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The Innovation Makerspace: Geographies of Digital Fabrication Innovation in
Greater New York City

by

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of the requirements for the degree of
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Abstract

Desktop digital fabrication technology has the potential to powerfully alter the economics, geography, and sociology of production. Because it enables the individual to produce highly customized and technically sophisticated objects for personal use, the technology poses a challenge to traditional small scale manufacturing. The desktop technology cannot reach its potential for widespread impact until it improves in quality and decreases in price. Makerspaces have emerged in the United States in the last eight years as informal social organizations where innovation in this technology may be occurring. This study examines whether innovation in digital fabrication technology has occurred, or has the potential to occur, at makerspaces in the New York City area. The findings of this study expand on previous research in technology innovation as it takes place in communities of practice, employing *knowing in action* typologies. Using spatial, social, organizational, and innovation factors as categories, the study performed a qualitative analysis of textual interview, document, and observational data to identify aspects of each knowing in action typology that applied to six New York City area makerspaces. The analysis found that makerspaces primarily produce incremental process and product innovation for digital design files and physical objects produced through digital fabrication, rather than consistently producing radical innovation on digital fabrication equipment. The makerspace as a community of learning and knowledge uniquely possesses the ability to integrate the digital and physical. It espouses a mission of education and openness: despite their ongoing challenges in maintaining diversity of membership, they may be seen as an engine of regional knowledge externalities.

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1. Introduction

"I have no interest in building my own 3D printer. A tool is a tool to me. I can draw, but I'm not going to go make a pencil to draw with."

- study participant

"For better or for worse...I want to make this [new type of 3D printer] because I wish I had one. Some people say that's a reason to do it. Others say it's not a real breakthrough.... Do something that's patented—who cares? Reinvent the wheel—no one cares!"

- study participant

Desktop digital fabrication technology has the potential to powerfully alter the economics, geography, and sociology of production. Because it enables the individual to produce highly customized and technically sophisticated objects for personal use, the technology poses a challenge to traditional small scale manufacturing (Gress and Kalafsky 2015, Bryson et al. 2015). The desktop technology cannot reach its potential for widespread impact until it improves in quality and decreases in price (Gershenfeld 2012, Finocchiaro 2013). Makerspaces have emerged in the United States in the last eight years as informal social organizations where innovation in this technology may be occurring. This study examines whether innovation in digital fabrication technology has occurred, or has the potential to occur, at makerspaces in the New York City area.

Digital fabrication is a suite of simple robotic technologies in which a tool is mounted on a sliding two- or three-dimensional plane, executing commands to produce or alter objects from a digital design file. The technologies addressed in this study are three-dimensional (3D) printers, laser cutters, and CNC machines. Makerspaces are emerging as sites of desktop digital fabrication and innovation. The makerspaces included in this study are small-scale, local, and nonprofit. They are publicly accessible workshops driven by communities with in-person and virtual manifestations.

Economic geography contains within it a variety of useful perspectives for the examination of the phenomenon of digital fabrication in makerspaces in the New York City area. Extensive research into

innovation in the context of the spatial and relational nature of communities, technology clusters, and regions exists in economic geography. However, work on the specific combination of high technology innovation at a small scale in collective organizations is recent, often unpublished as of this date, and almost exclusively sited in Western Europe. The work described in the following chapters attempts to apply economic geographic theories to innovation in digital fabrication technology as it occurs in New York City area makerspaces.

If digital fabrication technology is to achieve its full potential, we must study the communities of those who commonly use, modify, and sometimes create it. The communities of practice paradigm within economic geography provides a way to understand the organizational, social, and spatial dynamics that can effect, enhance, or hinder technology innovation arising from communities. Specifically, Gress and Kalafsky (2015), in one of the first published papers in economic geography on the geography of 3D printing, suggested the use of Amin and Roberts' (2008) *knowing in action* community typologies to characterize makerspaces in their capacity as loci of innovation. The knowing in action framework provides a means of describing a variety of typologies of communities of practice: craft-based, professional, epistemic and creative, and virtual communities. These typologies will be applied to makerspaces in the study area in the following sections. 2. *Review of the Literature* discusses innovation as it is defined in economic geography, the interaction between knowledge and space that leads to innovation, and innovation produced by organizations, including knowing in action typologies. 3. *Methodology* describes study design, sample selection, and data analysis using Mayring's (2014) Qualitative Content Analysis technique. 4. *Results* includes descriptions of each case, and a presentation of interview results organized by the categories derived from Qualitative Content Analysis. 5. *Discussion and Conclusions* analyzes and summarizes these conclusions.

2. Review of the Literature

This study researches innovation in digital fabrication technology (IDFT) as it occurs in makerspaces in the New York City region as a function of what type of community the makerspace is. By identifying variables that may lead to IDFT for a community like a makerspace, and characterizing its community typology, this study may contribute to the wider discussion of whether DFT and other technologies are able to emerge from small, local communities. In order to describe the nature of the makerspace-as-community, this study primarily employs a specific framework, Amin and Roberts' (2008) *Knowing in action: beyond communities of practice*. Gress and Kalafsky (2015) recommended the use of the knowing in action paradigm to explore the role of makerspaces as a site of the production of IDFT.

Knowing in action (KIA) is the term Amin and Roberts use to designate a new conception of "communities of practice", a term appearing widely in the literature in a variety of inconsistent forms. They developed a set of four typologies of KIA communities—craft, professional, epistemic, and virtual—in order to illustrate distinct typologies among the many characterizations of communities of practice. Differences among KIA communities are often based on proximity as a both spatial and relational concept. The variables that characterize the four KIA typologies are their type of innovation produced by the community, type of knowledge possessed by the community, social interactions that take place in the community, and organizational dynamic of the community.

The theoretical perspective employed here draws on a diverse body of literature primarily in economic geography, and also in "innovation studies" (Godin 2012), organizational innovation, management, and business. This literature demonstrates that knowledge, social interactions, and organizational structure are some of the most important determinants of technological innovation. Literature on innovation in digital fabrication technology in makerspaces is almost nonexistent, but these several niche literatures can be customized to the case of a particular technology (digital fabrication technology) in a particular organizational setting (makerspaces) situated in a particular region (the New

York City area). Geography contributes to the understanding of knowledge through explorations of proximity, which recently have expanded from spatial proximity to relational proximity (Amin and Thrift 2000, Bathelt and Glückler 2003, Sunley 2008, Fløysand and Jakobsen 2010), a useful development given increasing virtualization and digitization of economic activity (Kimble et al. 2000, Bathelt and Turi 2011, Kalafsky and Gress 2013).

That the literature referenced allows for flexible understandings of economic activity in space, including virtual space, enables the study of digital fabrication as an emerging technology saddling physical and material form. This technological duality extends to the process of innovation through knowledge relationships, which, reflecting the technology itself, are both in-person and virtual. The nature of innovation on this technology is often distributed, such that it benefits from frames of reference provided by literature on informal and loosely-defined communities. However, digital fabrication technology inevitably manifests in physical form. This guarantees the salience of spatial proximity and the usefulness of geographical theory to examine it.

The following review of the literature describes the main concepts and variables of innovation identified in Amin and Roberts (2008), and then discusses the work itself. **2.1 Defining innovation** explores the theoretical origins of the generally accepted definition of innovation, and the distinction among technological, business model, and organizational innovation. **2.2 How proximity affects innovation** summarizes the core function through which geography operates as an influence on innovation, proximity. **2.3 How proximity affects knowledge** describes how knowledge produces innovation, often through its spatial and relational features. **2.4 How communities produce innovation** presents the evidence in the literature for the effect of community size, location, age, hierarchy, openness, and several other factors on the community's ability to produce innovation.

2.1 Defining innovation

2.1.1 What counts as innovation

That an innovation is new is baked into the term's root. The innovation literature, whether within or outside economic geography, usually defines innovation as the creative inception of not only a novel feasible (Polyani 1961, Hellman and Puri 2000) product (or the intellectual property rights to it), but one that is subsequently successfully commercialized. According to MacPherson (1997), for example, innovation "...is defined as the successful design, development and subsequent commercialization of a new or substantially improved product (128)." Heirman and Clarysse (2004) describe the difference between innovation and imitation in a way similar to what Amin and Roberts (2008, 9) term radical and incremental innovation: "An innovator is a firm that creates mainly new, proprietary knowledge.... An imitator, on the other hand, rather uses existing knowledge and focuses on making (minor) improvements to it or synthesizes several existing technologies in its own proprietary products".

Innovation may be considered both creativity and artistry—and also a functioning, practical object, process, or service that proves to be market-viable. The task for the innovation scholar then becomes how to predict future economic payoff of a largely creative, and therefore cognitive, process not only before it has survived market introduction, but often before the product comes into existence (Freeman and Soete 1997, Jones and Wadhvani 2006, Feldman and Kogler 2010). Because 'innovation' is a "king of buzzwords" (Green 2013), its origins in Schumpeter's (1934) *Theory of Economic Development* as that which results in tangible economic impacts are sometimes lost in its common usage. A cutoff for qualification, made along the spectrum between art and commerce, is useful because human value is placed on that which can positively benefit others in "economic wellbeing, prosperity, and growth" (Feldman and Kogler, 2010). The distillation of the idea into something measurable is valuable to

researchers, and the market is adept at unitizing and quantifying utility. A precursor idea that is not subject to market sorting is therefore a mere invention instead of innovation (Feldman, 2000).

2.1.2 Measuring innovation

Innovation's origins in creative cognition mean that it must be measured in proxies, usually ones based on the commercialization-oriented definition. Patents are common proxies, though they are widely acknowledged to be flawed (Archibugi and Planta 1996): they do not reflect product viability, and so reflect invention more than innovation. Other proxies have been put forward as superior alternatives to patents such as new product introductions (Acs et al. 1994) and Small Business Administration (United States) data (Feldman 1994). Researchers employ these methods to determine the influence exerted by independent variables on the dependent variable of the innovation proxy in a large sample dataset. A business determining its innovation strategy, or determining its allocation of resources to attempts to innovate rather than many other pressing business costs, will often use return on innovation investment, a metric with proprietary inputs (Kandybin and Kihn 2004). Notably, firm innovation often falls under the line item of R&D, performed either in potentially siloed departments, or outsourced entirely (Ferrary 2011). The common thread running among these measures is that they make use of those proxies that leave a "paper trail" (Krugman 1991 Jaffe et al. 2003).

Innovation resists attempts at measurement. Committing the fallacy of survivorship bias is the risk involved in excluding from a study those innovations that do not leave a paper trail; defining an innovation as that which does leave a paper trail is rather too convenient. As with many fields, publications on innovation are skewed (especially toward high tech in the United States) because nonquantitative studies are rarely published (Jones and Wadhvani 2006). Brynjolfsson and McAfee (2012), technology theorists at MIT, famously argue that the market does not reflect large portions of economic utility in existence, particularly that produced by information technologies, digitization, and

automation. Objections to quantification are reflected in the national-level debate over the right balance between government investment in long-term, risky, basic science research and short-term, targeted applications of technology. Another weakness of the market-mediation approach to innovation is that market mechanisms have not proven themselves to effectively achieve the oft-exhorted poverty and environmental degradation reduction potential of innovation (Healy and Morgan 2012, "The Future of Urban Innovation: Startups" 2015).

The difficulty in quantification of innovation originates in its knowledge-based nature (Maskell and Malmberg 1999, Gertler 2003). Adam Smith, Karl Marx, and Josef Schumpeter all connected machine development to economic growth, and to varying degrees all wrote of the machines of the machine age as a materialization of human thought (Freeman and Soete 1997). However, economics has been slow to develop methods for describing how an ever-more knowledge-based economy works, such that Schumpeterian theory and innovation economics is still often considered outside the mainstream of economic thought, though it finds a home in modern economic geography. While the knowledge economy has entered more into the public consciousness in the post-financial crisis period of "software eating the world" (Andreessen 2011), a long line of literature has charted the increasing share of the economy for which knowledge is more important to technology than physical inputs (Machlup 1962, Porat 1977).

2.1.3 Historical approach

Academic analysis of the origins of innovation in knowledge often arrive in the context of a grander period analysis. This historical approach charts the transition from agricultural to industrial, and from industrial to information economies. Often these analyses are performed either from the perspective of industry and labor, or from that of creativity and innovation. For example, historical transition can either be from from Fordist to flexible production or from the Industrial to the Knowledge

Society (Ranga and Etzkowitz 2013). The connection between the two 'shifts' is that the knowledge society-economy creates changes in manufacturing and employment that have the effect of splintering and individualizing many formerly centralized activities, including innovation (Neff 2012). Some writers popularize the concept of a digitally-enabled "third industrial revolution", a historical movement toward democratized craft facilitated by high tech and new, more collaborative social organization (Anderson 2012, Fixon and Marion 2014, Kietzmann et al. 2015).

2.2 How proximity affects innovation

2.2.1 Spatial proximity

Innovation is one of the economic phenomena most sensitive to spatial variation (Feldman and Kogler 2010). The effect of Cartesian proximity on economic activity in economic geography goes back to von Thünen and gravity models, where distance to an urban center is often correlated with economic output. However, mechanistic models have gone the way of the quantitative revolution, subject to strong suspicion among geographers that reaches back even to Schumpeter's distaste for Keynes and Ricardo (Schumpeter and Schumpeter 1954). While economic geography still debates its cultural turn, both quantitative and qualitative research in the field routinely reaffirms the correlation between innovation, the font of economic growth, and measures of different types of proximity.

The distinction between centrality and proximity in the innovation literature is one of simplicity and complexity. Early geographic studies of economic activity recognized that urban agglomerations and industrial clusters generate externalities and increasing returns, or economic output beyond what the sum of their constituent parts would predict (Feldman 2009). Over time, geographers have been more willing to concede the inadequacy of the exclusive explanatory power of Cartesian distance (Martin 2010). Within geography there are currently a variety of definitions of 'proximity', which ultimately enables a nuanced understanding of economic phenomena such as innovation.

2.2.2 Relational proximity

Often the term 'proximity' is preferred over 'geography' when expressing a spatial concept, stretching the meaning of space to include that beyond the pedestrian physical. Types of proximity that extend beyond spatial proximity are often referred to in literature as relational proximity. They include social, business, and other relationships, connections, linkages, and networks. These relationships are characterized by interconnectivity (Fløysand and Jakobsen 2010). Bathelt and Glückler (2003, 125) give a succinct definition: "Research in relational economic geography...focuses on processes, such as institutional learning, creative interaction, economic innovation, and interorganizational communication, and investigates these through a geographical lens, rather than uncovering spatial regularities and structures."

One strain of literature in the geographic study of innovation argues that "relational proximity is not reducible to co-location (Amin and Roberts 2008, 354)" (Amin and Thrift 2000, Bathelt and Glückler 2003, Sunley 2008, Fløysand and Jakobsen 2010). Amin and Roberts (2008, 365) write, "Amongst economic geographers there has been a vigorous debate in recent years on the spatial form of tacit or community-based knowledge generation, with some commentators emphasizing the centrality of spatial proximity and others emphasizing the strength of relational ties in trans-local networks." Their logic depends upon an understanding of innovation as often created by a community, which elevates the need to understand the nature of the exchange of knowledge among individuals. Lundvall and Johnson (1994) were among the first to write of innovation in the sense that it is socially produced, arguing that it must be understood in system terms. Fløysand and Jakobsen (2010), contributing to what they call the "relational turn literature in economic geography", develop the concept of the *social field*. *Social fields* are "dense patterns of social relations, marked by a particular time-spatial scale and knowledge production that constrains and enables the agency of actors". The commonality among propositions for models of relational proximity such as Amin and Roberts' knowing in action typologies and Fløysand and Jakobsen's

social fields is that the web of relationships that results in innovation may or may not be local. Geographic regions, and even spatially-circumscribed entities such as a firm that occupies one building, according to relational proximity may exert less of an effect on innovation than previously thought.

2.2.3 Virtual proximity

The walking back of geography's determinant quality, the emergence of alternative relational, evolutionary, and ecological theories, and the complication of the term 'space' itself do not coincide with the digital revolution by accident. Indeed, the digital revolution long ago ceased to be solely a phenomenon of the communications, media, and information technology domains, and now permeates everyday life (in Western countries), both birthing and snuffing out a parade of legacy businesses and entire economic sectors. That the internet, digitization, virtualization etc. will mean the "end" or "death" of geography, as claimed by Cairncross (1997), has been repeatedly debunked by economic geographers over the last twenty years. Glückler and Sanchez-Hernandez (2013) call localization that is observed along with digitization, despite the globalizing potential of digital technologies, "the proximity paradox". Leamer and Storper (2001) argue that virtualization can lead to or reinforce geographic aggregation of technology production even while disaggregating some functions. Kalafsky and Gress (2013) have documented complex online relationships and business services that parallel and augment already-existing spatially proximate ones at Korean trade fairs. By affecting all information, virtualization affects both formal and informal market transactions, with implications for innovation.

2.3 How proximity affects knowledge

Unsurprisingly, economic geographical enquiry into innovation practice has found that decreased geographical distance enhances social relationships that result in innovation, but it has also questioned the salience of this argument. The knowledge that must be shared among individuals to result in innovation is either locked into a standardized symbolic format (codified) or resistant to explicit

transcription (tacit). Codified knowledge appears to not degrade over space, while tacit knowledge can often only be transmitted over short distances. This spatial degradation characteristic of tacit knowledge results from its requirement for face-to-face contact and social and cultural similarity and trust of participating parties (Gertler 2003, Howells 2002, McCann 2007). Because tacit knowledge presumably taps into the creative brain (Polyani 1961), and because it uniquely transmits the freshest, precodified information that can be used to predict trends and reduce risk (Feldman et al. 2005, Neff 2012), it is associated with innovation. Therefore, innovation tends to cluster in space because tacit knowledge provides a competitive advantage to where it pools. Much of the discussion in the literature concerns the truth of the assumption that tacit knowledge transfer is an almost exclusively local interpersonal relationship and its counterpart, that codified knowledge is a universally-decodable symbol corresponding accurately to the thoughts of the originator (Gertler 2003, Boschma 2005, Maskell and Malmberg 2006, D'Este et al. 2012, Ter Wal 2013).

2.3.1 Knowledge externalities

The economic mechanism through which geography affects innovation is local externalities. An externality is the effect on a third party of an economic transaction between two other parties. A *local* externality is one that is not only limited to a certain geography, but is created by that geography itself: "externalities tend to arise in space", complicating traditional economic models (a reason, but not a good one, that geography is often lumped into *ceteris paribus* assumptions and excluded) (Kanemoto and Miyao 1987). Knowledge externalities in geography, when referring to local knowledge moving from the original members of the transaction to other, local members to effect positive local returns, are termed 'knowledge spillovers'. Externality-producing transactions can be market-based or "pure", or non-market, which are arguably more interesting (Kanemoto 1988) and more difficult to identify (Boschma and Frenken 2006). Examples of externalities are often negative, like pollution or traffic congestion, but local

externalities can also create communal, accessible resources. Seemingly self-interested parties can create and contribute to resources that can be accessed by others, even competitors—sometimes neither consciously nor voluntarily (Bessant et al. 2012). The end result can be higher levels of innovation for the innovation system as a whole.

The components of a geography that generates externalities affecting innovation are (a) its labor supply, (b) the education and skills possessed by the population, (c) the social residue of business relationships such as between local suppliers and buyers, and (d) social networks that arise naturally through concentration of population or that are helped along by social organizations such as clubs and networking events (Saxenian 1991, Grabher 2004, Torre 2008). Public goods such as educational institutions, government services, libraries, legal frameworks, and physical infrastructure are partly designed to create positive externalities. However, private entities such as firms, particularly large ones, can achieve a similar effect (Feldman et al. 2005). Because externalities drive system-level innovation, they benefit small organizations more than large, and domestic innovation more than international (Lundvall 2010). The commonality among externalities is knowledge: the labor supply possesses it, public and private organizations create, share and trade it, and social networks circulate it.

2.3.2 Tacit knowledge

An important question in economic geography is how much of locally-circulating knowledge is tacit, and if tacit knowledge is the key to understanding or even reproducing and forcing a local innovation system. The traditional assertion is that knowledge travels efficiently at the local level (Audretsch and Feldman 1996) but also that the social friction of distance degrades the signal of tacit knowledge (the best knowledge) so rapidly that without direct human contact, it cannot make the leap from person to person. The spatial stickiness of tacit knowledge leads to the observed pattern of spatial clustering of knowledge-based economic activity. This logic, while widely acknowledged to be simplistic,

manifests itself in the form of concepts regarding the region, as in "local buzz" (Bathelt et al. 2004, Asheim et al. 2007), and concepts regarding the community or organization, as in "communities of practice" (Wenger et al. 2002, Gertler 2003, Asheim and Gertler 2005, Amin and Roberts 2008).

Tacit knowledge as a concept is problematic. For one, it has been found to be paradoxically damaging to innovation, at least after the initial phase of innovation system development (Audretsch and Feldman 1996), because it can produce a kind of groupthink called *lock in* (Hassink 2010) or the *competency trap* (Levitt and March 1996). Another issue is the vagueness, ambiguity, and incoherence it engenders in attempts to study it (Martin 1999, Moulaert and Sekia 2002, Amin and Roberts 2008, Sunley 2008). Economic geographers continue to find the dismemberment of innovation systems into their constituent parts a frustrating task, with few measurable proxies for knowledge flows available (Pratt 2014). Polyani, in *Knowing and Being* (1961), recognized the "difficulty of specificity" of the particular subcomponents of knowledge systems. A knowledge that arises from practice is difficult to specify, and the cognitive transaction itself is hidden: it is an "embodied, practiced, experimental, and always-provisional activity" (Amin and Roberts 2008, 365).

Geographers often assume that spatial proximity naturally breeds cognitive proximity, but some have proposed separating the two such that knowledge transfer can be understood relationally and socially rather than solely spatially (Fløysand and Jakobsen 2010). Distant knowledge transfer through a carefully-cultivated relationship can be meaningful, and the embedding of two parties in the same local culture does not guarantee they will decode codified knowledge in the same way (Allen 2000). The transfer of knowledge over online, virtual, at-a-distance communication channels will certainly be studied more in the future, and here especially, spatial determination of knowledge quality is not a given (von Hippel 2001). While most innovation geography research affirms at some point the essential quality of the *efficiency* of tacit knowledge transfer, social norms surrounding virtual communication are changing,

and possibly the fundamental cognitive capacity to derive value from them. Children raised from birth on electronic devices (so-called "digital natives") will likely find the literature's doubtfulness myopic.

2.4 How communities produce innovation

2.4.1 Definitions

2.4.1.1 Organization

The traditional conceptualization of the organization within economic geography is that of the firm as an integrator of labor, materials, and machinery, and other factors of production. However, the organization is not simply a changeless machine processing economic inputs and generating outputs. Its functions may be more or less integrated into the organization itself as in vertical integration or outsourcing. It is embedded in a wider region and maintains relationships outside of itself. It cannot be separated from the "social, cultural, and institutional (133)" networks that it is a part of (Bathelt and Glückler 2003).

