Atoms matter: The role of local makerspaces in the coming digital economy[§]

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1. Introduction

Since before the public Internet, there has been popular and scholarly interest in the creation of virtual, digital communities — self-selected affinity groups not bound by geographic propinquity or synchronicity. As Rheingold (1993: 4) observed: "The technology that makes virtual communities possible has the potential to bring enormous leverage to ordinary citizens at relatively little cost." Proclaiming the "death of distance," Cairncross (1997: xii) predicted that "Common interests, experiences, and pursuits rather than proximity will bind these communities together."

And yet, in the 21st century there is evidence that the importance of physical presence in building community cohesion is not dead yet. Whether tied to specific activities that require hands-on activity, the higher communications and relational bandwidth of face-to-face interaction — or merely a reaction against the virtualization of societal interaction — individuals continue to gather together for side-by-side, face-to-face interaction.

Here we focus on a particular class of local and physical community that is commonly referred to as a "makerspace." As the name implies, these are shared physical spaces that provide tools and other equipment that allow people to create tangible objects. While inspired and fed by the intrinsically motivated "maker" movement of the early 21st century, these facilities have also lowered entry barriers for entrepreneurs seeking to design new tangible products and bring them to market.

At the same time, these spaces are tied to the modern digital tools for creating, sharing and reproducing digital representations of physical objects, and new tools such as 3-D printers that fabricate the intangible into the tangible (cf. West & Kuk, 2016). If the late 20th century focused on digital designs that were comprised of bits, the early 21st century has brought a renewed interest in designing and making physical objects comprised of atoms.

Our analysis seeks to explain the societal and economic forces that have spawned and supported these facilities, and in particular, the different audiences that are served by these facilities. By contrasting them to the development of earlier clubs for personal computer hackers and other hobbyists, we suggest the potential long-term direct and indirect effects of these spaces on the maker movement, and discuss implications for makers and artisans more broadly.

2. Origin of Makers and Makerspaces

The focus of the "maker" movement is to leverage the latest knowledge and equipment to empower individuals to design and make physical objects. These individual inventors may have intrinsic motivation (personal enjoyment), a desire to create a profitable new business, or — as with user entrepreneurs (Shah & Tripsas, 2007) — a combination of both. These sort of creative

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individuals are not new, as they have existed for centuries (if not millennia); what's new is the availability of tools, knowledge, and institutions that both enable creating such objects, and also sharing the designs and skills for producing such creations.

The "Maker" Movement and its Antecedents

The maker movement of the 21st century involves individuals (not affiliated with a firm) creating new tangible objects. Some of these creations are highly innovative, while others are incremental or derivative of established designs. Similarly, some makers are motivated by the prospects of riches while others do so for intrinsic gratification. However, the common thread is reducing barriers and empowering individuals to design and make physical things.

There are many antecedents of the maker movement. Some can be traced to individual artisans in pre-industrial eras who made incremental improvements to their existing products (Epstein, 1998). Amateur inventors in the 18th century consciously sought breakthrough technologies to solve a long-held problem, whether carpenter John Harrison creating a chronometer accurate enough to calculate longitude (Gould, 1923) or would-be lawyer Eli Whitney building a gin to extract cotton fiber (but not seeds) from the cotton plant (Green, 1956).

Numerous antecedents can be found in the 20th century. Early in the century, tinkerer experiments were credited with inventing the airplane (Meyer, 2007) and perfecting the automobile (Franz, 2011). In the postwar era, individuals invented electromechanical devices such as automatic sprinklers and intermittent windshield wipers (Anderson, 2012) while hobbyists such as Steve Wozniak created the personal computer industry (Moritz, 1984).

A major influence came from the democratization of computing from 1975-2000, through the successive impact of personal computers, the Internet, and open source software. The Homebrew Computer Club began in March 1975 as a way for Silicon Valley hobbyists to discuss making the Altair 8800 kit computer, but shifted to discussing their own personal computer designs (Moritz, 1984). The club eventually spawned Apple Computer and more than a dozen other startups.

