subversion processes, which must be better understood and analyzed.

Around the World

As noted in the Introduction chapter, the scope of this research was, for practical reasons, circumscribed to an examination of the ethos and practices of European and American DIY hardware communities. However, the distributed approach to the development of technological artifacts is now practiced around the world. The geographical location of each of these DIY hardware groups matters, as their shared ethos is often meshed with local specificities. Thus, to grasp the broader potentialities and implications of distributed practices, it becomes necessary to study them in their disperse local settings and to understand how different communities interact with different cultural, legal, political, and economic settings.

As part of this global work, it is just as relevant to analyze how technologies designed in one part of the world are, or can be, adopted and adapted by other regions. This is, in fact, still another promising aspect of open source hardware. Rather than technology transfers being imposed by one culture onto another, open source hardware allows a more adaptable process of intercultural technological exchange—by enabling each particular community to autonomously select which technologies to adopt and how to adapt them to their specific needs.

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