2.4.1.2 Community

The community, as a set of relationships, may or may not be coterminous with an organization. It is as often fluid and ambiguous as it is clearly demarcated and identified. It may be informal or cultural, or highly cohesive. It is embedded in a region, but comprises its own small (or not so small) social ecosystem, or what Pratt (2014) calls "ecology of social knowing". A main concern in the study of technological innovation in communities is how internal community dynamics, and its relationship with the larger region, produce innovation. Many communities studied in the research are firms. The study of craft or other non-market, unsanctioned communities is usually separate (Pavlovskaya and St. Martin 2014). However, a hybrid stream of research to be presented in the following section examines

innovation-producing communities that may or may not exist within or across firms, and more often than not are small, changeable, and creatively agile.

2.4.2 Factors that affect innovation for the organization and community

2.4.2.1 Organizational size

Some literature proclaims the goodness of small organizational size for collective social, as well as private commercial, interests. Amin and Roberts (2008) write that the community of practice concept is in vogue because, "...normatively, it is a turn returning hope to the small community, the isolated region, and the disempowered collective in the new knowledge economy." They rightly caution, though, that social theorists should not pin their hopes only on spatial scale, as locality does not exclusively shape the webs of knowledge relations comprising an organization. It may be added that the small and local should not be automatically assigned the economic valor bestowed on the family-owned corner store in an era when high technology enables nearly laborless organizations to leverage their activity to globally influential levels. In the language of innovation studies, value is accorded to the impact of innovation on economic utility. It follows that the higher the level of innovation reached with the smallest level of resources, the more value it has achieved. As it happens, small organizational structure can often favor innovation over that of behemoths, although the same properties leave them vulnerable—a weakness that can be compensated for by obtaining exogenous resource subsidies.

Large organizations are in fact capable of successfully generating innovation. The transaction cost theory of the firm states that firm scale is directly proportional to its ability to reduce the burdens the market places on transactions such as communication, collaboration, and coordination (Coase 1937). Many innovation studies in economic geography take the firm, government, and university as units of study, as epitomized in triple helix theory (Ranga and Etzkowitz 2013). These three classic large institutions have historically run research and development wings producing disruptive technologies

(Teece 1987, Freeman 1995). Size captures the benefits of economies of scale; it concentrates—reduces the scarcity of—financial, material, and social, human, and labor capital; and it brings the influence needed to effect successful resource acquisition, supply chains, and distribution networks. The organizational cultures that emerge informally in large firms can facilitate innovation by creating communal values and reducing communication barriers among disparate group members. The organization motivates employees with both long-term organizational goals and short-term project-based goals. In terms of geography, a large organization on a fundamental level usually, via the office building, compresses together a variety of actors (Lawson and Lorenz 1999), which can assist in capitalization upon the innovation benefits of diversity (March 1991). The ability of a large organization to innovate is highly sensitive to its structure, hierarchy, and management of March's (1991) exploration and exploitation imperatives.

Contrarians offer a muted view of the innovation potential of the large organization. Link and Rees (1990) call the large-scale penalty on innovation "diseconomies of scale"; Chandy and Tellis (2000) call it "the incumbent's curse". The *bête noir* of innovation in large organizations is bureaucracy (Burns and Stalker 1961, March 1991, Acs et al. 1994). Dunbar (2003) famously proposed a cognitively-based numerical limit to group effectiveness based on the geographically-constricted environments of human evolution: large community size leads to breakdowns in communication. The converse of communication-facilitating corporate culture and proximity is rigid organizational routine (Cyert and March 1963, Neff and Stark 2004), the *competency trap*, and stale, homogeneous group composition (March 1991). Finally, firms increasingly outsource innovation to third parties, a possible sign that (a) they themselves have either perceived exogenous sources of innovation as superior to endogenous, intra-firm ones, or (b) that they have been dislodged from their domination by recent historical trends away from vertical integration and toward disaggregated networked regions of innovation (Ferrary 2011, Hassink and Klaerding 2012).

2.4.2.2 Risk tolerance

Innovation is an inherently risky act and can come at the cost of firm performance yet potentially yield no dividend. March's (1991) exploration-exploitation dyad describes a tradeoff between firm performance and "winning". Small organizations, especially those that have not yet coalesced into a firm, may accept risk more easily; they may not yet have performance to speak of. Given higher risk, potentially innovative projects are likely to be small; therefore, increasing the number of small projects managed by lower levels in the hierarchy (if one exists) can be an innovation strategy (March 1991). Two views exist on the reason the individual or small group such as a startup chooses risk. The entrepreneur sees opportunity and the potential for reward, and takes a calculated risk to innovate betting that the market will reward it (Feldman et al. 2005). Alternately, wider cultural norms, urged on by venture capital and the media, frame risk as socially desirable and therefore lure the dispensable small organization into taking on the risk that larger organizations are unwilling to (Neff 2012). As in the animal kingdom and insurance, the antidote to small size is safety in the group, such that the more connections that exist among small organizations, the greater their chance of survival and collective innovation.

2.4.2.3 Openness

Small organizations can have permeable boundaries, compensating for the limitations placed on them by their scale with others' resources. Openness is a strategy of sacrificing the competitive advantage of information asymmetry for greater knowledge than the small organization could have produced endogenously. Industry clusters with open innovation characteristics have disaggregated market share: instead of a dominant firm, a larger number of small organizations operate in an ecosystem (Barge-Gil 2010).

Openness is often developed out of necessity. Communal, networked, regional cooperation may seem, reflexively, contrary to traditional economic notions of agent motivation and behavior. The blind spot in economics for the innovation capacity of network-leveraged small organizations derives from a

historical belief that the heroic narrative of the innovating little man is a myth. John Kenneth Galbraith (1952) called the narrative of the "small man" compelled by his vulnerable position to higher creativity "a fiction". Even the critical theorist Curry (1993) has concluded that resource constraints on small organizations are so constraining that the flexible production small firms are said to engage in likely does not exist. He frames the concept of constraint-compelled innovation in craft as a "veneer" over the capitalist tendency to hegemony.

In a sense, Galbraith and Curry are correct: resource constraints do attenuate innovation capacity in the small organization. Product-based startups often are not offered financing, while for early-stage technology startups, the financing they receive is correlated with the human capital they start with. Maintaining innovator autonomy often comes at the cost of offering purely knowledge-based services such as consulting, rather than a physical product or technology (Heirman and Clarysse 2004). Another constraint small organizations often experience is that of the geography they begin in, since "many individuals have locational inertia" (Feldman et al. 2005). The risk innovators bear is itself a constraint: Feldman et al. (2005) find that a major trigger of innovation is a systemic shock that reduces risk, thereby creating opportunity. However, organizational openness can help small organizations move beyond some of the limitations of scale.

2.4.2.4 Hierarchy

A smaller organization is much less likely to have a hierarchical organizational structure than a larger one, and can therefore be less subject to hierarchy's innovation-damaging influence. Innovation drives change, but is also a way to cope with larger economic and technological changes buffeting the organization. Burns and Stalker's seminal 1961 *The Management of Innovation* created a model of management systems along a continuum between mechanistic and organic. Mechanistic systems are analogous to bureaucracies, in which individual agency is a function of the rules set out for her; the authors prescribe them for periods of stability. Organic systems' flexible stratification, which Neff and

Stark (2004) term 'heterarchies', in place of hierarchy is suited to change. They allow true agency, freeing the individual to respond to what she best judges benefits the company, blurring the lines between formal and informal boundaries and roles. Her personal motivation may even be to "the 'technological ethos' of material progress and expansion" rather than organizational "loyalty and obedience" (Burns and Stalker 1961), or even financial compensation (Thrift 2001). Though the organic system is stratified, to compensate for its lack of formal hierarchical structure, it consciously cultivates among its members shared ideology, beliefs, and values. Burns and Stalker emphasize that organic systems is a functional, pragmatic concept, driven by "the rationale of nondefinition" rather than "sociological ideology"—an ideology which presumably historically advocated for greater worker autonomy based on an ethic antagonistic to hierarchy, oppression, and hegemony, and which drives much of the work on craft communities in critical economic geography. Because innovation, or the creation of a novelty, causes and effects change, the less-hierarchical organic systems that small organizations possess structurally can advantage them over large organizations.

Many theories describe the effect on innovation of management, a firm's research and development (R&D) department, and 'floor' (those directly involved in technological design and production, and therefore potentially closer to the process of innovation) (Gertler 2003). The "floor" as capable of innovation emerged out of the study of process innovations in large Japanese firms such as Toyota (Sako 1999). However, the idea that innovation is best left to those specifically assigned to the task persists in some literature. Freeman (1995) writes of a historical recognition in the 70s and 80s that innovation does not only come from firm R&D. Showing himself as a student of Schumpeter, he also writes that innovation coming from "production engineers, from technicians and from the shop floor" tends to be incremental, while that from R&D is radical. Because there is often no distinction between R&D, management, and other types of workers in an small organization (Van de Ven et al. 1984), the relegation of floor to an inferior sort of innovation capacity needs reexamination—especially in an era of

increasing digitization of traditional analog manufacturing processes (Gress and Kalafsky 2015). The notion of the limited utility of the common worker is being challenged by no less than Google, which takes the threat of interference with the innovation capability of subordinates so seriously that it has pioneered techniques to neuter management (Bock 2015). Google, along with other Silicon Valley tech firms, encourages employee use of company time for self-initiated projects during both the normal workweek and specially-arranged hackathons, a practice that resulted in the creation of what are now core Google services such as Gmail (Tate 2012).

2.4.3 *Knowing in action* typologies

Digital fabrication as a production method is a hybrid of digital and physical, is employed by makers and industry alike, and is often situated in the organizational and community context of a makerspace. Confronting the technology as it is understood, used, developed, and innovated upon at the site of the makerspace therefore requires a flexible framework for identifying the organizational typology of the makerspace. Amin and Roberts (2008) offer a refinement of the generic communities of practice paradigm of innovation-generating social network, describing four typologies of "knowing in action" (KIA) – craft, professional, epistemic, and virtual communities. Each of these community typologies is characterized by a unique combination of factors, most of which draw from the literature discussed in the preceding sections. Knowing in action theory was specifically developed to contest solutionist notions appearing in much of the literature that promote a formula for regional innovation that emphasizes, to the exclusion of many other factors, the spatially proximate, small, and local nature of communities.

The authors derive KIA types from the communities of practice (CoP) concept, which developed in the early 1990s to explain innovation-generating group learning-through-doing, or what they variously call situated practice, socialities, collaborative working, and learning ecologies. As the CoP literature multiplied, the term came to be applied to many other types of community, including those less locally-

bound and less easily-identified as communities. In a review of hundreds of CoP publications, Amin and Roberts identify four typologies of communities that capture the variety in spatial relationships among community members, which has the effect of dislodging spatial proximity as a requisite quality of a CoP.

Craft, professional, epistemic, and virtual KIA types are each characterized by different knowledge dynamics, social interactions among members (including their spatial patterning), innovation outcomes, and forms of organization (hierarchical or siloed, open to outside knowledge, or open to change). The first and oldest KIA type is the craft-based community. Examples cited are flute makers, Xerox repair technicians, and some types of software development. Group members share and generate knowledge through the long-term physical enactment and performance of craft; knowledge is highly tacit and little-codified. Of all KIAs, craft requires the most face-to-face proximity of members for effective knowledge transfer because of the physicality of the medium of work, or its "kinaesthetic and aesthetic dimension". Social connection among group members is therefore the most ancient of anthropological types, trust-based, "communitarian", and hierarchical. They have a low rate of innovation, which is incremental rather than radical. Amin and Roberts also notably describe craft innovation as 'customized', implying that innovations tailored to the needs of a highly specific domain are not applicable outside that domain.

The second KIA type is the professional community. Examples cited are all in the field of health care. Its group knowledge is a combination of declarative and procedural; it is produced through a standardized, shared curriculum and common membership in institutions and professional organizations, and also through craft-like in-person training. Knowledge transfer requires group member proximity mostly for the initial training period. Trust is effected through professional standards rather than interpersonal interaction. Innovation can either be slow when stifled by the rigid organizational structure of accrediting bodies, or disruptive when professionals interact with outside communities.

The third KIA type is the epistemic community. Examples cited are financial trading, global advertising, and design engineering. Group members are experts in diverse domains of knowledge. Their interaction focuses on short-term shared projects rather than common institutional affiliation or the practice of a craft; the group has been constructed purposely to not be homogeneous. Social ties are weak and characterized by "cognitive friction". The epistemic community, while difficult to create given its potential for interpersonal discord, is the only KIA type characterized as always producing radical innovation.

The fourth KIA type is the virtual community. Examples cited are open source software, online teacher training sites, and online patient groups. Social interaction organizes around projects, either long-term in the case of open source, or project-oriented, in the case of sites set up by a brick-and-mortar organization purposely to address a specific issue. Group members are necessarily geographically distributed, fairly anonymous, and in place of the familiar sort of social trust display "commitment at a distance". The authors strike a doubtful tone, conceding that virtual communities are, though different from other CoPs, *some* sort of community—one that is capable of radical innovation. Perhaps a useful supplement to the virtual KIA is the "permanently beta" virtual organizational typology proposed by Neff and Stark (2004), which elaborates upon the "encoded values" driving groups who were traditionally considered consumers to volunteer themselves as producers, forcing concessions from business interests and creating innovation through nontraditional, chaotic processes. Similarly, Cohen (2007) describes virtual communities as possessing a new "sense of social space...[called] networked space" that interacts with real-world space, but frees it of geographic constraints and the geographies of power that arise from physical boundedness.

Amin and Roberts stress the sometimes nonlocal or translocal nature of group knowledge transfer in KIA types. Stakeholders in regional growth and innovation commit a reductionist fallacy to think that facilitating geographical proximity will inevitably lead to innovation. The common platitudes

about geographically-dependent knowledge interactions do not have "sufficient autonomous force to claim a distinctive knowledge practice (e.g. face-to-face equating to trust-based interaction, urban buzz equating to high creativity, or virtual contact equating to relational thinness) (366)". They argue that to pit the local against the global is false dualism, and that social interaction determines proximity rather than geography, shown by the variety among their four KIA typologies. They conclude by suggesting that exogenous regional factors might have a greater influence on local returns than the KIA typology.

2.5 Gaps in the literature

Digital fabrication has existed since the 1980s, but desktop digital fabrication only since the mid-2000s. Digital fabrication as a method of industrial production is increasing rapidly (Gress and Kalafsky 2015), but there is a paucity of research on desktop, consumer-grade digital fabrication technology and interactions with it outside the industrial and manufacturing sectors. It remains a niche technology among members of the public because of the usually-prohibitive costs of the high-end, professional-grade models, and lack of reliability and quality issues on the hobbyist desktop versions (Weller et al. 2015). Though spreading rapidly, the technology's wider breakthrough to the consumer market beyond hobbyists will be impeded by technical and economic factors until they improve.

The technology is in a developmental phase, perhaps transitioning from its infancy to growth; because of this, examining it from the perspective of innovation is just as important as from other angles such as market penetration and capitalization. Gress and Kalafsky (2015) urge research in two types of technological innovation for 3D printing, product and machine. They also issue a direct call for research on what may be considered the organizational innovation that is the makerspace. The technology is associated with the emerging organizational typology of the makerspace. Its organizational characteristics may be as relevant to innovation on the technology as other, material variables.

The ample extant literature on machine tooling, automation, robotics, and other high tech manufacturing cannot substitute for the study of digital fabrication. The literature on firms cannot substitute for the study of makerspaces, although frameworks for hybrid physical-digital organizations are promising. Studies exist of individual content creation in the media cannot substitute for computerized production technologies' direct adoption by the consumer. Digital fabrication creates a unique combination of digital technology and digitally-shaped social organizations that require a similar but tailored theoretical framework to the software and sharing economies.

Given that neither the technology nor the organization have received much attention, it would follow that the specific interaction between the makerspace and digital fabrication innovation has received even less. Within geography, only a handful of researchers have addressed the topic theoretically (Gress and Kalafsky 2015, Bryson et al. 2015). Data collection is almost exclusively based in Europe, ongoing but unpublished as of the date of this publication, and often being conducted by doctoral students (Garmulewicz 2014, Wijngaarden 2015, Pratt 2015). Studies of organizations similar to makerspaces usually examine them as sites of public or private investment as in "innovation hubs" (Friederici and Toivonen 2015) or fab labs (Garmulewicz 2014), or coworking spaces (Parrino 2013, Moriset 2014, Merkel 2015). A specific type of makerspace exists in the United States that does not receive outside funding and is significantly more bootstrapped than some of the European sites, deserving of separate treatment that builds on the European work but customizes it to the different structural and social milieu.

2.6 Research question

This study can contribute to the literature on the geography of innovation regarding an emerging individualized technology of the production of material goods through the use of digital- and knowledge-based processes. These processes are partly developing in a hybrid digital-physical organizational type

that has formed, at least in the United States, in the last ten years. The development of the novel organizational form has paralleled the development of the novel form of desktop technology. Digital fabrication technology is a method of high tech production, but its migration to desktop versions enables the involvement of a wide range of individual and organizational actors in its process and product innovation—often outside of the frame of the commercialization of transactions, relationships, services, products, and processes. The realities of distributed innovation and production in software are just beginning to migrate to hardware: disaggregated and small, but highly networked and regionally concentrated webs of social connections show signs of sophisticated innovation sometimes on par with that larger incumbent organizations create.

This study will explore makerspaces as communities capable of producing innovation in digital fabrication technology from the "bottom up" (Gress and Kalafsky 2015). The choice of makerspaces as case studies appears to limit the scope of the study to a highly local scale of innovation. However, the study's theoretical underpinnings allow for an exploration of extra- and trans-local and relational dynamics. Amin and Roberts' (2008) four knowing in action typologies provide templates of characterizations of groups that learn through practice (Gress and Kalafsky 2015). These typologies can accommodate the complex knowledge transfer around digital fabrication, a technology that is partly being developed outside traditional economic, industrial, manufacturing, and knowledge systems. An examination of group functions can clarify the effect of proximity and process of knowledge transfer internal to the organization, contributing to the discussion of whether innovation can emerge endogenously from individuals in a group setting. By also employing concepts of relational proximity, the study can also consider linkages between the makerspace and nonlocal actors.

The research question explored in this study asks:

to what extent is innovation in digital fabrication technology in NYC-area makerspaces due to endogenous effects of the makerspace organization's knowing in action type?

3. Methodology

The primary goal of this study was to test the research question stated in Section 2.6 *Research question*: to what extent is innovation in digital fabrication technology in NYC-area makerspaces due to endogenous effects of the makerspace organization's *knowing-in-action* type? The study employed qualitative instruments to examine the variables of knowing in action typologies identified by Amin and Roberts (2008). The methodology employed to test the research questions is presented in this chapter, with sections on research design (3.1), instrumentation (3.2), data collection (3.3), and data analysis (3.4).

3.1 Research design

3.1.1 Qualitative methodology

Text analysis of twenty-eight interviews through Mayring's (2014) Qualitative Content Analysis technique is the study's primary qualitative methodology. It also uses descriptive and summary techniques from the multiple case study methodology (Creswell 2007, Yin 2014). A qualitative methodology (rather than quantitative) was chosen for multiple reasons.

Qualitative methodology is often appropriate to a new or little-researched phenomenon that has not had sufficient time to produce enough data to be analyzed at a level achieving statistical significance. Little research exists on the topic of digital fabrication innovation in makerspaces, and what studies do exist do not apply to the sample population in the NYC area (Morse 1991). The technology of desktop, consumer-grade digital fabrication is much newer (i.e. developed within the last ten years) than the industrial version of the technology, which was developed in the 1980s. The social phenomenon of the makerspace has also only arisen within fewer than the last ten years. While databases containing global makerspaces exist, such as Hackerspaces.org and Meetup.com, no large-scale, accurate databases exist of makerspace inventories, memberships, human and financial capital, organizational structure, participant inventions, or product commercializations.

Also, given the geographical region of the study, the population of makerspaces was far below the population size for which Gay et al. (2006) recommend sampling, and for which they instead recommend including the entire population. The population of makerspaces itself, further narrowed by the criteria established for study inclusion, is too small to achieve statistical significance through a quantitative study, leaving qualitative methodology as the more robust option. It allows for in-depth, in-person examination of research questions that could not be achieved with a quantitative methodology such as surveys (Creswell 2007).

The study additionally sought to identify relationships such as personal connections, organizational partnerships, financial agreements, the day-to-day use of technology, and cognitive processes resulting in knowledge transfer that typically result in ambiguous answers and require follow-up questions. Responses were not amenable to quantification. Also, many factors identified in theory that were examined in this study were tacit or embodied in nature. Therefore, physical presence at the site of data collection was required to observe them.

3.1.2 Mayring's Qualitative Content Analysis

The method of data analysis employed by this study, Mayring's (2014) qualitative content analysis (QCA), applies the core elements of qualitative analysis: coding, categorizing, and displaying data in charts (Creswell 2007). The data that it analyzes is all data collected in textual format. The bulk of this data is the twenty-eight interview transcripts of members of six makerspaces in the New York City area. Other text data to which codes were assigned were field notes of participant and non-participant observation, documents (makerspace web pages, Meetup.com pages, and text derived from public email groups and extant written and video interviews of subjects). A detailed description of the QCA procedure appears in Section 3.5 *Data Analysis*.

QCA aims to be a structured procedure that can be applied to both quantitative and qualitative research designs equally, not granting one greater scientific validity over the other. It was developed by Mayring to compensate for the deficiencies of quantitative content analysis of text materials (including transcripts of the spoken word). At the same time as it seeks to be customizable enough to accommodate qualitative data, it is rigidly rules-based. As such, it has been referred to as a "rather positivist" methodology (Dobusch 2015). The methodology of QCA is accompanied by a software program, QCAMap (www.qcamap.org), which was employed in the data analysis phase of this study. This approach is referred to by Mayring as computer-assisted qualitative data analysis. The computer serves as central repository of collected data and as an assistant to their organization, culminating in the assigning of categories. However, it does not interpret or compare the categories. A computer-assisted analysis can also enable the quantitative analysis of text, but that feature of the software is not employed in this study.

3.1.3 Multiple case study principles

Descriptive and summary techniques derived from multiple case study methodology were chosen over other common qualitative methodologies such as phenomenology, narrative research, ethnography, or grounded theory (Yin 2014). This study is not a classic case study for two reasons. First, equal weight was not given to each case in that the number of participants interviewed and other textual data was not collected in the same way for every case. Second, the number of study participants per case was low enough that connecting specific text passages to an identified case would have allowed the personal identification of the participant's identity. The interview protocol developed with the Institutional Review Board prohibited this.

Developing in-depth case analyses of the six makerspaces as "containers" for communities of similar individuals would have been tantamount to an ethnography. An ethnography would have required

a larger number of interviews and more time spent at each case, with an eye to giving as equal weight as possible to each case. Instead, the six cases are briefly described factually in Section 4.1 *Case Descriptions*, and compared to each other. This comparison does not constitute a true cross-case analysis as described in Yin's (2014) *Case Study Research*. The bulk of the methodology instead lies in the QCA method applied to the interviews and other text-based materials as a group.

The study *does* employ certain principles of multiple case study design in the following ways. Makerspaces were chosen as the clearly-defined units of social activity in which to concentrate research efforts. The case, unlike ethnography, serves to illustrate a specific phenomenon as it occurs within the social group or culture. The makerspace constitutes the *case*, while the *function* under study that takes place in the context of the case is innovation in digital fabrication technology (Creswell 2007). The process of innovation in digital fabrication technology was selected as an object of study before the makerspaces were identified as the cases through which to study it. Makerspaces-as-cases were selected for their similarity to one another: the case was meant to be a typical case, rather than an extreme, critical, convenience, or politically important case (Lunenburg and Irby 2008).

3.1.4 Assumptions

Study design and sampling were informed by the following assumptions. The study was conceived as one that could be performed using makerspaces as cases because they are portrayed in the media as always possessing digital fabrication technologies. However, makerspaces cannot be simply convenient containers in which to locate—or serve as proxies for—individual owners of digital fabrication machines. Another assumption the study makes is that individuals are less likely to innovate in isolation than in groups. These assumptions cannot exclude the possibility that a population of individuals unconnected, at least physically, to a larger community of makers is actively innovating on DFT. The study also assumes that innovation in DFT is occurring on some level, even if a small one, in makerspaces. It assumes this only

because they possess the DFT. DFT is itself novel, requires digital design inputs and maintenance, and is inevitably used to produce customized objects that by definition did not exist before. The study does, however, make a distinction between incremental and radical innovation per Amin and Roberts' (2008) framework.

3.1.5 Researcher's perspective

The nature of qualitative methodology is interpretive. The human researcher cannot remove herself from her own assumptions, worldviews, beliefs, and philosophies. Preconditioning will be present and will inevitably influence the research through a Heisenberg uncertainty-like interaction: the outcome of the observation is affected through the act of observation itself (Lincoln and Guba 1985, Fetterman 2010). This section serves as a disclosure of this fact. The researcher does come to the examination of the subject from a critical realist perspective that borders on technologism and eco-centrism, resulting in a tendency to subscribe to technological solutionism. The wider community of hackers and makers also tends to subscribe to these worldviews (Anderson 2012). Researcher influence on a study can be driven by differences in gender, race, age, culture, socioeconomic background, and educational level between the researcher and study participants. The researcher conducting this study, however, is demographically similar to her research subjects in all of these ways, except in her educational, skill, and professional background. Even in this regard, her background in a technical field, geographic information systems, and experience with a common maker activity, unmanned aerial system building and testing, aligned her with participant experience and created common ground during interviews. Notably, though, the researcher differed from most participants in her gender, as all but two study participants were male. This may have influenced the structuring of questions regarding community diversity and participant responses to them.

3.1.6 Generalizability and Cautions

A case study is ultimately idiographic. Case study methodology does not permit generalizability of data to the population level in the way that statistical analytical methodology does. Even the use of multiple case study design principles does not permit generalizability from one case to another, although homogeneous sampling, which was employed in this study, can ameliorate this according to Creswell (2007). This study's methodology reports factually on the participants under study without attempting to state that any other makerspace, region, technology, or innovation process will be consistent with what is found in the study results. This methodology can, however, be repurposed given similar variables in this or other regions (Lunenburg and Irby 2008).

The study's research design brings with it certain cautions. This study cannot measure to a scientific level of objectivity all properties of makerspaces. The variables are difficult to measure, particularly those involving human cognition and communication in the production of knowledge that leads to innovation. Innovation as a variable itself is not defined by absolute or independently-established criteria. Because this study uses a low threshold for consideration of activity involving DFT as innovation, even if that innovation is characterized as 'incremental' rather than 'radical', it may overstate the incidence of innovation in makerspaces.

The study's assumption, though informed by theory, that individuals innovate less alone than networked or in organizations or communities drove the sampling procedure, which excludes individuals that are not affiliated with groups. This exclusion of a population that would have been difficult to access may resemble convenience sampling. The resulting study examines how group dynamics produce innovation—but only does so examining groups, thereby ensuring that the group will be found to produce any innovation that happens to be achieved by an individual participating in the group. The study does not compare these groups to any non-group individuals. It does not provide a control group, or even any other group besides the homogeneous ones selected, for comparison purposes.

This study's findings are limited to the region in which it was implemented, the New York City metropolitan area. It does not compare two regions, much less competing ones, as have Feldman and Romanelli (2013), Saxenian (1994), and Sorenson and Audia (2000). The study region is a unique case in the global and national context: New York City is highly agglomerated, diverse, and networked compared to other regions. Indeed one of the possible theoretical implications of digital fabrication technology is diffusion of production processes. Although much theory does predict a continuing agglomeration of digital fabrication activity, innovative and otherwise, a study that is conducted only in a highly agglomerated region will only confirm agglomeration theories.

Finally, the methodology implemented by this study is deductive in nature, which brings with it a classic tradeoff. Testing data against clearly predefined questions that derive variables directly from particular theories within the literature is more similar to quantitative analysis than more inductive methods. Quantitative analysis is the golden standard of scientific methodology: the creator of the methodology employed by this study, Mayring, writes, "In qualitatively oriented research it is repeatedly stressed that theoretical arguments must be used...technical fuzziness is compensated for by theoretical stringency (41)". The deductive category assignment technique employed by this study assigns categories *ex ante*, so the problem that arises in inductive category formation of whether one person would "find" the same categories in the data as the next person is not a concern. However, if a second reviewer had been employed as part of the QCA methodology, she would likely have assigned different text units to the predefined categories. What deductive methodology gains in validity from "theoretical stringency" it may lose in insight. Deductive category formation derives categories from theory, while inductive category formation forms general, exploratory questions from theory and allows the category formation to arise directly from the data collected. By forming *ex ante* categories, the strategy of deductive category formation may omit data that did not directly pertain to the research questions (Mayring 2014).

3.2 Selection of Participants

3.2.1 Region

This study derived a sample on three levels: region, organization, and individual. The New York City region was chosen because it has shown signs of an emerging digital fabrication technology cluster. The region has been home to an *information industries* cluster since the late 1990s, known metonymically as Silicon Alley, a word play on Silicon Valley (Neff 2012). New York was also historically home to manufacturing industries such as textiles and jewelry, which have been progressively pushed out of the city by rising property prices (Harris 1993). Specialty, low-batch forms of manufacturing do remain in the city (State of Local Manufacturing, 2013), of which digital fabrication is a growing one. Perhaps because of the dominance of the New York media industry in the national discourse on many social and economic phenomena, the success of MakerBot, a 3D printing company that arose out of the New York area makerspace NYC Resistor, is one of the most well-known examples of a desktop-scale digital fabrication company. The city possesses a high and dense population, and also a concentration of makerspaces and makerspace-like organizations such as fabrication shops, research laboratories, and co-working spaces. The study site of the New York City metropolitan area includes nearby Hoboken, New Jersey, a site that is as accessible from the center of the city as Staten Island Makerspace, even though the latter part of New York City proper.

3.2.2 Population

The target population of the study is all makerspaces in the New York City metropolitan area. The target population must be defined, as many organizations that could be considered makerspaces self-identify as hackerspaces, fab labs, or other appellations. This study establishes a set of criteria to select *typical, traditional, or core* makerspaces. The subset of makerspaces in the study area that meet the

criteria are characterized by a nonprofit organizational structure and the presence of digital fabrication technologies. By these criteria, the sample could be thought of as the population within the study area.

3.2.3 Sampling

This study's sampling, like many qualitative studies', is nonrandom, small, and purposeful rather than dictated by mere convenience. The sampling procedure adheres to homogeneous, criterion, and snowball sampling logics based on the researcher's knowledge of the type of group to be studied. The number of makerspace cases was set at six with a target of five participant interviews. The study achieved six case studies with 26 total interviews, or five per makerspace for five makerspaces, and one for the sixth makerspace. This resulted in a manageable, sufficient, and typical number for a multiple case study (Lunenburg and Irby 2008).

Because the case study model used is the typical case, members of the sample were selected for their adherence to a norm for makerspaces, resulting in their homogeneity (Lunenburg and Irby 2008). Makerspaces were chosen because of their similar organizational structures and geographical location.

The following criteria were used to select the six makerspaces under study and the approximately five participants per makerspace that were interviewed. These criteria follow a "norm" for makerspaces as they are represented in the media and through initial exploratory initial research.

Makerspaces:

- are not venues for coding only
- maintain an inventory of digital fabrication technology, defined as equipment for crafting physical objects that is in some way computerized (as opposed to only coding or only handtools)
- do not primarily serve as coworking spaces
- are supported to a large degree by member financial contributions
- are independent
- allow membership to be open to the public
- are in the New York City metropolitan area.

These criteria seek to isolate and distinguish makerspaces from similar organizations. Because the research questions focused on knowledge transfer and a supposedly democratizing technology, the study design sought to exclude an obvious market-based imperative as a factor potentially driving cognitive processes and behavior. The typical-case makerspace does not follow a for-profit model. Also, many other organizations or temporary communities such as meetups in the New York City area exist that also employ the terms 'hackerspace', 'hacking', or 'hackathons', but differ from makerspaces not only in that they contain no digital fabrication technology, but primarily focus on coding and therefore are not obliged to meet the spatial demands of an extensive material inventory.

These criteria notably do not include the makerspaces'—or individual participants'—current active status. Participants did not have to be makerspace members or leaders or meet a certain minimum number of days attending, but only had to have been there in the capacity as a "maker" (most makerspaces make a distinction in their membership models between full members and those who come to "open nights"). Participants were also not chosen by race or gender given the snowball sampling procedure.

Participants were usually chosen based on the recommendation of the makerspace organizer (key informant), who identified participants who would most likely be willing to interview, who were known to have opinions on either makerspaces or digital fabrication technology, or who had experience with digital fabrication machines in the makerspace. Makerspace participants were not chosen exclusively based on whether they have ever used or built digital fabrication equipment, as in some cases, there were fewer participants than five in a given makerspace who had ever used this equipment. Also, much information gathered based on the research questions was not specific to digital fabrication technology and could be garnered by interviewing a participant who was not actively involved in using digital fabrication.

Table 1: Makerspaces included in the study and characteristics of participants

Makerspace	Number interviewed	Number female	Number non-white
NYC Resistor	2	0	(1)*
Alpha One Labs	4	1	1
Hack Manhattan	5	0	2
Staten Island Makerspace	3	1	0
MakerBar	6	1	0
Fat Cat Fab Lab	6	2	2

*This individual was a visitor to more than one makerspace and had been interviewed in his capacity as a visitor to a different makerspace

The demographics of the participant sample were relatively homogeneous: most were white, male, and of a relatively high income level. The notable gender and racial imbalance in the sample were partly a result of the snowball sampling technique, in which makerspace organizers in leadership positions recommended who to talk to based on either availability, perceived interest in participating, or experience in digital fabrication. Organizer recommendations were rarely female or nonwhite, but the population of makers in any given makerspace was reported by participants to be overwhelmingly white and male, with two exceptions. Those participants who used digital fabrication technology were generally even more likely than the total maker population to be white and male. The racial minority constituting the largest percentage of makers was East Asian. Racial minorities constituting the smallest percentages of makers were black and Hispanic. Three black, one Hispanic, and one East Asian participant were interviewed through snowball sampling techniques.

3.3 Instrumentation

The study employed four instruments: interviews, document analysis, observation, and researcher participation. Interviews were open-ended and semi-structured allowing flexibility in the researcher's ability to customize interview questions to the individual participant while maintaining a level of similarity, if not standardization, across participants. Follow-up questions that may not have been originally included in the structured interview question sheet (Section 6.1) were able to be asked, and questions were able to be asked out of order, allowing the interview to become more conversational and for the researcher to elicit higher-quality information.

3.3.1 Interviews

Interview questions were informed by the research question, which was in turn informed by Amin and Roberts' (2008) knowing in action theory (see Section 6.3). The interview questions fall into three themes: organizational information, social interactions, and digital fabrication innovation. Organizational information questions were designed to elicit information about the organizational structure, leadership, management, hierarchy; membership and revenue models; relationships with any outside entities; interior (building layout) and exterior (building location) spatial context; and material inventories of the makerspaces. Social interaction questions were designed to elicit information about knowledge transfer among participants; the relative importance of the community to participants versus access to physical capital; the relative importance of face-to-face versus online interactions; and perceptions of knowledge status of group members. Digital fabrication innovation questions were designed to elicit information about the makerspace's material inventory of digital fabrication equipment; the equipment's typical use and by whom; examples of participants' projects using the equipment; and participants' thoughts on innovation, innovation in digital fabrication technology, and whether innovation in digital fabrication technology was occurring at their makerspace.

3.3.2 Document analysis

Documents that were analyzed to contribute to a characterization of the makerspaces were makerspace websites, makerspace Meetup.com pages, makerspace communication channels such as email groups and listservs, and extant written and video interviews of subjects.

3.3.3 Participant and non-participant observation

The types of observational records made for this study were participant and non-participant observation. The participant observation did not meet the standards prescribed by Fetterman (2010) for ethnography, which recommend an extended period, typically at least six months, of immersion in the organization. Instead, over the course of two months, the researcher made four trips to one makerspace and, along with a female colleague, repaired, partially rebuilt, and tested a small unmanned aerial system quadcopter under the supervision and advisement of a study participant. This part of the study illustrates a characteristic of the qualitative approach, emergent design (Morgan 2008). The participant observation was unplanned and evolved naturally as the study participant continued to offer assistance freely both to us and to others, behavior that is typical of makerspace participants. Non-participant observation took the form of visits to makerspaces in which the researcher stayed for the duration of open hours for all makerspaces but one, and in one instance observed the instruction of a class on the use of band saws.

3.4 Data collection

3.4.1 Preparation

Two initial interviews that constituted a pilot study occurred in October 2014 and February 2015. Data collection then began in February 2015 and lasted until August 2015, a six-month window. Exploratory research preceding the data collection phase began with in-person visits to two makerspaces, one in February 2014 to Fat Cat Fab Lab, and the other in October 2014 to Hack Manhattan. This

exploratory phase also included attending Maker Faire, a well-known, well-regarded convention for makers, in New York City in September 2014, where the researcher spoke with speakers, vendors, and convention participants concerning digital fabrication. The researcher also attended several coding meetups in New York City, which are similar in concept to the makerspace but served to establish the key distinctions between a computer- and software-centered gathering, and a material- and place-dependent gathering later used in the design of sampling criteria. Two interviews constituting the pilot test were also performed with leaders of a makerspace and a makerspace-like coworking space. These interviews, consistent with Mayring's (2014) notion of a pretest of data collection protocols, yielded information about makerspaces in general and in the region that served to develop the study's sampling criteria and change the planned interview question design.

Preparation for the data collection phase involved performing document analysis on the targeted makerspaces prior to initiating contact with them, to include reviewing Meetup.com pages, websites, communication channels, and extant articles, interviews, and videos of makerspace participants. To prepare for the interviews, the researcher usually asked the makerspace organizer or leader for recommendations and contact information for potential interviewees; obtained verbal or written assent from interviewees; selected interview locations to minimize distraction; explained the purpose, format, and length of interview; and during the interview relied on a device (the native voice recording application of the Samsung Galaxy Note 4) to aid memory recall. The interview location was not usually in the natural setting of the organization, the makerspace, to minimize disruption of participants' activity, and was usually set at an independent location such as a cafe or diner, or conducted via phone. A detailed list of questions was prepared for use by the researcher, while a simplified list of those questions was prepared to hand to subjects during the interview. The Hunter College IRB informed consent form, which did not require a signature, was emailed or handed to participants before interviews. They were asked before turning on the recording device for permission to be recorded. Funds were also made

available to the researcher for meals for participants during interviews via a Master's Thesis Support Grant offered to the researcher by the College of Arts and Sciences of Hunter College. Funds were also provided for three months' worth of transportation to sites in the field.

3.4.2 Implementation

First, makerspace organizers were contacted in person on a makerspace open night; via Meetup.com messaging, email, phone; or in one case through a mutual acquaintance to gain their consent for the interviews and ask for recommendations for willing and informed potential interviewees. After permission to contact makerspace participants had been granted by an organizer, participants were approached to ask to schedule interviews in person or via email if an address had been provided by the organizer. The email explained the purpose of the study, provided a link to the informed consent form, explained that funds were available for meals associated with interviews, and requested an interview of between 30 and 45 minutes at a time and location most convenient for the participant.

At the beginning of an interview, the participant was again informed of the purpose of the study and the use of his or her recorded voice. If the interview was in person, the interviewee was handed a sheet of questions that would be asked. The researcher kept a corresponding sheet, but with additional questions on it that were deemed to be optional, potential follow-up questions, or those that would clutter the sheet given to the participant. If the interview was over the phone, the participant was briefed on the types of questions that would be asked. During the interview, the researcher rearranged, omitted, and asked follow-up questions appropriate to the flow of the conversation. After the interview, the researcher thanked the participant, asked if they had any questions, and sent him or her any information requested. The voice recordings made of interviews were then transcribed to prepare them for data analysis. All interviews but one were individual interviews. One was a group interview of five participants

all from the same makerspace. Time elapsed between interviews varied between two days and two weeks.

Participant observation was performed on four separate visits to one makerspace with the objective to troubleshoot, modify, rebuild, and test a small unmanned aerial system "quadcopter" along with a colleague, and under the supervision and tutelage of a maker whose specialty at the makerspace was drones. The maker offered his time and assistance freely to us and to others. The participant observation emerged as part of the study as the maker continued to offer assistance over the course of two months. As the makerspace's policy permitted, the researcher was allowed entry to the makerspace during the day when the makerspace was not open to the public because she was hosted by one of its members. Field notes were taken, producing written material for subsequent analysis.

Non-participant observation occurred on several occasions as the researcher visited makerspaces to recruit participants and observe participant activities. The observation was performed without extensive participation in makerspace activities in order not to interfere with the participants' work. The researcher would quietly open a laptop and go through 3D design software tutorials or unmanned aerial system planning software while making observations. Most other participants are also on laptops during much of their time at open nights. All makerspaces offered one to two open nights per week, in which members of the public were allowed to enter the makerspace with no reservation. Each open night lasted approximately three hours, typically from 18:00 or 19:00 to 21:00 or 22:00. Again, field notes were taken to provide text-based material for analysis.

3.5 Data analysis

The data analysis performed in 4. *Results* is divided into two sections:

4.1 A description of each of the six separate cases that comprise the study.

4.2 Content analysis of all text material gathered as data, primarily the twenty-eight interviews conducted at the six sites, but also documents and participant and non-participant observational field notes. A discussion follows each separate category explored in the content analysis.

Mayring's Qualitative Content Analysis (QCA) is the specific technique for the organization, preparation, codification, and categorization of qualitative text-type data employed by this study as part of its case study design. QCA achieved the goal of reducing large amounts of text data into manageable and meaningful units. It allowed categories to be established to which relevant units of text, or semes, were assigned.

QCA as a method and software (QCAmap.org) offers three techniques for analysis, of which two were considered for this study: summary and structuring. Summary analyses are inductive and appropriate for exploratory research questions which do not necessarily rely on particular extant theories and the variables they specify. They result in the formation of categories from the text itself; the category system then "actually constitutes the findings of the analysis (Mayring 2014, 40)". Structuring analyses are deductive and appropriate for more-specific theories that provide ready-made variables for study. Despite the inductive-deductive difference between summary and structuring approaches, QCA requires a certain level of deduction for both, in that the research questions and general themes guiding analysis are derived from theory. This study's research question is derived clearly-named variables in Amin and Roberts (2008, 364). These variables as appear in their *Table 2, Varieties of knowing in action* (Section 6.3). Because the variables that characterize knowing in action typologies are discrete and clear, they were used to create categories *before* content analysis was performed. This methodology is the "structuring" form of interpretation in Mayring's QCA technique.

QCA obliges the researcher to define and follow a procedural model in advance of coding text data (Section 7.4). For the structuring approach, after a research question is defined, categories and subcategories are defined based the theory that informed the research question. Then parameters are established for coding called the coding guideline. For each subcategory established, this coding guideline contains the definition of the subcategory, anchor examples, and coding rules. After performing a preliminary coding, the researcher iteratively recalibrates the subcategories if needed and recodes the

dataset. For example, the subcategory "declarative knowledge" was eliminated after the first coding because all text assigned to it had also been assigned to "expert knowledge". "Fast and asynchronous interaction" was eliminated because its content was subsumed by "technology-mediated communication". As a final step, categories are subject to the researcher's interpretation.

The rules established prior to coding are laid out in the coding agenda (Section 6.2). Category definitions and coding rules are established for the research question. The category system definition "precisely [determines] which text components belong in a given category (Mayring 2014, 95)". The coding guideline sets criteria for a text unit's assignment to or exclusion from any given category. The system of categorization in this study abstracts categories to two levels: subcategory and category. Because parent categories inherit child subcategories, the definitions for categories reflect the subcategory definitions. For example, the definitions for the subcategories of "incremental" and "radical" are that incremental innovations are changes to products or processes that are limited in scope and impact, while radical innovations are broadly impactful. The definition for the category of "innovation" is therefore changes to products or processes that are either incremental or radical in nature.

4. Results

4.1 Case Descriptions

Descriptions of each of the six cases give their time of founding, location, a description of the space they occupy, general organizational structure and membership model, classes offered, and a description of the digital fabrication tools owned by the makerspace. The three oldest makerspaces describe themselves as hackerspaces, while the three newer makerspaces describe themselves as either makerspaces or a fab lab (fabrication laboratory). Makerspaces are listed in order of their founding.

NYC Resistor

NYC Resistor is the oldest of the regional makerspaces, founded in 2007. It was created by a small group of people from Brooklyn possessing technical skills in electronics who met on a trip to the Chaos Communications Camp (CCC), a hackerspace near Berlin. They imported the concept to the U.S. and were among the first, along with Noisebridge in California, to establish a hackerspace based on the CCC model. An original CCC flag, resembling a pirate's flag, hangs inside NYC Resistor overlooking the central, communal table (Figure 1).



Figure 1: Chaos Communications Camp flag overlooking a common area

Resistor's profile increased considerably because of the successful commercialization of a 3D printer project, MakerBot, that emerged from the space. MakerBot was acquired in 2013 by a 3D printing industry incumbent, Stratasys, that owns 57% of 3D printing market share (Wile 2014), partly because it was one of the most well-known brands of printers to the public (Lee 2015). All 3D printers at Resistor are MakerBots. The makerspace also owns a variety of CNC machines and a heavily-used laser cutter, which is rented out by the hour or minute. The laser cutter was in such demand that Resistor added an additional open night solely to provide access to and instruction on it.

Resistor is located in an industrial but trendy area in Brooklyn near the Atlantic Avenue subway station, a major public transportation hub. It is located on the top floor of a walk-up building whose other tenants are design businesses and artists. Its square footage is greater than many other makerspaces, but is still dwarfed by the largest, Staten Island Makerspace. Members receive large lockers as storage space.

Alpha One Labs

Alpha One Labs was founded by a former member of NYC Resistor in 2009. It changed location four times in Brooklyn, seeking better rent, each time further away from a subway station. Its last location was a storefront space of 1,000 square feet. Since the spring of 2015 the time of writing in the summer of 2015, it has left its last brick-and-mortar location and has developed a mobile bus that can travel among area makerspaces and schools.

Alpha One Labs espouses an educational mission. Its description on Hackerspaces.org reads, "Promoting radical inclusivity, Alpha One Labs aims to provide a fun, tool rich space for users of all ages and interests to work on projects together" and its website describes it as a "New York State Certified Educational Non Profit Organization". Its membership fee had been considerably lower than other makerspaces'. It offered workshops to the public for activities such as assembling 3D printers and soldering.

Hack Manhattan

Hack Manhattan was founded by a member of Alpha One Labs in 2010. It currently maintains the most compact space among cases in the study, and is densely-packed with equipment and parts. Members receive small plastic bins as storage space, while other small bins hold communal tools. Through participant observation that occurred at this makerspace (Figure 2), the researcher was often brought bins containing the precise tool or part needed, and freely given materials such as screws or shrink-wrap tubing.

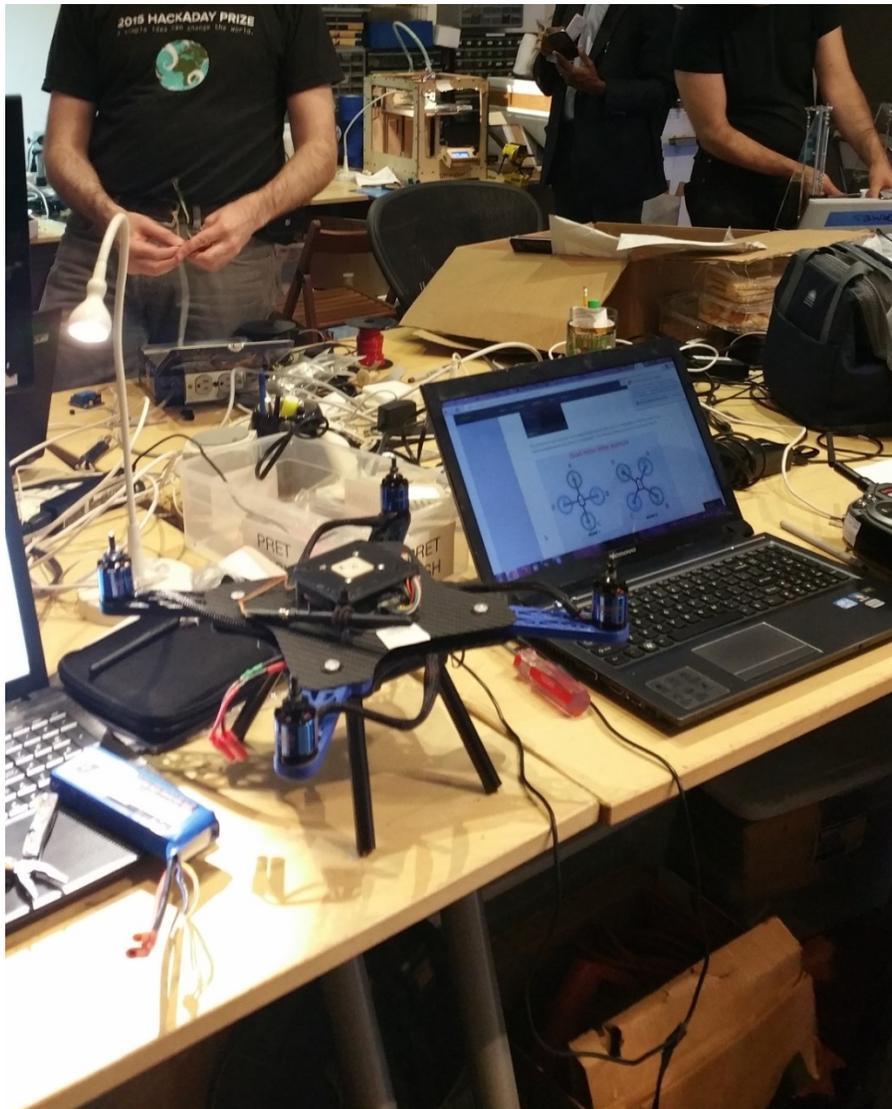


Figure 2: Participant observation – repairing a small quadcopter

It is located on the same block as the 6th Avenue/14th Street subway station in Manhattan, an area of the city with a very high level of foot traffic. Its entrance is not obviously marked and entry is secured by a radio frequency identification and camera system created by makerspace members. Members enter with a key fob, while guests, visible to the camera, are buzzed in. A hardware store that many members make use of and often referred to in interviews lies directly across the street. The space is one of others in a building whose landlord offers a lowered rent to Hack Manhattan and an artists' collective on the same floor.

Hack Manhattan offers workshops to the public and two open nights, Tech Tuesday and 3D Thursday. Classes usually teach a specialized technical skill such as Arduino, building a 3D printer, a music composition programming language, or how to fix broken electronics and appliances. Some classes specify a requirement of some coding knowledge to attend. Because of one member's passion the space also offers a regular Shakespeare reading night and occasional sewing classes.

Under the "Community" section of its website are links to sign up for a heavily-used mailing list and a Wiki, a more or less static repository of information about the space. Members often post arcane technical questions on the mailing list and receive responses from those who have knowledge of it or where to find information elsewhere online. The Wiki contains a list of current projects involving equipment such as CNC machines, 3D printers, and the laser cutter, along to links of profiles of members who are actively working on them.

A small core group of members actively develops individual projects either using or creating 3D printers. These members know of each other and will offer each other assistance freely. One member in particular is regarded as an expert in 3D printers by members of Hack Manhattan. Members of another makerspace mentioned this expert by name and said they refer their own members with serious 3D printing questions to him.

Staten Island Makerspace

Staten Island Makerspace (SIM) was founded by a married couple after hurricane Sandy damaged their metalworking studio. The space is the largest among the cases studied at 6,000 square feet. Some makerspaces occupy only one room, while SIM's large footprint allows subdivision into distinct subareas, each with its own central table for collaboration (heavy machinery, wood shop, freecycle zone (Figure 3), conference room, individual workspaces, sewing room, 3D printing room, and lounge area with leather seating and a kitchenette). A central project room used as a multipurpose classroom, event space, and workspace hosts one large and several small tables that are shifted to accommodate the variety of activities held there.



Figure 3: Communal materials in a 'freecycle zone'

Its location is accessible by ferry, bus, car, or local train system, with no direct connection to the New York City train system. Most of its regular members live on Staten Island. Notably, many regular visitors and members of SIM come from the wider tristate (New York, New Jersey, and Connecticut) area, and other boroughs of New York City. International and out of state visitors sometimes use SIM as a "home base" while they are temporarily in the area.

SIM is heavily influenced by its origins in metalworking and heavy machinery, but is consciously expanding its focus to include more DF. It recently hired a recent graduate of a university program specifically geared toward DFT as an intern to teach classes as part of this effort. Its inventory of DFT includes three printers, a Lulzbot, Replicator2 (by MakerBot), Mendel Max (an open source design); a four-foot by eight-foot CNC router (which three members contributed money to buy, and then assembled and customized), a desktop mill (described as a learning tool); and a laser cutter that will be placed on a truck that will travel to schools throughout the metropolitan area.

At the same time it was founded, SIM won a contract from the New York City Economic Development Corporation as a business incubator. It has also pursued several other sources of funding available to nonprofits. The founders initiate and pursue many of these contracts, with input from an advisory board. Because of this focus on fostering businesses, workspaces are rented to entrepreneurs rather than hobbyists, and the makerspace management actively assists them with some business needs. Its membership and participation model is event- and workshop-based: it hosts open build events, free public events, and low-cost workshops. It also pursues a large number of partnerships with other organizations such as libraries and schools, most recently a month-long program for a school group that travels twice weekly from Queens.

MakerBar

MakerBar was founded in 2012 and is located in Hoboken, New Jersey. Hoboken is geographically close to and easily reached from Manhattan, but the makerspace is located several blocks from the nearest train station. Its membership is largely local, but its members are mobile, often visiting other New York City area makerspaces. It is the second-largest of the spaces and contains some heavy machinery. Their Replicator2 (MakerBot) and Delta 3D printers receive heavy use by members. One member is assembling a CNC router.

Its membership base is largely composed of those with formal educational backgrounds in engineering and computer science. Members cited the proximity of Stevens Institute of Technology as an influence on the composition of the membership. However, MakerBar hosts a notably large number of diverse classes, including those on handicrafts such as sewing, chocolate-making, and soap making. Classes are publicized heavily on Meetup.com

Classes offered on DF technologies are often provided in partnership with companies that provide DF equipment. These companies seek visibility for their products and content marketing. Instructables, an online division of Autodesk (a market-leading vendor of computer aided design software) devoted to providing step-by-step instructions for a variety of activities, exchanges products from companies in exchange for MakerBar members' posting instructions for the products' use on the website. Other companies send speakers to the space, or sponsor food. The relationships between MakerBar and companies allow the makerspace access to free tools and other products, publicity, and increase its number of visitors.

Fat Cat Fab Lab

Fat Cat Fab Lab is the newest of the makerspaces. Though it was founded in 2013, it began offering monthly memberships of the kind offered by most of the other makerspaces on July 31, 2015. The introduction of the membership model coincided with the completion of renovations to a new, fairly large space within the same building in Greenwich Village. Prior to the renovation, the organization existed in three small rooms, was run by a small core group of founders, and visitors to open nights. Unlike other makerspaces, it has retained the professional services of a makerspace consultancy to develop its organizational model.

Fat Cat Fab Lab maintains a close relationship with the Fat Cat Jazz Club, a large lounge offering a bar, live music, and games such as pool and ping pong. At least one owner of the club was a founder of the fab lab. The fab lab and the club share a lease in the building they both occupy (the club in the

basement and the fab lab on the top floor). The lounge promotes the fab lab's events through its own website. The fab lab's organizers view patrons of the lounge as potential patrons of the fab lab: "[W]e see the lab as an extension of the club. Instead of playing pool and listening to music, people upstairs can fabricate and hack objects. [It is] a different kind of learning and hanging out."

The space is equipped with core digital fabrication equipment: three 3D printers, a laser cutter, and a CNC mill. Fat Cat offers classes on the use of this equipment; the most publicized class is for the laser cutter. It offers one open night a week, but as it is the newest of the makerspaces profiled and is in the process of transitioning to a novel organizational model, its weekly schedule has not been established as of the time of writing (August 2015).

Comparison of cases

Makerspaces in the study shared similar layouts. Large, central worktables were common. Storage was at a premium, and materials were usually packed together tightly. Individual members were often allotted space in plastic bins or lockers (Figure 4). In one case, they could rent workstations (Figure 5).



Figure 4: Organization of materials and equipment



Figure 5: Independent workspaces rented to members at one makerspace

Makerspaces as organizations can exist along a spectrum of emphasis on purely handtools or purely coding. All cases in this study do maintain an inventory of physical equipment (Figures 6-10), some of which is used for digital fabrication and requires some knowledge of coding (such as Arduino or Raspberry Pi) or computer aided design to operate.



Figure 6: A laser cutter



Figure 7: A CNC mill



Figure 8: A CNC lathe protected by a case

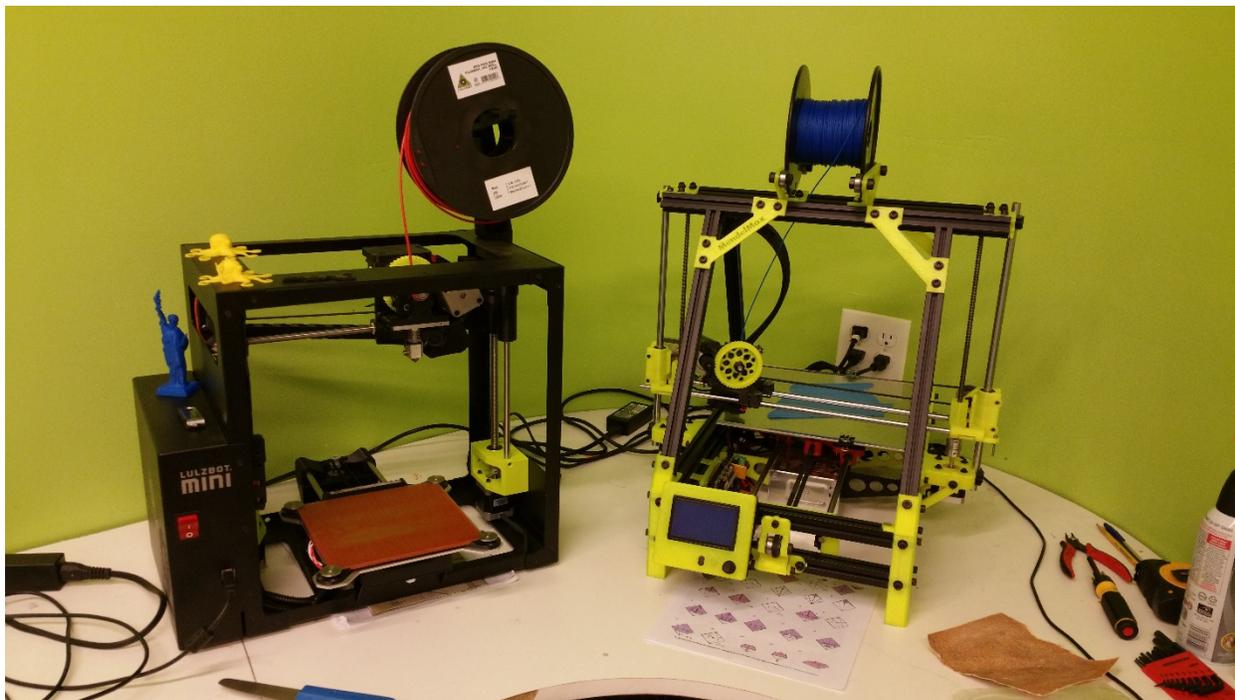


Figure 9: Lulzbot Mini and MendelMax 3D printers (the MendelMax is an iteration of the RepRap, the original open source 3D printer)



Figure 10: Two generations of MakerBot 3D printers

All cases but one were 501c3 nonprofit organizations; the sixth is in the process of filing its 501c3 paperwork. All had similar membership structures, with fees charged to officially-inducted members. Fees averaged roughly \$100 per month, and were discounted for students and instructors. The established makerspaces had memberships of between thirty and fifty full members.

In three of the cases, artist's shops or collectives occupied space in the same building as the makerspace. In two cases, there was a small amount of flow between the artists and makerspaces. All makerspaces' memberships were primarily composed of those with technical backgrounds, though they all had members who were artists (some were digital artists and others craft-based).

In each case, members spoke of "the community" in three distinct ways. They referred to their own memberships as a community. They referred to the global network of those self-identified as makers and hackers as a community. They also referred to the immediate neighborhood surrounding the physical building the makerspace was housed in as "the community". Members often expressed a sense of obligation toward, or desire to connect with, this local community.

Use of equipment that was observed in all makerspaces was sewing, tabletop sawing, soldering, 3D printing, laser cutting, and CNC machining. 3D printers were generally considered a cheaper, more accessible, and more common form of DFT than lasers and CNC machines: "my direct group of friends in the maker scene, few of them have seen laser cutters and CNCs - it's very very rare." While all makerspaces in the study had laser cutters and CNC machines, usually at least a CNC mill, more members had experience with 3D printers. Most had some basic woodworking capabilities even though woodworking was not a well-developed function of the makerspaces, with the exception of Staten Island Makerspace. Despite the capabilities of digital fabrication to produce highly specific objects such as customized parts and scale models (Figures 11-12), DFT often required the use of analog or power tools such as woodworking tools in order to create parts or other pieces useful to the creation or testing of an object.

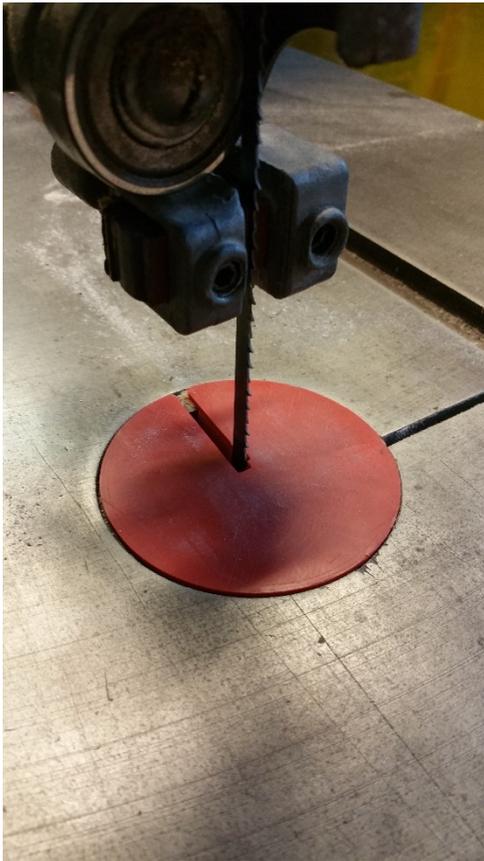


Figure 11: A guide piece for a band saw



Figure 12: A to-scale model of a product

Although many participants described a chronology and lineage of makerspaces in the New York City area, and situated them within the broader global makerspace movement, one participant summarized it succinctly. He identified three waves or eras in makerspaces. 2007 stood out as the year that "the hackerspace design patterns migrated from Germany"; this wave lasted until 2009 and was highly influenced by the philosophy of the original German hackerspace. "Second wave groups" emerged between 2009-2012 and, according to the participant, were characterized by diversification of income sources, participant demographics and skill backgrounds, and community participation and outreach. From 2012 to the present in mid-2015, models have undergone "massive diversification" and exhibit "maturity" while maintaining a "common operational and philosophical framework underneath." Some partner with large for-profit and nonprofit institutions, form co-ops, and even appear as a line item on real estate development plans. The six cases included in this study may roughly fall into this three-wave classification. The newer the makerspace, the more likely it is to pursue exogenous partnerships and funding (half mentioned DARPA as a past or possible source of grants).

4.2 Qualitative Content Analysis

A presentation of the results of the Qualitative Content Analysis categorization follows. Four main categories, 4.2.1 type of knowledge, 4.2.2 social interactions, 4.2.3 organizational dynamic, and 4.2.4 innovation are presented, along with each of their subcategories.

The material provided by the participants are factual descriptions of materials and organizational policies, and are also subjective interpretations of the topics presented in the interview questions.

Italicized words within quotes are my emphasis, not the participant's. Brackets contain information the participant was referring to at the time he was speaking or questions posed by the researcher.

4.2.1 Type of knowledge

The category of "type of knowledge" is divided into (kin)aesthetic or embodied, expert, and codified knowledge. Knowledge is that knowledge related to the activity at hand, which is the use of digital fabrication technology in this study. This knowledge is possessed by individuals, acquired by individuals, transferred between individuals, and possessed and circulated on the level of the group. Individual knowledge is meaningful in this framework in the individual's capacity as a member of the community. The knowledge that is highlighted here is that which is at some point passed from person to person, whether directly or indirectly, formally or informally.

4.2.1.1 (Kin)aesthetic or embodied knowledge

Participants consistently identified a physical, kinaesthetic, embodied component of the process by which they learned new skills and interacted with technology in the makerspace. The physical nature of their interaction with DF was usually contrasted with a purely digital interaction with either the technology or others.

"But you can't test [things in a virtual environment]. You can't see if they're going to wear out, heat up, or short out."

"I can show you a picture of the half scale printer that looks just like the full scale printer but that's not interesting. We're 3D printing things. We have to pick them up and touch them."

"Picking something up is really different from a picture. A picture worth a thousand words, so the real thing is worth even more."

The physical nature of learning was partly driven by the limitations of the technology; being mechanical, it tended to break (Figures 13-14):

"Companies benefit from makerspaces because they're free testers - how good materials are or machine, drop it off in the morning and see how long it takes for disaster to strike."

[What do you do with 3D printers?] "I repair them. I take them apart to fix it. At school I set up part of them. 3D printers have to be constantly repaired."

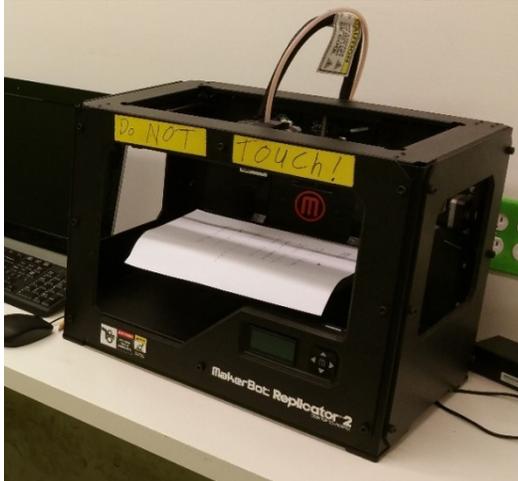


Figure 13: Signage warning against touching

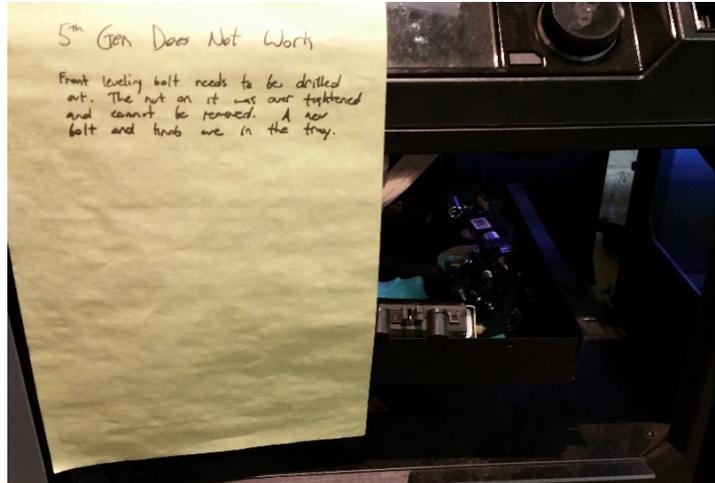


Figure 14: Signage describing nature of the problem

Observation was crucial to understanding the kinaesthetic component of learning, which by its nature requires presence. The use of most materials and equipment in a makerspace involved the senses of smell, sight, touch, sound, and even taste in the case of beer and algae brewing. 3D printing plastic gave many makerspaces a similar, slightly sweet odor of molten plastic.

The use of electrical equipment brought with it the risk of fire, and participants seemed to be alert to changes in odor. In one case, a participant being interviewed asked another participant if he smelled toast. They were relieved after they identified the odor as coming from the laser cutter, which was being used on balsam wood. This laser cutter was housed in its own room equipped with do-it-yourself ventilation and camera systems. Strong chemicals were often used. One participant cleaned a piece to a milling machine with kerosene for the entire forty-five minute interview. Acetone baths were said to be used on completed 3D printed pieces, and were spoken of with respect for its flammability.

Participants often spoke of the "feel" to what they were doing, and how it allowed them to avoid breaking things or endangering others' safety. During participant observation, the researcher struggled to attain the fine-grained, precise, and smooth control of the flight of the quadcopter, which the sponsor was able to fly in circles only inches above the ground in a small recess of the makerspace. For this activity, we wore safety goggles given that the difference between losing and keeping an eye, whether

one's own or others', could be a millimeter's worth of movement of the thumb on the transmitter lever. At one point, the researcher was unable to judge where to place a component on the frame of the quadcopter so that it would not cause an imbalance. The researcher was unable to identify the center of gravity of the frame, but the sponsor and mentor was able to balance the frame on his forefingers and gauge where to place the component.

Pieces produced with 3D printers were tested for fit with the object they had been customized to. If the fit was not tight, the piece was discarded. Participants assembled, tested, and became familiar with objects by weighing them in their hands, shaking them, and rubbing them. Sometimes "feel" was described in terms of an intuition about a certain piece of equipment: perhaps it was about to break, or was uncomfortably dangerous to use. The uneasy feeling some equipment imparted into certain participants was notably related to heavy equipment such as band saws.

During observation, makerspace members who the researcher was not directly engaged with often passed by and briefly gave unsolicited but desired advice about what something looked like. Visual inspection was key to operation of DF equipment. Molten plastic often accumulated around a 3D printer's extruder during the automated printout of a digital file, and the job had to be canceled and nozzle cleaned. Material placed in a laser cutter had to be precisely positioned so that the design applied by the design file was placed correctly on the material.

Another sense employed by makerspace members appeared to be a sense of spatial orientation. The researcher observed many occasions on which a member needed an item, but could not remember either its name or where to find it. Members were observed often asking another member for an item, and the second member would rise and, seemingly guided by a sixth sense, find his way to the item based on what appeared to be a spatial memory of the complicated layout of densely-packed makerspaces.

4.2.1.2 Expert knowledge

Most participants, whether or not they considered themselves to be experts in the activity or technology they were engaging with at the makerspace, had university educations. Many had advanced degrees in subjects that were directly or tangentially related to technologies at the makerspaces, such as electrical, mechanical, or software engineering. They generally knew more about one technical or artistic domain than either the general public or any other participant at the makerspace.

Only three had formal education specifically in DFT. Of them, two were entrepreneurs in DF and no longer actively involved with the makerspace because other spaces were better suited to their material needs. The third was a recent university graduate and had sought out and begun an internship at a makerspace:

"My degree is kind of in manufacturing, and a lot of people in this field go into manufacturing but I want to go more toward makerspaces."

Expert knowledge plays one important role in the makerspace: it allows makerspaces to offer classes.

"Makerspaces tend to be clients or people wanting to learn skillset I already have - so I'm an outsider looking in."

"This technology [DF] was being underutilized at [the makerspace].... There wasn't anyone at [the makerspace] prior to me. I think I have a more complete understanding of how the machines work, conceptually, more than someone without a formal training. The first day I got to [the makerspace] this summer I instantly jumped right in and instantly started using everything." [This participant was scheduled to begin his makerspace's first classes on the use of DFT].

4.2.1.3 Codified knowledge

Participants all made extensive use of sources of codified knowledge, most of which were obtained by "googl[ing] it". Most makerspaces also had a small library of books on topics such as electronics (Arduino, Raspberry Pi, circuitry), coding, sewing, woodworking, and beer brewing. During one interview, a conversation between two members occurred in which one gently chided the other for the "useless" and extremely large and heavy electronics book he was holding; he then offered him the entire

book series in electronic format. Many noted that digital codification of knowledge had made their pursuits possible in recent years:

"If I want to make something like a circuit board I should ask the internet if it already exists".

"It's much easier now to learn something without an engineering degree. You can go on YouTube and watch a few videos."

"I simply avoid forums and things like that. To me it's absolutely no appeal. *I'll look for information other people posted.* I don't want to participate, don't want to make an account."

Most mentioned their extensive use of open source information:

"The market breakdown. You have your diehard Rep Rap people - that's the original movement.... People would put the schematics up, share the info, that's what created some of the first desktop, easy-use 3D printers."

Participants were active users of, contributors to, and proponents of open source DF designs for machines and products that could be made with DFT (Figures 15-17). One makerspace's refrigerator had been covered with pro-open source stickers (Figure 15), and members were involved in the operation of the Open Source Hardware Association.



Figure 15: Stickers on refrigerator, including many for open source software



Figure 16: Sticker supporting online freedom



Figure 17: Stickers supporting open source software, including a sticker for the Noisebridge hackerspace

4.2.2 Social interaction

Social interactions as a category contains within it many more subcategories than the others derived from Amin and Roberts (2008). It is divided into three subcategories: proximity and nature of communication, temporal aspects, and nature of social ties. Social interactions are affected by different types of proximity, two of which, colocation and face-to-face communication, require physical spatial proximity. The other types of proximity are less dependent on, or independent of, space. The temporal aspects of social interaction mirror those of proximity: some require or are enhanced by spatial proximity, while others can seemingly operate independently of it. The subcategories belonging to the category "nature of social ties" all reference types of trust. Forms of trust are related to the amount and spatial dimension of contact between people.

Data collected on social interactions within makerspaces did not confine those social interactions to the use of DFT. All participants were asked about their own interactions, their perception of others' interactions, and their estimation of the typical, common forms of interactions in their own and in other makerspaces.

4.2.2.1 Social interaction: Proximity and nature of communication

4.2.2.1.1 Colocation

Colocation is a more complicated subcategory than others defined in the schema. It produced many textual units with different meanings. These extended meanings were extrapolated from the concept of colocation despite the limiting nature of the coding guideline developed through the QCA methodology in order to take advantage of important concepts that participants expressed repeatedly across makerspaces. Colocation at its simplest, and as Amin and Roberts intended, is defined to mean that community members engage in an activity physically in the same location. However, for a makerspace, many spatial and geographic factors contributed to whether colocation was possible at all.

The sometimes-tenuous existence of the physical space, enabler of participant colocation, emerged as an often-repeated narrative.

Most participants reported that physical presence in a space with other members of the community allowed or enhanced their activities because it created face-to-face contact (next section). However, they almost uniformly said that the reason they came to the makerspace was twofold: it contained equipment *and* a community:

"So coming to a space like this does give you access to almost every tool imaginable but also to people. The people at the end of the day are what really kind of what drives this as a community organization and makes it really important."

"A lot of times living in a big city you wouldn't find people like that [who would help you build a bookshelf]. And they wouldn't have access to tools either. So go to a place where people have access to other tools and people and similar interests, it becomes multiple things."

Explanations of why being in the same place was helpful were partly social, and partly conditioned by the material nature of the technology:

"I think show and tell is a big part of it. We feel proud of what we do and want to show it to people and we've been doing that since elementary school."

"It's tangible. It's definitely real stuff. People ask questions about what I'm doing.... I'll be able to explain, there'll be more ideas coming out of it. I was trying to make a printer and then somebody came in and they came up with a bill of materials to see how much it would cost and it was good to have someone interested who helped. Another guy helped me build a little 3D printer."

While most participants thought physical colocation was a necessity, most also had clearly given much previous thought to the difficulty of obtaining and maintaining a physical space in the New York City area—a difficulty directly related to the cost of rent:

""In New York City it's very difficult. Metal filings on the bed are not comfortable. It's mainly space. If you had a backyard, you wouldn't need to come to a makerspace other than to meet people from the community."

"It's so hard to have a makerspace. You need rent coming in. It's hard... New York rent is ridiculous, that's the big thing."

"Even if they get together and do a startup and find a space that's directly related to their work - it's not hard finding a space, it's hard keeping it. You have to raise the money to pay the rent. This is one reason these coworking spaces are so big now. You can pay \$400 a month and get a coworking space - that's why they're popping up all over. But once you expand, you need office space, overhead costs, it all adds up eventually. The trouble is you're not getting an income, or it's not enough for the space. It's a big problem in NYC."

"Well when you don't have enough people to pay the rent, at some point you cease to exist."

"In a realistic market like New York it's so hard to find a place to the point where we all just have to agree we're gonna have to be underwriting these things in some manner."

Besides the binary question of whether a space could exist, its size emerged as an issue. The largest makerspace by far, at 6,000 square feet, was also the makerspace with the most heavy equipment and one that struggled less than others to make rent. Members of the smallest makerspace noted that it was a typical size for a New York City building. One member said that the size of the space had been doubled in the time since its founding, allowing much more equipment to be brought in and a woodworking area to be created. The overall size of the space, with the expansion, still left it the smallest among the six cases.

"...[W]e're bound by our locker space. Either we run out of lockers or we stop inducting members for a bit."

Geographic location of the makerspace also posed an existential threat or benefit. The makerspace that currently does not have a space in a building had moved location four times in almost as many years, each time farther away from a subway station. The last location was particularly far and membership fell to the point where rent could not be paid. The largest makerspace that struggled less with rent than others was also the furthest from the city center and not quickly accessible by the public transportation system. Many participants from other makerspaces remarked that they had not been

there and did not plan to go because of its location. The one makerspace that reported members visiting the farthest makerspace was also outside of the city in an area where many members had cars. A successful space was located in a fashionable area near a large subway station:

"This location has been in part a key to our success. And just sort of key to us continuing to function well."

"We got really lucky with the space we're in right now. We got a good deal on the lease, which is why we can have this much space in an area like this.... I don't know how we found it. We got lucky."

"So we actually recently accidentally performed this experiment ourselves.... We came into ownership of a large amount of heavy machinery.... And a subgroup of the members decided to try to essentially make an additional offshoot of the space...in which to store this material because it was all very valuable machinery and a lot of us wanted to be able to use it. The space we ended up being able to find was...[s]o far out...the project failed...because no one went. Because it was just a pain to get to. So a large part of our success is our location, and we sort of recognize that, right."

Some participants speculated on solutions to the city-specific problems of rent and space. One suggested that a tradeoff exists between rent (and therefore space) and location:

[Question: should the makerspace physically expand?] "I actually mean geographically. Some of these places are rent focused. They get cheaper rent by being in places that have no transportation.... So the physical space gets built out, or they move to a place with more expensive rent with better exposure."

"I always felt if a makerspace was successful would have a prime real estate. The Makery in Boerum Hill was a donated space [with a] storefront. That storefront really changed the public environment. You had a 3D printing robot drawing on the window with a dry erase marker, and you just saw people's eyes light up."

Others suggested that makerspaces be less dependent on a permanent, fixed space:

"[In regard to makerspaces that have closed their doors] Some of the makerspaces have more of a kind of popup model, that's kind of in their nature."

"[A mobile makerspace concept is] a way to get around the rent and location issue and tie the makerspaces [together] again."

"I have a community [several meetup groups], but no space. We're looking at partnering with places like this so the community can have a place to meet at."

Some participants offered the opposite perspective of most: they asserted that the makerspace was not necessary either for access to others, to knowledge, or tools. This perspective was shared by almost all participants who were actively monetizing or seeking to monetize their DF knowledge.

4.2.2.1.2 Face-to-face communication

Participants often spoke of "face to face" contact without prompting when asked why they came to a makerspace. Although the term "face-to-face" is used throughout the literature, it is a phrase of common usage and was readily understood to mean in-person, close, and immediate communication. Many descriptions of the connection between face-to-face communication and accomplishing their goals using DFT were about tacit social signals:

"Interaction with people face to face is still very important.... Face to face you can read their emotions, see their face, hear their voice."

"I have you in front of me, and I'm talking to you, and when I say something I can see how you react, I can see how you move, how you think, and so I know if I need to press a point how to press it, or if I need to back off on a point how to back off on it. And so through those subtle social cues you can get stuff done a lot faster."

"...[I]t also gives you opportunities to collaborate, something that you might not necessarily have with Google."

Several offered a functional reason for seeking out face to face communication. It is "efficient":

"When you walk into that space it's amplified. Whatever capacity you have.... You can borrow parts from each other. These guys completely understand any point I'm trying to make, I'll be right or wrong, but I'll get to the answer faster."

"It's just easier to share information. Electronic communication, as much as it's made the world smaller, it's less efficient I find usually."

However, it is important to note that not all participants engaged in face to face communication merely as a byproduct of colocation. Indeed, some observed that certain visitors or members rarely spoke

to anyone. Some participants speculated that face to face communication was hampered by certain personality traits members commonly possessed:

"I don't notice that I care about other people's projects. I think they care about my projects when they talk to me. We have a general interest that we don't care about. We don't worry about if a project is enough. I'm not being tested to see if I'm being social. We're all introverts and antisocial and live in caves. Showing any interest at all in anyone's work is great. There's a large percentage of introverts."

4.2.2.1.3 Relational proximity

While participants were spatially proximate to other participants of the same makerspace, they were also socially proximate. Many spoke of forming friendships with other members, and of enjoying the similarity between themselves and the type of person that came to makerspaces:

"...[I] went there to meet likeminded people."

"People miss their friendships [in an increasingly virtual world]. There's a social need."

"Unless you're really well educated and financially [successful]...usually you haven't been surrounded by people of the same intellect and lifestyle [that you find in] hacker communities."

"...[I]f I ever want to use one of them [another member] they're the person I talk to, and I know them, and we're friends and we have this connection."

Others believed they were easily able to communicate because they had similar skills:

"[Laughs] We're all pretty good with computers here."

4.2.2.1.4 Technology-mediated communication (face-to-screen)

Communication among members of the same makerspace outside of their face to face time was almost always facilitated by an email group, some of which were partly public. This communication often served to organized in-person gatherings, but also allowed makerspace participants to ask technical, often arcane questions. Other plans were made and relationships formed:

"I'm going to write a book with [someone I met in the makerspace's chatroom]".

Participants reflected that the fact that they could potentially see someone they communicated with in this way in-person affected how they communicated:

"I might want to ask something in a forum but I want an answer right away. These people on the other end...the people who are ready to answer right away are the ones who have no lives. Then there's flame wars. The people are real on [the makerspace's email group].... We might actually have to meet each other in person. We don't want to say something we don't really know."

Communication between the makerspace and members of the public was always facilitated by the makerspace's website and, in all cases, also by a page on Meetup.com. All makerspaces but one actively posted open nights and classes on Meetup.com. Two makerspaces exploit meetup more than the others, offering a variety of ever-changing classes each week.

"We like Meetup. You can throw anything on Meetup."

However, many members criticized digital communication as they praised face to face communication:

"Before I lose this thought, I'd love for you to prove to people that online networking is not adequate."

"Electronic communication, as much as it's made the world smaller, it's less efficient I find usually."

"Sometimes it's not enough to watch a video."

4.2.2.2 Social interaction: Temporal aspects

4.2.2.2.1 Long-lived

Makerspaces can be places of long- and short-term social interaction. The oldest makerspace was founded in 2007 and is currently only eight years old; the rest are between one and five years old. Already, the incumbent makerspace maintains the longest relationships. Age brought with it the benefits of a larger network of connections, many of whom were former participants or members:

"...[W]e know people in the maker community because we've been in the maker community so long."

Another makerspace noted that attrition in membership, which caused temporal breaks in the continuity of relationships, had an effect on the nature of social interaction:

"By moving to this location [as membership has dropped], the energy has fizzled out."

4.2.2.2.2 Slow changing

Despite makerspaces' youth as a class of organizations, a small number of participants describe a phenomenon of increasing inertia in social interactions, even within the span of two or three years:

"A big part of it is getting new people and new minds acting together. If you've existed for too long none of the minds are new to each other.... It's the same with a college. It's like the freshman class and you just never let them leave. You get stagnant."

"...[I]t is very easy for an organization like ours to become very...um...rich white male."

For one makerspace, the slow pace of membership turnover (a new member about once every three months) offered the benefit of a strong community:

"The goal is that you feel comfortable with all the members, which is a difficult thing to achieve. It takes a lot of time. Because of that, we don't really have people who stop being members."

Some mentioned, though, that classes are the primary way a makerspace brings in new members and new ideas.

4.2.2.2.3 Apprenticeship-based

As will be discussed in 4.2.2.2.4 *Develops socio-cultural institutional structures*, makerspaces typically espoused an ethic of individualism and noninterference in others' projects, although they freely offered help on an as-needed basis for specific problems a member had. Makerspaces almost never have a classic apprenticeship model given that they do not, as organizations, seek to train or employ individuals. Still, most makerspaces depend heavily on classes for new members, who bring with them

revenue and new ideas. The one makerspace that was founded at the same time as it obtained a contract with the city's Economic Development Corporation as a business incubator does teach classes in order to train local residents for jobs, and actively encourages and assists entrepreneurs coming to the makerspace to pursue business plans. This training been in heavy industry skills and the makerspace does have plans in to increasingly offer training in DFT.

4.2.2.2.4 Develops socio-cultural institutional structures

Makerspaces formed complex cultures. To illustrate the nature of the cultures that have emerged within makerspaces, a few common narratives that emerged from participant interviews are listed below.

- *The maker or hacker as doer and builder of things.* Participants often used the word 'tinkerer' to describe a typical member. Members were characterized as people who naturally desired to do things themselves (Figure 18) in defiance of or in contrast to large corporations (Figure 15). The narrative of the hacker is characterized as much by what it is not as by what it is. Participants commonly discussed the negative connotation of 'hacker' in the public mind and believed it to be a misperception. One makerspace had difficulty obtaining insurance because the underwriter was put off by the word hacker. Another rebranded a proposed facility to take "hacker" out of its name. One participant spoke of writing 'maker' on his nametag rather than 'hacker' to avoid having to explain himself repeatedly.



Figure 18: Self-repair manifesto

- *An ethic of self-reliance, independence, and self-improvement.* Most participants made comments suggesting that they felt their participation in a makerspace benefited them by freeing them to take actions and make things that were personally fulfilling to them. These narratives focused on the individual and the independence the makerspace-as-organization allowed them.

"It's a do-ocracy around here. If you want to do it, do it."

"They are funky individualists."

"The core philosophy is kind of like a gym in a sense."

"[It's like] a health club for the brain."

"That's one reason why makerspaces are very popular. They allow people to be creative in their own way, nurture their own ideas."

- *Purism through self-regulating ethical behavior.* Many members believed that issues that related to money were dangerous to the organization, and that reducing the organization's and members' interaction with matters of money ensured the continuing trust, comfort, and confidence members could have in the makerspace.

"...[T]hat's the culture of the space. In this space here we all have an understanding we're not here to do those backdoor deals. I don't feel the culture here is of that."

"I think that we're reducing the chance that there's an issue, because money makes people do stupid things. Uh, very consistently. I think we started with that understanding. We don't want it to get in the way. We want enough money to be able to function but that's all we need. Large purchases we get together and pool money and buy things like the [names DF equipment] - a bunch of members got together and bought that."

A small number of participants who were also entrepreneurs in DFT maintained a counternarrative to that of the ethical makerspace, saying that their aversion to money—what one participant called "strong resistance to commercialization"—was ill-advised.

"[A makerspace that only exists for a short amount of time is] almost like the purist idea, like what everyone runs a makerspace kind of wants, where it's not about the money but about teaching people, you don't have to worry about staying open, you just do it and it's done."

"[X] wanted it to be a nice tight community but didn't want it to be too expensive for individuals.... But being nonprofit you need to make money."

"A lot of people don't want to start things, they don't want to be involved in it if you do get money. Say someone gives me money, that means I wouldn't be able to do the job I do, I would never be able to touch a laser cutter again, so that's a problem with growing.... Because they're in relationships with people there, often they're close friends, and if they get money...then the rent goes up for everyone."

"Stuff on Hackerspaces.org has a philosophical cast, that anti-capitalism ethos, it's infused with all of that stuff."

- *Exceptionalism*. Another cultural narrative mentioned often enough to be noteworthy is that of maker exceptionalism in motivation, perception, vision, understanding. The maker's attributes were often contrasted with those who lacked them:

"The typical American is [expletive] lazy."

"I just don't think enough people have the initiative to [make their own things with DFT] in this country."

"No, I think that's very rare [that people that come into the makerspace have the vision the participant possesses]."

- *Communal harmony.* Almost all participants offered a narrative of cooperation, collaboration, friendliness, and camaraderie among makerspace members, nonmembers and visitors. They shared tools, supplies, and ideas freely. Most even said they would not bother patenting any of their current or past projects.

"Its' not like all flower child, peace, love, and harmony. On the other hand, it's pretty nice."

"Other people would just want to help, no project in mind, just want to join someone else's project."

- *Division in the community.* When participants spoke of community diversity, they usually referred to diversity in areas of expertise or the focus of one's projects. Differences in preferred projects implied diversity in member skills, backgrounds, and for some (though not for others), gender. The narrative of a division in the community between soft hacking (that tended to be more analog or incorporate fabric or traditional crafts) and hard hacking (that tended to be more electronic or mechanical) contradicted the narrative of communal harmony that many participants expressed.

"It...depends on the community. In many cases crafting is more social - knitting and coffee - whereas some...[are] focused on 3D printing and tech. You find entrepreneur people, heavy engineering type attitude, that goes along with traditional hackerspace. But the moment you walk in and do soft circuitry they stare at you like you have three heads.... It's a divided community. You have art backgrounds and engineering backgrounds. It can work really well or bomb."

"People should be allowed to learn new things, learn on their own. The idea of respecting diversity. Yesterday I got mad at someone who was acting in a discriminatory way. He said that person he was referring to doesn't hack the way you hack. You don't discriminate that way. They had different lifestyles. Forget the drama, whatever, but it was like a hacker's way of saying it. Some people may hack this or that, may hack fabric. We used to have photography equipment.... You have to fight to

keep people equal because people are all walking in with their knowledge set and they think they know everything. I've dealt with that all my life, I always knew a bunch of tech and others didn't."

4.2.2.2.5 Short-lived

Participants often came to makerspaces with a project in mind. Makerspaces maintained a base of paying members who were more stable over time than non-paying members, but many other interactions took place on a project basis and were shorter.

"I'm not there a lot; I joined, had a spurt of going there for a daily basis for a month or so.... Maybe I had two spurts."

"I see a lot of people come by when they're interested in a project and then don't come by when they don't have as much motivation after the project ends."

"A lot of people would come in just for the meetups and just talk about their projects, and not even work on anything. A lot of people would come by and work on the machines, would sometimes work alone. Other people would just want to help, no project in mind, just want to join someone else's project."

One participant said that the limitations in a makerspace's resources limited the time than any given project could take:

"Conventional engineering is about spending years to design something.... We don't have the same resources, experience, and time as big engineering firm."

4.2.2.2.6 Accessing diverse institutional resources

Many participants indicated that they drew on institutional resources from a variety of epistemic/creative fields. Members themselves constituted repositories of knowledge acquired through their formal training, work, or self-learning.

"Sometimes you need to talk to someone that has knowledge in a particular craft or field....I have knowledge in some of my own fields and specialities that he wouldn't have even thought of using, so there's a collaborative effort...."

"[X university] is also in [the area of the makerspace], and they do mostly mechanical engineering, actual engineering professions. So they churn out a lot of people who qualify as engineers, as opposed to software engineers. And so you get a mix of people who work in finance and work in programming, people who do mechanical engineering and everything in between."

Sometimes diversity in skill deriving from novel and recent syntheses of technical

domains were not readily integrated into all makerspaces:

"I'm an oddity. Females in hackerspaces with engineering backgrounds are few and far between. Some of the more craft elements knitting sewing crafting, soft circuitry, that's where there's a break in the community. It's still a really weird mix, from programming backgrounds, mechanical backgrounds."

Some resources from professional fields that may have been unavailable due to cost were available specifically to makerspaces:

"There is at least one group of pro bono legal counsel who help makerspaces with becoming nonprofit organizations.... There's things like the hackerspace wiki.... Like if you're going to make a hackerspace, here's how you do it. We follow a lot of those, actually."

4.2.2.3 Social interaction: Nature of social ties

4.2.2.3.1 Interpersonal trust

Participants almost universally indicated deep trust of other participants. If the participant was a member, he would often refer to those he trusted who were also other members, with whom he had had a longer period of contact. Many referred to each other as friends. Their trust was meaningfully evident in their behavior: they placed their personal belongings in common areas and left their materials out even when they were not in the makerspace. Members valued conflict resolution skills:

"It's pretty common for us to disagree on something flat out and then pick up on something else and have no problem interacting. It's almost a must. You need to be at peace in this place and be social.... It's not like all flower child and peace love and harmony. On the other hand, it's pretty nice."

Lack of trust was often reserved for outside visitors:

"In this space here we all have an understanding we're not here to do those backdoor deals.... The only guy I'm worried about is [gives physical description of man]."

4.2.2.3.2 Institutional trust

Much of the trust members had for each other was derived from their capacity as members of the makerspace. Each makerspace maintained its own identity as a trustworthy organization, while other makerspaces were, on occasion, not trusted:

"We don't have the drama that others have."

"The freeloaders that run it [another makerspace] said they couldn't use [part of the makerspace] anymore."

Part of the trust participants placed in their makerspaces was related to the cultural narrative described in 4.2.2.2.4 *Develops socio-cultural institutional structures*—that of independence. The makerspace could be trusted because it allowed members the freedom they needed:

"So [makerspace X] the organization does very little.... The organization exists to make sure that [makerspace X] the space continues to function."

However, some participants believed that trust based on a principle of noninterference undermined trust in the organization to manage itself:

"I moved here for hackerspaces, 3D printing - hackerspaces didn't exist everywhere.... I thought...you paid a membership and had access.... Architecture firms - they couldn't be more different an environment from makerspaces. They're super clean, everything's planned in phases, everyone's working toward one goal. A hackerspace is chaotic more like an art studio."

4.2.2.3.3 Reputational trust

Participants rarely referred to other members' degrees or places of work: they instead referred to each other by markers of skill. A member would be referred to as an engineer, coder, or crafter. Some listed members they knew of who had a certain skill, such as the ability to create 3D models, even if they

had never interacted with them directly. Every member, at least every official member, was thought by participants to have some identifiable skill:

"No one comes in as a blank slate."

However, participants often were careful to communicate that they did not select for skill in their memberships:

"All of our members have been selected because of who they are, as people, not because of what attributes they have."

Makers were trusted as a class of individuals or type of personality or mindset:

"Even though I'm not at a hackerspace if I'm meeting with a fabricator if that fabricator comes from a hackerspace they will get it, they won't be like oh the drawings are wrong. So there's more that culture of learning."

Participants sometimes indicated the reputation of makerspaces themselves:

"[Makerspace X] raised their reputational currency, raised their perceived value, so they probably get more support and recognition when it comes to money. I don't know where they get money from, but I think that absolutely has an affect and [the participant's makerspace] is kind of in the gutter."

4.2.2.3.4 Trust from weak social ties

Members often did not directly know other members of the same or different makerspaces, but nevertheless often indirectly benefited from common membership in the organization or membership in the larger regional community of makers.

"If you're moving from San Francisco or another environment [to New York City], directly jumping into a hackerspace is really great for getting to meet people, almost like a social club. I've definitely gotten jobs out of there, that's been huge."

One member described how this principle operates in Amsterdam-area makerspaces, which the participant is involved in:

"Small companies are it. There's sort of that network - Amsterdam's that great network.... Everyone knows everybody. For some reason everyone's tied to Amsterdam."

4.2.3 Organizational dynamic

Categorization of text units under the subcategories belonging to 4.2.3 *Organizational dynamic* fell along a spectrum formalized, structured, closed, and hierarchical to informal, unstructured, open, and peer managed. Participants were asked for their roles in the organizational structure and their understanding of how their own and other makerspaces were managed. Information garnered included membership structures, management models, nonprofit status and structure, revenue models, decision-making procedures, rules, and a description of the actors involved and the social dynamic among them.

4.2.3.1 Hierarchically managed

Many participants responded with a simple, reflexive "no" when asked if there was a hierarchy within the makerspace. Most referred to cultural narratives of equality and "democracy" when refuting the makerspace's need for a hierarchy.

"There's some people who do treat it like there's seniority and they're better than other people, but it's not the norm."

A notable number of participants referenced the same story of a failed for-profit, makerspace-like company, the management of which had been under the control of one individual:

"The problem was there was a shady guy that was there [a for-profit makerspace-like organization that was not part of this study], one of the owners, stole money from the membership and destroyed it. He's doing pretty well."

Some participants saw hierarchy as synonymous with a focus on monetization of makerspace resources. Others saw a difference between values and actual management:

"[The founder] was spending so much of his own money he didn't want that [board] structure."

"It's interesting to see founding members' impact, the local ideology, who is it descended from.... There's news articles and publications on those spaces.... how the general culture wants to see them. Versus the actual people interacting. It seems often strange because it's a very

communal thing people want to do but they also want to keep it isolated and pure."

4.2.3.2 Peer management

Makerspaces in the study were all 501c3 nonprofits or becoming ones. All had boards or groups of advisers. Most had weekly meetings to which all full, paying members were invited. Input was encouraged both during the meeting and before, in emails that were circulated among members detailing topics to be covered. Participants generally regarded decision-making as communal:

"No hierarchy.... The group, a quorum [makes decisions]."

"Usually everyone needs to chip in."

Some participants noted that the choice to be a nonprofit did not guarantee cooperative management structures:

"There is no reason to be a nonprofit, but it's a typical makerspace model that worked well for large groups of people."

The inclusion of a large number of people in the decision-making process was managed in one makerspace through adherence to rules:

"The monthly meetings run smoothly because the meeting procedures are modeled after some well-known set of rules - don't spend too much time on decisions, and if no one objects to something we move forward."

Other participants firmly believed the typical makerspace peer management model did not work well and led to "chaotic" organizations:

"[Another makerspace's equipment] wasn't broken because [the other makerspace] wasn't a disorganized mess. There's pluses and minuses."

"Hackerspaces are great but I don't know if 3D printers are the thing to be in there, and I also don't know if you can get a space to run efficiently with the members having directive as to what the space will do. The core part of hackerspaces is people's excitement about it - so the excitement changes how things progress, how things change."

4.2.3.3 Institutional restriction on entry of new members

All makerspaces in the study had rules for the induction of new members, and relied on memberships and the fees they brought with them for survival. However, makerspaces also depended on

a flow of non-members through the makerspaces and all but one maintained open nights to encourage visits by the public.

Some makerspaces did not take action to limit memberships by turning down applications for membership (but in these cases, potential members were more or less self-selecting):

"I've don't believe we've ever turned down a member that applied. In the sense of being public. I just want to clarify. People can just walk in, it's not really public. It's open when there's a member that's willing to let someone in. It's not completely open, but there's no barrier...."

Membership was perceived as a responsibility as well as a privilege:

"So we are somehow responsible for the operation of the space, and so we just sort of share that responsibility. Other than that, so, membership is a sort of long process...."

The restriction on the entry of new members, though it was directly or indirectly practiced by all makerspaces, created a perception of exclusivity among some:

"...[H]e got the distinct impression it's a bunch of snobs. I think it was influenced by their [membership] policy...."

4.2.3.4 Group or project managed

Makerspace activities usually take the form of discrete projects, but these projects almost always take place at the individual level. Occasionally a group within a makerspace would work on a project together. In these cases, the project tended to be large and impressive, and representatives of the makerspace would display the project at Maker Faire. Membership was not contingent upon participation in, much less completion of, a project. Projects occurred on the individual level—they were owned by one person—despite the fact that members generally helped each other. A number of projects were educational in nature, such as going out to schools to run classes. Makerspace classes and workshops, which were designed to be inexpensive, can be considered projects put forth by the community as a whole. However, the way that participants spoke of 'projects' usually referred to the individual-level project:

"I see a lot of people come by when they're interested in a project and then don't come by when they don't have as much motivation after the project ends."

"A lot of people would come in just for the meetups and just talk about their projects, and not even work on anything. A lot of people would come by and work on the machines, would sometimes work alone. Other people would just want to help, no project in mind, just want to join someone else's project."

"And you say you come in with a goal. I generally don't, actually. I've been here since...2012...whenever it started. I do a lot of talking to people, trying to get people learning new things talking to other people. I haven't finished a project in far too long."

"I don't notice that I care about other people's projects. I think they care about my projects when they talk to me. We have a general interest that we don't care about. We don't worry about if a project is enough. I'm not being tested to see if I'm being social."

4.2.3.5 Openness: self-regulating

Under the peer management model, members agreed to have open nights to allow the public to visit the space. Many participants expressed ambivalence about openness:

"In many ways, [open nights] are a necessary evil."

Many gave examples of the negative consequences of too much openness:

"[No one is barred from entry] unless there's been an explicit reason why we've blocked you from the space. These kinds of things happen.... It's what happens when you have a community. Occasionally you need to not have people be a part of it.... Someone said the other day, 'we are exclusive so we may be inclusive'."

A handful mentioned the same example as a cautionary parable about the dangers of too much openness. They referred to Noisebridge in San Francisco, the first-generation American hackerspace founded near the same time as NYC Resistor. Noisebridge was described as having too much openness encoded in its rules, and having become home to what amounted to squatters. A small group within it mounted a "takeover" and "cleaned it up":

"Oddly, the common sense of people taking action overcame the established protocol".

One participant attributed a certain lack of openness to the culture of makerspaces in New York City (as a note, while this participant mentioned closed-mindedness in New York City in the context of openness, several other participants mentioned the same phenomenon in a variety of other contexts):

"New York seems particularly...culturally is behind, behind [the West Coast], behind the Midwest, behind everywhere."

4.2.4 Innovation

The category of innovation only contained two subcategories, but a large amount of textual units were coded to both the incremental and radical innovation subcategories. Units of meanings in the text that regarded the creation of new processes, designs, physical objects, or machines were coded for innovation. Participant opinions about IDFT or the economic, historical, or cultural trends surrounding DFT were also included. To be considered radical innovation, passages had to indicate that what had been developed had been successful on the market, had achieved a notable level of adoption, or constituted an important change in product or process. To be considered incremental innovation, passages had to indicate that what had been developed had been small in scale and scope, not broadly impactful on the market economy, and customized to the individual needs of the participant.

4.2.4.1 Incremental

When asked in what ways they or others working with DFT used, modified, and developed the technology, many participants pointed out that much of what is made with 3D printers would not be considered innovation:

"Think about the majority of people printing off stuff...most people print out plastic trinkets."

At the same time, observation showed that much of what was printed, as well as laser cut and CNC machined, were highly customized parts designed to fit to other objects. During observation of the band saw class, the instructor pointed out a small circular guide piece (Figure 11) that had been designed to precisely fit around the blade of the saw. The saw itself was quite old but in good working condition. Its own plastic guide piece had deteriorated over the years and posed a safety hazard. The sponsor who hosted the researcher for participant observation printed leg extensions to be fitted onto an injection-molded plastic frame he had purchased from a Chinese parts site. These extensions allowed the quadcopter to accommodate a camera on a special mount, which needed clearance above the ground. Many reported having printed custom-fit casings to protect electronics and wiring for moving devices they had built or assembled.

The only type of DF machine that could be designed and built in a makerspace was the 3D printer. Laser cutters were complicated and expensive machines that came under warranty. CNC machines, particularly routers, could be assembled but not built from scratch. Of those few participants who had ever not only built but also designed a 3D printer, one gave his motivation for doing such a thing as highly personal: he simply wanted to have such a printer himself. He remarked that he had asked himself whether the 3D printers he had developed were truly new technology:

"For better or for worse...I want to make this [new type of 3D printer] because I wish I had one. Some people say that's a reason to do it. Others say it's not a real breakthrough. People don't say it's not right or wrong in the practical not moral sense. Do something that's patented, who cares. Reinvent the wheel, no one cares!"

Participants often built their own DFT solely to save money on the fully assembled versions. Two makerspaces reported pooling money to purchase CNC router kits and assembling and customizing them at the makerspace. Cost was more an issue for CNC routers, which were often described as "tabletop",

than for other types of DFT described as "desktop". One participant explained the economics and psychology behind his decision to assemble and customize his own CNC router:

"We're at this point where you can buy kits. You can't really buy a CNC router for a reasonable price.... An out of the box ShopBot [a commercial CNC router] was \$10,000. The Shapeoko [a desktop CNC milling machine] was \$2,000 but can't do what the ShopBot does. I'm going to build one for \$2,000 with the quality of a ShopBot. [But then would you commercialize what you built?] No, I [had been] doing this with hand tools in my backyard. I was like hey, I'll build my own CNC router because I'm much better at computer design than at the drawing and marking stuff.... I'm easily putting in \$8,000 worth of labor, but I don't value my time like I do my money."

Many participants explained that the same cost dynamic only a few years ago applied to 3D printers, which makerspace members would assemble from open source plans or kits. Even the MakerBot, which many participants noted somewhat resentfully could not legally be modified (or "hacked"), began as a kit. Many remarked that building a 3D printer from scratch was no longer worth the time when they were selling for as little as \$200-\$500, down from \$2,000 a few years ago:

"[X makerspace] is slowly moving into digital....That's the next step for manufacturing, the digital world. The cost of entry is going down. We got the CNC router for much less than it would have been in the past. Same with 3D printers. 10 years ago no one knew what a 3D printer was. The cost going down and interest is going up."

Most participants were not as interested in building DF machines as they were in employing design processes that took advantage of the customization afforded by DFT:

"As soon as you start making money it's better to have equipment that is proprietary and well-made. The [makerspace's] laser cutter...I repaired very often.... [He describes the difficulty of using the makerspace's relatively inexpensive laser cutter]. It's cool with CNC's - you almost always have to pseudokit - you buy gantries and router and set up the table and it's a mix and match of things and you tinker it. I've always found that the making the machines wasn't the exciting part for me."

"I have no interest in building my own 3D printer. A tool is a tool to me. I can draw, but I'm not going to go make a pencil to draw with."

This participant also pointed to a common interaction between maker and machine, that of repair and maintenance on often unreliable equipment.

In a discussion that turned philosophical, one participant mused that digital fabrication would not significantly alter the manufacture of goods:

"The benefits of scale is a fundamental economic concept. I don't think you can get around that."

4.2.4.2 Radical

Especially among those who were entrepreneurs, the makerspace was regarded as a place for the prototyping of new products.

"What happens now is that a makerspace is a kind of go-between from your idea to getting the prototype, and then you would leave and go to a manufacturing facility or outsource."

One makerspace in particular was widely known to have generated many commercially successful products, but a participant of that makerspace described success as accidental:

"A lot of companies have come out of this [makerspace].... Occasionally companies will occasionally--accidentally—come out of it...."

The most successful and famous product to come out of a makerspace in the study was the MakerBot. All participants were aware of the creation story of the MakerBot and knew that it had been created from open source designs.

"Designing a new machine is difficult. And one could make an argument that the original MakerBots weren't really - they were based on prior art anyway, previous machines. It's the classic sort of standing on the shoulders of giants."

"MakerBot didn't set out to make a company. They set out to make the rep rap suck less, and they were like, well I guess we could sell it. To some level it was we could probably sell this so let's work on it, but a lot of it was like, we have this thing, and it sucks, let's make it better. Oh, by the way, we could probably sell it."

Participants' attitudes toward a makerspace's potential to produce groundbreaking products or processes was either that displayed by the above participant, as a fortuitous accident, or disbelief. Especially those working as entrepreneurs in DFT voiced the opinion that the private sector would create new machines:

"I think the professional force is going to drive that and then there will be a trickle-down effect."

When asked what they thought innovation in DFT was, participants cited the need for improvement in the technology:

"[IDFT is] how to make it faster, cost less, make it more available."

"I say in the next 20 years it's gonna happen [every home will have a 3D printer]. I think there is a big need for the final quality of these machines before they enter everyone's home."

"[The 3D printer will be] a device that you press a button and out comes an ipad - that's where we're going to, that's the goal."

Innovation was perceived by many participants as a capacity residing within the individual and dependent upon his or her state of mind, a state of mind they believed makerspaces cultivated:

"[The difference between those who innovate and don't] is not education, it's drive and motivation, it's a personality trait - if you have the motivation to work on something you're passionate about."

"The best way to predict the future is to create it. If someone else doesn't do it, I'm definitely going to do it".

"We're trying to explore the more creative aspects of things. It is about abandoning the conventional wisdom and going for that kind of break through."

5. Discussion and Conclusions

Building on the summary and qualitative content analysis (QCA) of the data collected from twenty-eight participant interviews, documents, and participant and non-participant observation at six New York City area makerspaces presented in the previous section, this section presents a discussion of the findings of this study, implications for practice, recommendations for further research, and conclusions.

The goal of the research question

to what extent is innovation in digital fabrication technology in New York City area makerspaces due to its knowing in action typology?

was to examine the existence, prevalence, amount, and type of innovation in digital fabrication technology (DFT) as it occurs at the site of the typical makerspace in the New York City area. In order to achieve this goal, this study derived categories for the analysis of qualitative data directly from the schema of characteristics of four community typologies presented in Amin and Roberts' (2008) *Knowing in action: beyond communities of practice*.

In order to identify aspects of knowing in action typologies that apply to the cases included in this study, Section 5.1 *Discussion of knowing in action typologies*, performs an analysis within and comparison across categories identified in the QCA. Following this, Section 5.2 *Implications for practice*, summarizes those findings that are potentially relevant to those with an interest in digital fabrication technology innovation such as policymakers. Before final conclusions in 5.4, Section 5.3 *Recommendations for further research* identifies those aspects of the phenomenon under study that were not addressed by this study but would be beneficial in furthering an understanding of innovation in digital fabrication technology, especially as it occurs on the local and small scale.

5.1 Discussion of the findings

5.1.1 Type of knowing

Data analyzed for this study indicated a high level of (kin)esthetic and embodied knowledge at the site of the makerspace, but also a high level of virtual codified knowledge. Participants very clearly transferred knowledge among themselves during their activities at the makerspace, and did so in a tacit manner. They relied heavily on their senses and were often observed intuiting each other's needs rather than explicitly stating them. Even when engaging with DFT — when it was not in the virtual environment of computer assisted design programs — participants used context- and sense-based, real-time information to learn about, operate, maintain, and troubleshoot equipment as it executed a design file or simply broke. Participants reported that the DF machines they worked with were far from autonomous, requiring at least some colocation of operator and machine. Most participants, with the notable exception of experts in DFT, preferred a collaborative, group learning environment for these tasks. According to theories of tacit knowledge transfer, these interactions are not easy to describe, quantify, codify, or reproduce (Maskell and Malmberg 1999, Gertler 2003). Despite the fact that a large part of the learning process for DFT is tacit, codification of knowledge was observed in two situations, that of virtual interactions and expert knowledge.

All participants used Internet repositories of knowledge and interactive learning environments such as forums, tutorials, product webpages and manuals, and YouTube and other videos for learning. Much of the knowledge about DF product and machine design was open source. Desktop DFT as it appears in makerspaces has its origins in open source projects, notably the Rep Rap. Some participants reported contributing to the virtual knowledge base themselves through sharing knowledge in forums and online tutorials, and uploading design files to public repositories. The relationship between DF design files and the products they create poses an interesting development in the context of the transition to the

"Knowledge Society" (Ranga and Etzkowitz 2013). Because of the nature of DFT, it may be considered a materialization of human thought in the sense that Adam Smith, Karl Marx, and Josef Schumpeter wrote of the machines of the machine age (Freeman and Soete, 1997). However, the digital design files for machines and the objects they create constitute a latent, potential, codified materialization of thought.

Codification of knowledge was also observed in the case of experts in DFT. Six of the twenty-eight participants may be classified as both experts and entrepreneurs in DFT. They had almost all gained their expert knowledge through formal education in DFT. Possessing expert knowledge of DFT appeared to have the effects of either reducing, formalizing, or changing the nature of participant interactions with makerspaces. Some experts reported having little need for makerspaces as places of learning. Several interacted with makerspaces as instructors, leading revenue-generating classes and workshops for the makerspace, usually for pay. Others' expert interactions with makerspaces were changed by their expert knowledge from places of learning to places of knowledge synthesis and networking. Many reported the benefit of contact with the makerspace community, even if periodic, as providing them with access to a variety of other minds that enhanced their own creativity. Most other participants were what one called "skilled amateurs" in DFT. However, most were experts in their own fields, many of which were a form of engineering; expert knowledge in these related fields enhanced learning related to DFT. These skilled amateurs who were experts in other technical or artistic areas consistently reported needing to go to the makerspace in order to gain knowledge of DFT, while experts in DFT consistently reported having gone, at least at one point, to the makerspace in order to gain knowledge of other domains.

5.1.2 Social interactions

Social interactions within and among makerspaces, and between makerspaces and external individuals, communities, organizations, and institutions, were characterized by both spatial and relational proximity. The first subcategory of social interactions, colocation, allowed for an exploration of

the cruciality of spatial proximity, or lack thereof. Most participants reported that they needed to go to the makerspace for access to both equipment and the community of knowledge found there. They cited the nature of many technologies employed at the makerspace as requiring the pooling of resources that colocation allowed. Many of these technologies were too expensive for the individual to own, too large to fit in the small indoor dwellings typical of New York City, or were too complicated to be worth the cost and effort of learning in isolation. The makerspace was seen as a communal effort necessary to procure materials and equipment, space, and advantageous geographical location.

However, most participants who were entrepreneurs and experts in DFT did not believe that they had to be colocated at the site of the makerspace with other makers. In the case of desktop 3D printing, the cost and space requirements of the machines allowed them to be used at home. Most experts had already moved to other facilities such as coworking spaces or fabrication facilities in order to prototype with better, higher-capacity machines. All but two believed that the DF equipment makerspaces typically maintained was not professional-grade, not capable of meeting their production needs as entrepreneurs, and best suited for learning rather than true manufacturing.

Participants reported that spatial proximity to one another enabled and enhanced learning, an instance of what Bathelt and Glückler (2003) call "creative interaction". They attributed enhanced learning through colocation to face-to-face communication. Many participants used this exact phrase in an almost identical way as it is used in the economic geography literature (Gertler 2003, Howells 2002, McCann 2007) to describe the reason they preferred learning in a makerspace environment to what they said was the alternative, a virtual environment. They portrayed face-to-face knowledge transfer as more "efficient" than virtual forms of communication. Because of the variety of different, but generally technical, knowledge and skills possessed by other makerspace members, participants believed they could almost instantly achieve a highly relevant response to even arcane questions posed to colocated members.

Much like the Korean trade fairs researched by Gress and Kalafsky (2013), makerspace communities appeared in a parallel form on the Internet as webpages, forums, email groups, and listservs. Interestingly, two participants gave opposite assessments of the implications of the parallel virtual version of the makerspace. One believed that the fact that members understood they would potentially see each other in person moderated the behavior and tone of email groups and facilitated good communication. Another believed that the homogeneity (in demographics and skill and educational background) of the community members constituting the email groups led to aggression and petty infighting. In either interpretation, these virtual versions of makerspaces were characterized by a high degree of relational thickness, or relationships characteristic of a culture rather than functionalism (Sack 1997). In the second interpretation, the antidote to the potentially negative effects of high relational proximity and thickness is diversity, a view that is supported by March (1991), Asheim et al. (2011), and Neff (2012).

The online version of the in-person makerspace communities appears to support the contested (von Hippel 2001, Amin and Roberts 2008) notion that geography inevitably exerts a strong, even determining influence on communities. These online environments were created *after* the physical makerspace was established and a culture had formed within it over time, and were therefore in a way shadows of the colocated community. However, if one also considers the highly virtual nature of "interorganizational communication" (Bathelt and Glückler 2003) — the essential virtual interactions between makerspace members and the larger, external "community" of "makers" — geography appears far less deterministic in the process of knowledge and innovation in the makerspace. Some makerspaces had begun to experiment with ways of accommodating the community outside of the confines of the makerspace building, as in mobile truck and mobile meetup concepts, in which a community that is organized online meets at different locations.

The connections and relationships among community of makers sited in makerspaces mostly manifested a high degree of relational proximity characterized by thick relationships. Participants appeared similar to one another, and many even noted these similarities during interviews, describing them as matters of "lifestyle". They cited these similarities as a reason that they communicated easily among each other. Makerspaces appeared to have their own unique cultures that formed over time. Participants exhibited mostly high levels of trust toward other individuals in makerspaces and often described their relationships as friendships, some of which had been formed over the course of years. The process of membership meant that members had been at the makerspace longer than nonmembers and had been subject to a process of group and self-selection that appeared to have the effect of homogenizing member values, personalities, skills, backgrounds, and as an effect, demographic traits. This homogeneity, while unintentional and perhaps a result of what Rivera (2012) has called "cultural matching", may have the potential to enhance innovation in its initial stage (Boschma and Frenken 2006), but also to stifle it in later stages (March 1991).

Most participants described makerspaces as dynamic and diverse, and observation indicated that makerspaces, reflecting the highly mobile nature of the New York City area population, experienced a significant amount of churn among visitors, nonmembers, and to a lesser extent, members. However, makerspace communities did retain a core of constant members as a result of "locational inertia" (Feldman et al. 2005). Some participants observed that colocation in a makerspace did not always lead to mutual understanding for some community members: as Allen (2000) noted, embeddedness in a culture does not guarantee knowledge transfer. Those participants who were less involved with a makerspace were likely to suggest that they viewed the cultures that had formed at makerspaces over time as potentially or becoming "stagnant". This data suggests that a high degree of relational proximity over time among the same community members, not just spatial proximity, can enhance but also potentially

impede learning within a community, and therefore innovation. This notion is similar to the concept of *lock in* (Hassink 2010) and the *competency trap* (Levitt and March 1996).

5.1.3 Organizational dynamic

Makerspaces as organizations possess and promote beliefs that hierarchical organizational structure harms the community. Compared to firms and universities, all were small organizations in both membership and size. All were nonprofits or becoming nonprofits. All had boards or otherwise made decisions communally. In many cases, the capabilities of the organization to move as a single entity were purposely curtailed. Most makerspaces appeared to induce various states of resource scarcity in the organization in exchange for freedom from the perceived obligations, impositions, and burdens on the community that formalism might bring. Most turned down opportunities to monetize assets, rejected overtures from business interests, shielded their members' privacy from external inquiries, distanced themselves from the entrepreneurial actions of individual members, and consciously declined to take on the role of business incubator or technology accelerator.

These organizational values perhaps may be compared, as a microcosm, to regional innovation systems, in which the motivating factor behind the creation of in-common resources that lead to innovation is self-interest (Bessant et al. 2012). Unlike a wider regional system, though, makers maintain thick interpersonal relationships rather than distanced, contractual ones. Unlike a system guided by market forces, makers consciously chose to collectively pool resources. Much like in the transaction cost theory of the firm (Coase 1937), the management structure that oversaw the pooling and division of resources existed to reduce as many transaction costs for makers as possible. The extent to which they reduced these transaction costs went beyond that of most other types of organizations despite their small organizational size.

However, the organizational structure of makerspaces can be described as cryptohierarchical: none was governed by complete anarchy. Each had decision-making structures in place. Veteran members in reality wielded more influence than newcomers or nonmembers. Where lack of formal structure existed, self-regulation stepped in. Therefore, the organizational dynamic was tied to social interactions. This may explain why makerspaces consistently instilled core beliefs in their members about the community's democratic, independent, and communal values.

Entrepreneurs in DFT were aware of, but less likely to subscribe to, these beliefs and wished for more organizational formalism. Many cited organizational structure as the reason they diminished or ended their relationships with makerspaces. This dynamic illustrates one of the roles of makerspaces in innovation. Entrepreneurs engaged with makerspaces for creative needs such as idea generation, prototyping, and networking. However, once the maker transitions to entrepreneur — and transitions to the material, technological, and space needs increased production capacity or quality entails — they often loses their place in the community both spatially and socially. To the DFT entrepreneurs, the organizational benefits of the resource constraints makerspaces imposed on themselves were outweighed by their costs, consistent with Curry's (1993) theory that the narrative of resource constraints propelling small organizations to innovation may be, at the very least, misguided.

It could be argued that makerspace values and organizational actions (or decisions not to act) had the effect of increasing risk-taking behavior among participants. Because most did not engage in an activity in order to monetize that activity, they felt free to experiment with designs and objects that ran the risk of not functioning as they had been hoped to. However, those participants who engaged the most with DFT were both experts and entrepreneurs. Their entrepreneurial efforts ran the risk of failure in the market. Market pressure appeared to drive a high level of specialization among the entrepreneurs, which required more material, knowledge, and relationship resources than makerspaces alone were able to provide. If DFT entrepreneurs could be said to be making a tradeoff between March's (1991)

exploration and exploitation dyad, their migration from makerspaces to professional or independent spaces could indicate a transition from *exploration* to *exploitation* of innovative processes. However, makerspaces were still one important element in the wider system of resources that DFT experts accessed, arguably maintaining within the study area centers of nearly-pure *exploration*.

The observed division between skilled amateur community members and DFT entrepreneurs in attitude toward risk may be explained through Neff's (2012) framework of *venture labor*. She proposes that firms have, since the 1990s, been able to essentially relieve themselves of the costs of labor involved in innovation by outsourcing it to individuals—largely because of the widespread diffusion (in Western countries and the United States in particular) in the culture of the notion that bearing risk is normal, even valorous. She specifically cites Turner's (2010) research on cyberculture proposing that utopian, cyberlibertarian values grew up around computer and Internet technologies in the 1980s and 1990s. She argues that these values led to higher levels of risk among individual entrepreneurs in Silicon Alley and resulted in the dot com bust of 2001. Makerspace communities in the study area, which is the same area as Silicon Alley, appear to espouse values of self-sufficiency and independent, unfinanced innovation. It remains an open question but an interesting avenue for future research as to whether or not makerspaces are sites of the outsourced labor of innovation.

5.1.4 Innovation

In the knowing in action typology schema, innovation can be either radical or incremental. The division of innovation into radical and incremental is similar to the division in many definitions of innovation between creative process that lead to a successfully-commercialized product, and the successfully-commercialized product itself (MacPherson 1997, Feldman 2000, Hellman and Puri 2000, Heirman and Clarysse 2004). This study's data show that the type of innovation on DFT (IDFT) taking place in New York City area makerspaces appears to be primarily incremental. In one key case, that of

MakerBot, IDFT is easily-identifiable as radical. Whether other successfully-commercialized instances of DFT can be classified as radical may be debated, but add to the argument that makerspaces *are* potential sites of innovation. Whether instances of novel and creative uses of DFT, which are classified as "incremental" innovation, are part of a set of traits possessed by makerspaces that make it a fertile ground for radical innovation can only be suggested — not proven — by the data.

Radical machine IDFT in the cases under study was very rare. Laser cutters and CNC machines were never built at makerspaces, except in the case of CNC routers, which were assembled from kits and customized. MakerBot is the prime example of a DFT to originate in a makerspace in the study area and to have achieved influence in the market. MakerBot 3D printers were prototyped in a makerspace, and then commercialized first into kits and then into fully assembled products. Almost every participant that mentioned the case of MakerBot noted that it was a development of the Rep Rap, an open source and therefore preexisting 3D printer project. They also noted that the first MakerBot 3D printer was of a far lower quality than printers on the market today and did not constitute what Heirman and Clarysse (2004) describe as a substantial improvement over existing technology. The case of the MakerBot therefore matches the description of imitative (Heirman and Clarysse 2004) or incremental innovation because it was, at least at first, a modification of an existing design. However, it impacted the consumer 3D printer market widely, and this fact alone allows it to be classified as radical innovation. Some participants, in discussing what they believed IDFT to be, felt that the impact of a product on the market may be more related to the timing of its introduction and marketing than to technological innovation per se.

Several participants had assembled and built 3D printers from open source plans. Only one participant had designed his own machine, and knew of one other member of his makerspace who had done the same. Many other participants explained that they would not build their own machines because machines were either now inexpensive in the case of 3D printers, or too technically challenging and expensive in the case of CNC machines and laser cutters. The question of whether makerspaces can

produce radical machine innovation is important because the DF machine constitutes a platform for the creation of a wide variety of products (Heirman and Clarysse 2004), potentially including some of its own parts. Therefore, innovation on one machine can affect a nearly infinite number of products that can come out of it. For now, makerspaces in the study area appear unlikely to produce another radical machine innovation unless one of the two new 3D printer projects mentioned becomes commercially successful.

Most participants voiced the opinion that DFT was a means to an end: they would achieve their primary goal to create customized objects through the most efficient way of procuring a machine that could create them. They observed that the economics of obtaining DFT suitable for their needs had changed rapidly in recent years, for the most part removing the designing and assembling component of DFT from makerspaces. However, most still offered classes and workshops on assembling 3D printers from kits. All offered classes on both 3D modeling and 3D printing as a process. Those that had laser cutters offered classes on their use, though not on design (two-dimensional design is a more common skill than 3D design). CNC machining was rarely taught in classes, though the relationship between the cost of CNC router kits and the time and skill necessary to assemble them meant that they, like 3D printers a few years ago, are still assembled at makerspaces rather than bought whole out-of-the-box.

IDFT that can more easily be described as incremental (rather than radical) was common in makerspaces. If innovation may be considered a novelty of potential value that emerges from the creative mind (Polyani 1961) rather than solely a commercialized product with notable market impact, makerspaces are factories of innovation. Makerspaces are still young organizations. The oldest of the makerspaces is barely eight years old, and has produced the largest number of subsequently commercialized projects. The significance of the question of whether makerspaces' environment of rather random, chaotic, diverse, idiosyncratic, and usually uncoordinated but often syncretic activities is that it may be precisely in these environments that innovation occurs *before it arrives at market*

(Freeman and Soete 1997, Jones and Wadhvani 2006, Feldman and Kogler 2010). Common proxy measures of innovation such as new product introductions (Acs et al. 1994) cannot capture the observed relationships, network and social dynamics, knowledge generation, or fortuitous cross-pollination of ideas that occur at makerspaces as they leave no "paper trail" (Krugman 1991, Jaffe et al. 2003). This study can contribute to a paper trail documenting the antecedent processes of innovation missing in the literature.

Makerspaces' primary reason for existence is to allow 'makers' to 'make' things, not to produce products that will be commercialized, widely adopted, or even adopted by anyone other than the individual maker. In the case of DFT, these 'made' objects are novel in that their designs almost never existed before. Participants were observed crafting specially-fitted, highly customized parts in computer aided design programs for assembly into other projects, and printing, lasing, milling, or routing them iteratively until the desired piece was achieved. Besides novel objects, incremental IDFT took the form of novel processes. While parts created with DFT were meant to be used in one specific instance, their design files continued to exist beyond the first printed, cut, or milled object. Members scanned objects at will to create 3D design files that could be further refined or discarded in favor of another scan.

The most common use of DFT in a makerspace was to create components of other (not exclusively DFT-based) projects, which themselves were novel. The "[synthesis of] several existing technologies" is a characteristic of imitative innovation (Heirman and Clarysse 2004, 9). It may be noted that even though DFT is an existing technology, any customized object and corresponding design file it creates may constitute a completely novel development. Moreover, these novel objects and their virtual, immortal avatars in the form of design files may be, in theory, repeatedly modified, redesigned, refined, and then repeatedly printed, lased, etc. as needed for any number of projects. These projects may incorporate any number of other, non-DFT parts and technologies, notably electrical wiring and microprocessors that can result in an object connected to the Internet of Things (IoT). The labeling of processes of technological combination, reuse, and synthesis as "imitative" or "incremental" may be

shortsighted. Indeed, the foundational, underlying ethic of the entire maker (hacker) movement is "hacking", the very definition of which encapsulates the concept of creative recombination.

5.1.5 Which organizational typology best applies to makerspaces

No one of the four knowing in action typologies can be assigned to makerspaces in its entirety. Makerspaces do primarily possess the characteristics of craft-based and virtual communities. They display none of the attributes associated with professional communities, and only some of those associated with epistemic and creative communities. The ways in which makerspaces partially fulfill the typology of epistemic and creative communities highlight complexities and evolutions in their organizational and community structure.

Makerspaces, as sites of material as well as digital production, are bound to place by the nature of the technology they are organized to engage with. As with traditional craft communities, a makerspace community as a site of learning and innovation must at some point have regular access to a particular space inside a building. The age and maturity of the culture formed by the community are proportional to the age of the space itself. The stationarity of the community tracks the stationarity of the space. Members of the community are usually colocated in the space during times of activity resulting in regular face to face communication: knowledge transfer is often embodied and social, based on trust cultivated over time. Members often describe their activity as craft, reflecting not necessarily its physical nature, as many regard coding to also be craft, but reflecting the fact of their making a unique thing that did not exist before. The type of innovation produced at makerspaces is often extremely customized and would usually be characterized as incremental, as with craft communities.

However, makerspaces differ markedly from traditional craft communities in several regards. They cannot in fairness be characterized as "hierarchically managed". They do not pass on skills through apprenticeships and members limit their involvement with others' craft to advice and periodic help. Most

importantly, traditional craft communities practice one type of craft. Makerspaces by definition are places for the exploration of nearly-infinite types of crafts. DFT in particular allows the creation of customized objects or parts for any project. While DFT may be considered one type of technology, and the development of DFT machines one specialized type of craft, the use of DFT allows the creation of a nearly-infinite number of other objects. Makerspaces can therefore be the site of a large number of *crafts* in the plural.

Makerspaces existed on the Internet in parallel to their physical form. Virtualization happened in three respects relevant to IDFT. The community of members of the New York City area based makerspace maintained communication online that allowed interaction among members even though they were not physically colocated. This online communication generally had the effect of reinforcing the community and reproducing it as an idea and set of values in members' minds. Communication and learning online also occurred between individuals and online repositories of knowledge about DFT. These online interactions were not only with static tutorials and instructional videos, but could also be with others with specialized knowledge in DFT whose geographical locations were not known. Lastly, the nature of DFT itself involves the virtual codification of the object to be made. DFT requires design files to be used to make objects. The 'making' involved in DF mostly occurs in a virtual environment in the form of 3D designs. Once a DF machine is instructed to execute a design file, it is almost never touched during the actual production process, though it is periodically checked for malfunctions and needed maintenance.

Makerspaces resemble the professional community least. Most members are not certified in their knowledge by any organization that confers certificates, honors, or titles. Members often did have professional affiliations, but these were relevant to their professions they engaged in during the daytime and were downplayed through repeated assertions by members that anyone could be a maker and the community did not select for skill. Those participants who had expert knowledge of DFT had notably fewer interactions with makerspaces than did those without expert knowledge who nonetheless used the

technology at makerspaces. That experts taught classes served to transfer the knowledge they gained in educational and professional settings to those who did not regularly interact with DFT. Makerspaces are different in one regard from most communities of practice described in Amin and Roberts (2008, 354): they are not a type of "collaborative working" because the majority of the activity that takes place in them would not be termed by the participants themselves as 'work'. They consistently described what they did as leisure activity. Those with expert knowledge in DFT have in most cases moved their independent production and consultancy operations to coworking or fabrication spaces or their own homes. Much of the reason that makerspaces do not possess the qualities of professional communities is because they construct the organization so as to prevent professionalization.

The most ambiguous assignment of typology is that to epistemic and creative community. The hallmarks of this type of community are single project-based, intensive group interactions where members of the group come from a wide variety of specializations and connections among them are weak ties, based on reputational trust, and oriented toward the completion of the goal rather than toward the perpetuation of the community itself. Whether or not makerspaces possess traits of epistemic and creative communities is significant because Amin and Roberts (2008) portray these communities as those that are consistently capable of producing radical innovation. A main reason they give for this unique capability is the diversity among community members. Part of the reason they can be so diverse is that some of them are drawn from diverse geographical locations, leading to a combination of face-to-face and virtual communication. Another reason is that the diverse assets of individual members are channeled toward one goal, managed by intermediaries chosen for the project at hand rather than inflexible hierarchies. Makerspace communities do have diverse members, although many participants indicated that memberships were not as diverse as they needed to be. They do maintain sometimes distanced relationships, though their primary dynamic is colocation and face to face communication.

Though they rarely collaborate on single projects communally if the project is taken to be a physical object, those projects that are community projects tend to be large, impressive, and displayed at Maker Faire. The majority of collaborative interactions at makerspaces are when one member helps another with his own project, with the implicit understanding that the recipient of the help may potentially return the favor in the future. Organizational values propagated throughout the community encourage a collaborative ethic, but also encourage individualism in the pursuit of one's own projects. These values instill in the community a sense of trust that the organization will not interfere with the individual's pursuits. Therefore, projects that do emerge within makerspaces are informal, spontaneous collaborations among a core group of full members. These projects are usually crafted to be aesthetically interesting. Less often, material projects were completed in response to a need expressed by members of the local community such as libraries or schools.

However, it may be a mistake to regard makerspaces as exclusively sites of the production of physical objects. More often, the project of collaboration meant to fulfill a need in the community is that of education. The community often either brings in groups of students from local schools to the makerspace for a class or itself travels to schools to run classes. One participant even noted that, although radical machine innovation is more likely to emerge from universities and firms than makerspaces, an important innovation the makerspace produced was a wider understanding and awareness of, appreciation for, and exposure to DFT among youth and the public. Another participant believed that makerspaces, if they are managed in such a way as to increase their public visibility, particularly through "storefront" property, contributed to public interest in DFT that drove demand for DF products, thereby driving innovation. The many free and low-cost classes and workshops on the design for and use of DFT also contribute to public awareness of and demand for DFT. Many participants noted that area universities with DFT capabilities were closed to the public and to themselves, but makerspaces in the study area were uniquely able to interact with the public. In these ways, the makerspace is capable

of widespread influence on the market even without always directly interacting with it. Through their educational aspect, they may indeed indirectly drive "economic well being, prosperity, and growth" through innovation (Feldman and Kogler 2010).

5.2 Implications for practice

The findings of this study have implications for the practice of policy, regional innovation, firm-level innovation, and makerspace organizations and communities. Policymakers maintain strategies for resource allocation that often include funding for technology incubators, accelerators, and hubs. Makerspaces are also potential sites of innovation. However, because of their nonprofit status and organizational orientation away from commercialization, they should be regarded more as part of the "local knowledge structure" (Jaffe et al. 1993), as public goods, or as educational organizations rather than incubators. Makerspaces generally resist funding that obligates them to produce measurable economic impact unless this dynamic was built into the organizational model from the beginning. Public goods that produce systemic knowledge externalities such as libraries and schools, though, are usually not held to the same standards of economic impact as are incubators. Makerspaces, like libraries and schools, increase the local knowledge base with diffuse but real effects on the local economy (Nijkamp et al. 2007).

What makerspaces lack in terms of resources and organizational structure, compared to large institutions such as universities, they make up for in openness, creativity, and agility. Theirs is a different model of learning, one that can only inject more possibilities for innovation in digital fabrication and other technologies into the system. However, the constraints on resources they experience do affect their ability to procure the space and equipment to accommodate the community members and their learning processes. Makerspaces can potentially cooperate or partner with educational institutions, government

initiatives, and even firms without altering their community beyond recognition. These partnerships would benefit both makerspace and other partner.

5.3 Recommendations for further research

Further research suggested by this study would address different methodologies, understandings of makerspaces as cultures and networks, and place the context of makerspaces in the wider regional innovation system. This study approached innovation in digital fabrication technology in one study region, the New York City area, through a modified case study approach. In this approach, cases were described, but the data that was examined in depth was that of interviews of members belonging to each case. A true multiple case study could use grounded theory or ethnography to create more in-depth portraits of makerspaces and take advantage of the possibilities of inductive data analysis. This study did not compare two or more regions, much less competing ones, as have Feldman and Romanelli (2013), Saxenian (1994), and Sorenson and Audia (2000); further research could compare the New York City region to other regions or clusters of digital fabrication technology such as the Boston area or those under study by geographers in Europe. An interesting comparison study would be between regions with a concentration of makerspaces but no corresponding digital fabrication industry, and a cluster of digital fabrication technology with no corresponding concentration of makerspaces. Another interesting comparison would be between individuals who innovate on digital fabrication technology with no face-to-face contact with members of a larger maker community, and those who do so at makerspaces. Besides these suggested qualitative approaches, quantitative data on innovation in digital fabrication technology is needed. This may take the form of a national or international survey of makerspaces.

This study was limited to six regional makerspaces and twenty-eight individuals within them. However, study findings coming from entrepreneurs indicate that the makerspace is only one part of a wider regional innovation system in digital fabrication technology. Further research could perform a

social network analysis of the digital fabrication or wider digital hardware innovation systems. Such research would be able to include digital fabrication manufacturers, retailers, fabricators, and a distributed network of manufacturing called 3D Hubs. A useful approach to the study of networks and communities not bound by place, as the study of makerspaces tends to do, is that of the economic geography of temporary sites of the production of knowledge, as in Grahber (2004), Bathelt and Schudt (2008), Torre (2008), and Kalafsky and Gress (2013). Within the specific region of New York City as the technology cluster called Silicon Alley, further research could build upon Neff's (2012) findings that the dissonance between the cultures of finance, technology, and art was detrimental to innovation in the region. Some of this study's findings indicated that this dissonance still exists, but that now, the technology part of this equation includes digital hardware in addition to software and internet technologies.

5.4 Conclusions

The findings of this study expand on previous research in technology innovation as it takes place in communities of practice. The study specifically employed the knowing in action typologies established by Amin and Roberts, a framework for the examination of the role of makerspaces in the innovation of digital fabrication technology suggested by Gress and Kalafsky (2015). Using spatial, social, organizational, and innovation factors laid out by Amin and Roberts (2008) as categories in Qualitative Content Analysis (Mayring 2014), the study identified aspects of each knowing in action typology that applied to six New York City area makerspaces. It used a cross-category comparison to explore whether and to what extent makerspaces in the study area generated innovation in digital fabrication technology. It found that makerspaces in the New York City area are rich sites of principally *incremental* innovation.

This study found that makerspaces are a combination of craft and virtual community typologies, and possess some elements of creative and epistemic communities. Craft as it is practiced in makerspaces

and as it is applied to digital fabrication technology is both physical and digital in nature. The makerspace as a community therefore exists both within the spatial boundaries of the makerspace as a space and organization, and in fluid virtual forms involving a wider, global community of makers. The technology of digital fabrication, like the community of the makerspace, was found to be physical and virtual in nature. The needs of the technology as sometimes large, mostly expensive, and always knowledge-intensive equipment concentrated it, and the knowledge community around it, in space. The nature of the technology as digital, open source, and knowledge-intensive concentrated the knowledge community during the learning process, and simultaneously dispersed it throughout the Internet. The community usually operated as a collective of individuals, but sometimes acted in concert to create projects. Project-based community efforts, especially educational initiatives, had the effect of educating and increasing awareness and demand among the public for digital fabrication technologies.

Makerspaces were shown to be sites of innovation in digital fabrication technology. They drive process innovation directly through their fostering of a wide variety of creative and unique projects. They drive product innovation directly, but examples of this are rare. They more often drive product innovation indirectly through possibly increasing public demand for the technology. Makerspaces can also indirectly affect innovation by contributing to the regional knowledge base, producing non-market knowledge externalities with low barriers to access.

In an era of "software eating the world" (Andreessen 2011), very small organizations have destroyed very large ones through leveraging digital technologies. A question of concern in the study of technology innovation is whether this logic can be transferred from the digital to the physical, from software to hardware, from the information and telecommunications industry to manufacturing. Digital fabrication is one technological development that holds the potential to apply the efficiencies of digital technologies to the production of material goods. Makerspaces are hives of activities combining, or hacking, together software and hardware. Digital fabrication is emblematic of this synthesis. The

makerspace as a community of learning and knowledge that uniquely possesses the ability to integrate "bits and atoms (Gershenfeld 2012)" may be seen as an engine of regional knowledge externalities.

6. Appendix

6.1 Interview Guide

The following are guiding questions for interviews used by the researcher. Interviews were semi-structured and open-ended. The following questions were used as guides for interviews, but were not rigidly adhered to. Each interview lasted from 15 minutes to two hours in the longest case. They were typically 45 minutes in length. The identity of participants' specific responses to questions are kept confidential, as well as their makerspace affiliation. Participants were given an informed consent form. These and other interviewing procedures were approved by the Hunter College Institutional Review Board as described in section 6.6 *Institutional Review Board approval for this study*. Questions are grouped by themes in the research.

General

How does this makerspace work?

Membership requirements, fees

Rules

Hierarchy, leaders

Financial structure (e.g. 501c3)

Location: is it convenient? Near transportation? What type of neighborhood? Why is it located here? What is the space like? Rent?

What do you think a 'makerspace' is? Or a hackerspace? What do those words mean to you? Where do you think those terms came from?

Knowledge

What is your specialty here?

What is your skill set or professional background? [E.g. are you an artist, programmer, graphic designer, engineer?]

Do you do similar work (to what you do at the makerspace) at an institution such as a company, school, or non-profit? Or is what you do at the makerspace different from what you do anywhere else?

To do what you do at the makerspace, do you use the expertise you already have (e.g. what you learned at college), or do you gain expertise through your involvement with the makerspace?

Learning

What do others here look to you for help with?

Who do people ask for help the most from here?

Who do you ask the most for help?

Have you worked on projects with other members? Which projects? How many?

Where do you do what you do? At the makerspace itself, at home, or online?

What percentage of the time you are participating in the activity of digital fabrication are you online versus physically at the makerspace?

Do you feel you learn more in-person at the makerspace or online?

Do you or anyone you know here use the online marketplaces (Shapeways, Ponoko, Thingiverse) for design files, transfers design files to others, receives design files from others? Opinion on them?

Why do you need to come to the makerspace instead of just doing this at home?

Does this makerspace have an online presence (e.g. message boards, forums, email groups)?

Do you know of anyone here that goes to other makerspaces?

Does this makerspace have any relationship with any other organization, company, or sponsor?

Innovation

In your own words, what do you think innovation in digital fabrication is?

Is there innovation in digital fabrication at this makerspace?

Has anybody made any products they are planning to sell? Any they have sold? Is anybody seeking financing?

Do some people innovate more than others? Why do you think they do?

What do you think motivates innovation among “makers”?

Do people here have the tools/equipment they need to do what they want? Do people find ways around lack of equipment? Is lack of equipment the biggest obstacle to getting projects done, or something else?

6.2 Coding Agenda

Table 2: Coding agenda for interview questions, as described in Mayring's (2014) Chapter 6.5, Structuring – Deductive Category Assignment

Category	Subcategory	Definition	Anchor examples	Coding rules
C1: Type of knowledge	SC1: (Kin)aesthetic or embodied knowledge	Knowledge is transferred within the KIA community through direct contact, physical sensation, observation, and imitation.	<p>"But you can't test [things in a virtual environment]. You can't see if they're going to wear out, heat up, or short out."</p> <p>"Picking something up is really different from a picture. A picture worth a thousand words, so the real thing is worth even more."</p>	Knowledge must be imparted through presence, involving the physical use of artefacts.
C1: Type of knowledge	SC2: Expert knowledge	Knowledge that is transferred within the KIA community that was acquired through acquired through formal training.	<p>"Makerspaces tend to be clients or people wanting to learn skillset I already have - so I'm an outsider looking in."</p> <p>"This technology [digital fabrication] was being underutilized at [the makerspace before I arrived]...."</p>	Knowledge that an individual possesses s/he must only possess due to having attended a formalized program of study that conferred an official sanction, such as a certificate, degree, or title.
C1: Type of knowledge	SC3: Codified knowledge	Knowledge is transferred within the KIA community that is recorded digitally in language, code, numbers, or other data.	<p>"It's much easier now to learn something without an engineering degree. You can go on YouTube and watch a few videos."</p> <p>"The market breakdown. You have your diehard Rep Rap people - that's the original movement.... People would put the schematics up, share the info, that's what created some of the first desktop, easy-use 3D printers."</p>	The knowledge is transferred from "face to screen"; it does not require human colocation to be transferred.

C2: Social interaction: Proximity and nature of communication	CS4: Colocation	Community members must be in the same physical space.	<p>"So coming to a space like this does give you access to almost every tool imaginable but also to people. The people at the end of the day are what really kind of what drives this as a community organization and makes it really important."</p> <p>"In New York City it's very difficult. Metal filings on the bed are not comfortable. It's mainly space. If you had a backyard, you wouldn't need to come to a makerspace other than to meet people from the community."</p>	Occupying the same physical space during the performance of the activity must allow for the possibility of face-to-face contact between community members.
C2: Social interaction: Proximity and nature of communication	CS5: Face-to-face communication	A type of social interaction in which communication is performed by two or more people in-person.	<p>"Interaction with people face to face is still very important.... Face to face you can read their emotions, see their face, hear their voice."</p> <p>"...[I]t also gives you opportunities to collaborate, something that you might not necessarily have with Google."</p>	The community members must be physically present and directly communicating with each other without the mediation of technology.
C2: Social interaction: Proximity and nature of communication	CS6: Relational proximity	A type of social interaction in which community members' communication is effected and enhanced through nonspatial proximity.	<p>"...[I] went there to meet likeminded people."</p> <p>"...[I]f I ever want to use one of them [another member] they're the person I talk to, and I know them, and we're friends and we have this connection."</p>	The communication may be spatially proximate, but is not limited to being spatially proximate. The proximity described may also be the proximity created through similarity and strength in social or business connections and relationships, skillsets, or educational or demographic

backgrounds.

C2: Social interaction: Proximity and nature of communication

CS7: Technology-mediated communication (face-to-screen)

A type of social interaction in which communication occurs between community members that are not colocated at the time of communication and that occurs on the internet.

"Before I lose this thought, I'd love for you to prove to people that online networking is not adequate."

"Electronic communication, as much as it's made the world smaller, it's less efficient I find usually."

"Sometimes it's not enough to watch a video."

The communication may not be between community members who are physically colocated, but must instead be mediated through the internet because it is at a distance. The requirement of physical distance only applies at the time of communication, because those who may at times be colocated may at other times communicate at a distance. Long duration is indicated by the participant's assessment of 'long'. Long-lived social interactions, unlike short ones, will often have no particular focus on achieving a goal. They may develop as incidental to participants' colocation.

C2: Social interaction: Temporal aspects

CS8: Long-lived social interactions

Social interactions occurring in the community are of long duration.

"The goal is that you feel comfortable with all the members, which is a difficult thing to achieve. It takes a lot of time. Because of that, we don't really have people who stop being members."

"By moving to this location, the energy has fizzled out."

C2: Social interaction:
Temporal aspects

CS9: Slow-changing social interactions

Social interactions in the community are slow to change over time.

"...[W]e know people in the maker community because we've been in the maker community so long."

The assessment of the slowness of change is made by the participant.

"A big part of it is getting new people and new minds acting together. If you've existed for too long none of the minds are new to each other.... It's the same with a college. It's like the freshman class and you just never let them leave. You get stagnant."

C2: Social interaction:
Temporal aspects

CS10: Apprenticeship-based social interactions

Social interactions in the community follow an apprenticeship model, in which a mentor teaches a novice a skill or craft.

"We hired an educational director to help with classes."

An apprenticeship model will contain one person in the role of mentor and one person in the role of subordinate learner. The relationship must occur over time and be formed with the intent to cultivate expertise in a skill in the learner.

C2: Social interaction: Temporal aspects	CS11: Socio-cultural institutional structures	Social interactions develop socio-cultural institutional structures, or social group coherence and commonality through exposure to one another.	<p>"It's a do-ocracy around here. If you want to do it, do it."</p> <p>"It...depends on the community. In many cases crafting is more social - knitting and coffee - whereas some...[are] focused on 3D printing and tech. You find entrepreneur people, heavy engineering type attitude, that goes along with traditional hackerspace...."</p> <p>"[X] wanted it to be a nice tight community but didn't want it to be too expensive for individuals.... But being nonprofit you need to make money."</p>	The social interactions described must lead to structures that are not formal or rigidly codified. They will instead form more of a shared culture among the group cultivated through their time spent together.
C2: Social interaction: Temporal aspects	CS12: Short-lived social interactions	Social interactions are short in duration and usually centered on a project.	<p>"I'm not there a lot; I joined, had a spurt of going there for a daily basis for a month or so.... Maybe I had two spurts."</p> <p>"I see a lot of people come by when they're interested in a project and then don't come by when they don't have as much motivation after the project ends."</p>	Social interactions must be confined by the boundaries of a project or some temporary activity. They will not extend over time merely through participants' incidental colocation at the makerspace. Short-lived social interactions are often focused and goal-driven.

C2: Social interaction:
Temporal aspects

CS13: Accessing diverse institutional resources

Social interactions draw on institutional resources from a variety of epistemic or creative fields.

"Sometimes you need to talk to someone that has knowledge in a particular craft or field....I have knowledge in some of my own fields and specialities that he wouldn't have even thought of using, so there's a collaborative effort...."

"I'm an oddity. Females in hackerspaces with engineering backgrounds are few and far between. Some of the more craft elements knitting sewing crafting, soft circuitry, that's where there's a break in the community. It's still a really weird mix, from programming backgrounds, mechanical backgrounds."

These social interactions do not only draw upon the skills of the individual community members for their success. Member skills come in the context of the member's belonging to a certain field, whether a professional, epistemic one or a creative field. The institution of the field has conferred the skill on the community member, not the community itself.

C3: Social interaction:
Nature of social ties

CS14: Interpersonal trust

Social interactions are characterized by trust between community members that comes from their interaction with one another over time.

"We don't have the drama that others have."

"It's not like all flower child and peace love and harmony. On the other hand, it's pretty nice."

"In this space here we all have an understanding we're not here to do those backdoor deals.... The only guy I'm worried about is [describes man]."

Trust of the interpersonal variety is developed through community members' exposure to one another. This exposure does not have to be face-to-face.

C3: Social interaction: Nature of social ties	CS15: Institutional trust	Social interactions are enhanced by the trust community members have given other members' affiliation with a certain institution. The institution provides the standards and vetting process that engender trustworthiness.	"I moved here for hackerspaces, 3D printing - hackerspaces didn't exist everywhere.... I thought...you paid a membership and had access.... Architecture firms - they couldn't be more different an environment from makerspaces. They're super clean, everything's planned in phases, everyone's working toward one goal. A hackerspace is chaotic more like an art studio." "So [makerspace X] the organization does very little.... The organization exists to make sure that [makerspace X] the space continues to function."	Institutional trust may not be trust that comes from spatial or relational proximity over time, or even membership in the community itself. The community is separate from the institution. The institution confers legitimacy on the individual.
C3: Social interaction: Nature of social ties	CS16: Reputational trust	Social interactions that are enhanced by reputational trust depend on the knowledge the community member has of another member's skills, personality, or other assets.	"All of our members have been selected because of who they are, as people, not because of what attributes they have." "Even though I'm not at a hackerspace if I'm meeting with a fabricator if that fabricator comes from a hackerspace they will get it, they won't be like oh the drawings are wrong. So there's more that culture of learning."	Reputational trust differs from interpersonal trust in that the trust may precede the community member's exposure to another community member. The reputation of a community member is promulgated through the group such that one member of the group that has never met another will trust the other.
C3: Social interaction: Nature of social ties	CS17: Trust from weak social ties	Social interactions that depend on trust from weak social ties are those resulting from participating in a common activity	"Small companies are it. There's sort of that network - Amsterdam's that great network....[describes 3D Hubs]. Everyone knows everybody. For some reason everyone's tied to Amsterdam." "If you're moving from San Francisco or another	Weak social ties will be those that have involved notably limited contact between community members. Community members will be fairly autonomous. Their connection will have come

but not from direct contact.

environment, directly jumping into a hackerspace is really great for getting to meet people, almost like a social club. I've definitely gotten jobs out of there, that's been huge."

about through common work, common institutional affiliation, or calculated loyalty.

C4: Innovation

CS18: Radical innovation

Innovation produced by community members will be broadly impactful on the market economy.

"[IDFT is] how to make it faster, cost less, make it more available."

"I say in the next 20 years it's gonna happen [every home will have a 3D printer]. I think there is a big need for the final quality of these machines before they enter everyone's home."

Radical innovation must be successful on the market, achieved a notable level of adoption, and constitute an important change in product or process.

"The best way to predict the future is to create it. If someone else doesn't do it, I'm definitely going to do it".

"[The difference between those who innovate and don't] is not education, it's drive and motivation, it's a personality trait - if you have the motivation to work on something you're passionate about."

"A lot of companies have come out of this [makerspace]."

"I think the professional force is going to drive that and then there will be a trickle down effect."

C4: Innovation

CS19: Incremental innovation

Innovation produced by community members is customized, small in scale and scope, and not broadly impactful on the market economy.

"The benefits of scale is a fundamental economic concept, I don't think you can get around that."

"Think about the majority of people printing off stuff...most people print out plastic trinkets."

"What happens now is that a makerspace is a kind of go-between from your idea to getting the prototype, and then you would leave and go to a manufacturing facility or outsource."

"For better or for worse - people have said to me, I want to make this [new type of 3D printer] because I wish I had one. Some people say that's a reason to do it. Others say it's not a real breakthrough. People don't say it's not right or wrong in the practical not moral sense. Do something that's patented, who cares. Reinvent the wheel, no one cares!"

"As soon as you start making money it's better to have equipment that is proprietary and well-made."

Incremental innovation may achieve success in the market, but will not be impactful due to its limited functionality and adoption. It will constitute a change in product or process, but will not be a significant change.

C5: Organizational dynamic	CS20: Hierarchically managed	The community is managed hierarchically, with centralized control of decision-making, asset allocation, and membership and partnership policies.	<p>"[The founder] was spending so much of his own money he didn't want that [board] structure."</p> <p>"It's interesting to see founding members' impact, the local ideology, who is it descended from.... There's news articles and publications on those spaces.... how the general culture wants to see them. Versus the actual people interacting. It seems often strange because it's a very communal thing people want to do but they also want to keep it isolated and pure."</p>	The structure of the organization is centralized under a small number of people who have exerted control over major decision-making, assets, and organization policies over time. Decision-making is effectively unopposed and fast. Community members do not have substantial input into organization management.
C5: Organizational dynamic	CS21: Peer management	The community-as-organization is managed by most community members rather than by a small number of community leaders.	<p>"There is no reason to be a nonprofit, but it's a typical makerspace model that worked well for large groups of people."</p> <p>"No hierarchy.... The group, a quorum [makes decisions]."</p> <p>"Hackerspaces are great but I don't know if 3D printers are the thing to be in there, and I also don't know if you can get a space to run efficiently with the members having directive as to what the space will do. The core part of hackerspaces is people's excitement about it - so the excitement changes how things progress, how things change."</p>	The structure of the organization is distributed over a large percentage of the membership. Decision-making is subject to the influence of many members, who have substantial input.

C5: Organizational dynamic	CS22: Institutional restriction on entry of new members	The organization sets criteria for member inclusion and accepts and rejects applicants based on them.	<p>"I've don't believe we've ever turned down a member that applied. In the sense of being public. I just want to clarify. People can just walk in, it's not really public. It's open when there's a member that's willing to let someone in. It's not completely open, but there's no barrier...."</p> <p>"So we are somehow responsible for the operation of the space, and so we just sort of share that responsibility. Other than that, so (sighs), membership is a sort of long process...."</p>	The organization will have either written or unwritten criteria to guide decision-making on the induction of new members. Membership will not be open to all who are interested or can pay the membership fee. It is instead determined by incumbent members.
C5: Organizational dynamic	CS23: Group or project managed	Management of community activities is by a group that has formed to address a specific project, rather than by the entire organization or institution.	<p>"I see a lot of people come by when they're interested in a project and then don't come by when they don't have as much motivation after the project ends."</p> <p>"I don't notice that I care about other people's projects. I think they care about my projects when they talk to me. We have a general interest that we don't care about. We don't worry about if a project is enough. I'm not being tested to see if I'm being social."</p>	Group members are (a) subset(s) of an organization(s). Management is tailored to this temporary group and designed to effect the successful completion of a project.
C5: Organizational dynamic	CS24: Organizational openness: self- regulating	The level of openness of the organization is self- regulated by all community members without the use of or need for a centralized, coordinating body.	<p>"[No one is barred from entry] unless there's been an explicit reason why we've blocked you from the space. These kinds of things happen.... It's what happens when you have a community. Occasionally you need to not have people be a part of it.... Someone said the other day, 'we are exclusive so we may be inclusive'."</p> <p>"If the makerspace is about entrepreneurship,</p>	To be self-regulating in its openness, a community will collectively come to decisions. A central managing body or group moderators will not decide on new members, rules for participation, decisions to partner with outside

Self-regulation characterizes open source development communities.

depends on people and how they see themselves - if they're guarded [in regard to intellectual property] they'll never get it off the ground."

organizations, or other policies of openness.

6.3 *Knowing in action* schema

Table 3: Categories for Qualitative Content Analysis were deductively derived from the varieties of knowing in action given in this table from Amin and Roberts (2008)

Varieties of knowing in action						
Activity	Type of knowledge	Social interaction			Innovation	Organisational dynamic
		Proximity/nature of communication	Temporal aspects	Nature of social ties		
Craft/task-based	Aesthetic, kinaesthetic and embodied knowledge	Knowledge transfer requires co-location—face-to-face communication, importance of demonstration	Long-lived and apprenticeship-based Developing socio-cultural institutional structures	Interpersonal trust—mutuality through the performance of shared tasks	Customised, incremental	Hierarchically managed Open to new members
Professional	Specialised expert knowledge acquired through prolonged periods of education and training Declarative knowledge Mind-matter and technologically embodied (aesthetic and kinaesthetic dimensions)	Co-location required in the development of professional status for communication through demonstration. Not as important thereafter	Long-lived and slow to change. Developing formal regulatory institutions	Institutional trust based on professional standards of conduct	Incremental or radical but strongly bound by institutional/professional rules Radical innovation stimulated by contact with other communities	Large hierarchical managed organisations or small peer managed organisations Institutional restrictions on the entry of new members
Epistemic/creative	Specialised and expert knowledge, including standards and codes, (including meta-codes) Exist to extend knowledge base Temporary creative coalitions; knowledge changing rapidly	Spatial and/or relational proximity. Communication facilitated through a combination of face-to-face and distanced contact	Short-lived drawing on institutional resources from a variety of epistemic/creative fields	Trust based on reputation and expertise, weak social ties	High energy, radical innovation	Group/project managed Open to those with a reputation in the field Management through intermediaries and boundary objects
Virtual	Codified and tacit from codified Exploratory and exploitative	Social interaction mediated through technology—face-to-screen. Distanced communication Rich web-based anthropology	Long and short lived Developing through fast and asynchronous interaction	Weak social ties; reputational trust; object orientation	Incremental and radical	Carefully managed by community moderators or technological sequences Open, but self regulating

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6.4 Process model for deductive category assignment

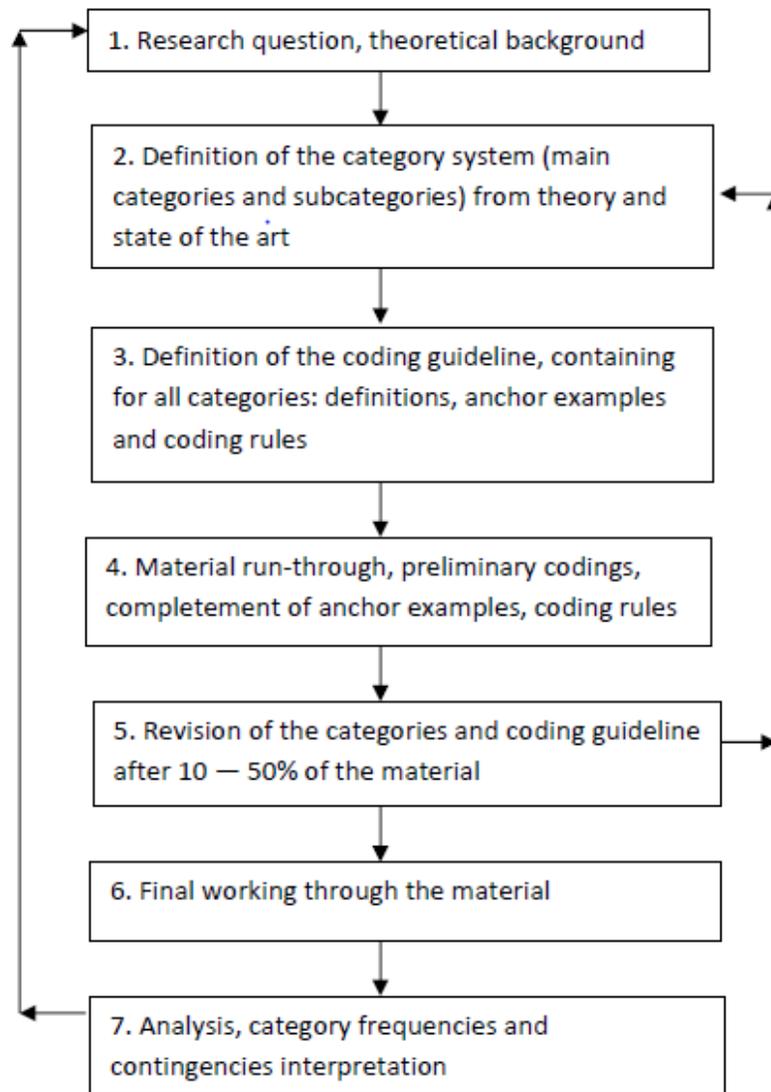


Figure 19: The process model for deductive category assignment as in Mayring (2014) chapter 4.6.4

6.6 Institutional Review Board approval for this study

This study, **IRBNet ID 591708-1**, was approved by the Hunter College Institutional Review Board, or the Hunter College Human Research Protection Program (HRPP) office. The research institution it was associated with was Hunter College (CUNY), New York, NY.

The effective date of its approval was 9/24/2014 under the title “The Innovation Makerspace: Innovation in 3D Printing on the Scale of the Meetup”. Its expiration date is 9/23/2015.

The principal investigator was listed as Kathryn Dickerson.

Documents submitted to and approved by the Hunter College IRB were:

- CUNY - Application for Approval to Use Human Participants in Research, Part I
- Application Part II
- Supplement Part E
- Informed Consent
- Consent - oral and internet
- Interview Questions - Makerspace Participants
- Interview Questions - Expert Interviews
- Short Survey
- Intro Script (to introduce self to recruit subjects)
- Email - Requesting Permission to Conduct Interviews at Makerspace
- Email - Proposing In-Person Interview
- Email - Proposing Email Interview
- Email - Proposing Phone Interview

The Hunter College Human Research Protection Program (HRPP) office may be contacted at (212) 650-3053 or via email at hrpp@hunter.cuny.edu.

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