The PC revolution empowered individual consumers, hobbyists and entrepreneurs, leveraging Moore's Law to put ever more powerful computing equipment in the hands of individuals. By the end of the century, the average (developed country) consumer owned a personal computer that was orders of magnitude faster than a 1970s-era supercomputer such as the Cray-1, enabling computer-aided design and manufacturing of 3-dimensional objects on ordinary home computers.

Meanwhile, the Internet enabled individuals to form online virtual communities around a range of personal, social and political interest (Rheingold, 2000). Together, the diffusion of personal computer and Internet technologies enabled such virtual collaborations to produce a class of shared information good known as open source software (West & Gallagher, 2006). The advent of free and open source software created legal and social institutions that reduced the transaction costs of collaboration, by providing role models, contracts, licenses and tools that made it easier to form new collaborative efforts (Dalle & Julien, 2003).

Individuals contributed to peer production of open source software for a variety of reasons, including intrinsic enjoyment, personal utility ("scratching an itch") and signaling skills to the job market (von Krogh et al, 2012). In other cases, entrepreneurial programmers took advantage of the lowered entry barriers to start new companies (Dahlander, 2007).

The linkage between digital and physical design — and the relative neglect of "atoms" in favor of "bits" during the 1980s and 1990s — was ironically[1] identified early in this century by the MIT Media Lab. In November 2001, the lab announced it had received $13.75 million National Science Foundation grant to form a new center, the Center for Bits and Atoms "to explore how the content of information relates to its physical representation. … Among the challenges to be tackled will be developing 'personal fabricators' to bring the malleability that personal computers provide for the digital world into the physical world" (MIT, 2001).

Built using the same microprocessors that made possible the personal computer, the ability to translate digital designs directly into physical objects was made possible in the 1970s by the sale and adoption of computer numerically controlled (CNC) mills and lathes — first connected to large computers, and then as stand-alone and PC-enabled devices. When combined with computer-aided design (CAD), these tools allowed for high-speed cutting a computer-defined design from a raw piece of wood or metal (Åstebro, 2002; Gibson et al, 2010: 9-12).

In 1987, the first "additive" manufacturing machine was sold that allowed computer-controlled creation of arbitrary shapes by melting plastic (later metal powder) — launching a new product category later termed a "3-D printer"; these early machines sold to large industrial customers for more than $100,000 each (West & Kuk, 2016). Beginning in 2005, consumer oriented 3-D printers were sold for less than $10,000 and later $1,000, with low entry barriers spawning the entry of more than 140 new manufacturers in this segment in less than a decade — most of these in the US and Europe (Bock et al, 2014).

The modern "maker" movement is often traced to the January 2005 launch of *Make* magazine by O'Reilly Media, the leading U.S. publisher of books on open source software. The planned launch was announced the previous July at O'Reilly's annual open source software conference by O'Reilly vice president Dale Dougherty (Tocchetti, 2012). As publisher of *Make,* Dougherty is credited with coining the terms "maker" and "maker movement."

In April 2006, the magazine launched an annual "Maker Faire" in San Mateo, midway between San Francisco and Palo Alto. The annual fair grew from 22,000 attendees in 2006 to 215,000 attendees in San Mateo and New York City in 2014 (with another 545,000 attendees at related events in seven countries that year) (Maker Media, 2015). Attendees at the 2014 conference were interested in science (64%), 3D printing (56%), electronics (53%) and robotics (44%) with substantial interest in cooking (50%), photography (40%), gardening (38%) and woodworking (33%). They tended to be married men, with a median household income of $130,000 and a median age of 44; 78% were college graduates and 35% had a graduate degree (Maker Media, 2014).

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[1] The Media Lab was founded in 1985 to focus on the digitalization of design (and society more broadly) into binary digits (bits). It was most prominently identified with Nicholas Negroponte, its founder and director from 1985-2000, who made his reputation in the 1990s as a leading futurist and advocate of such digitalization (e.g. Negroponte, 1995).

The maker movement subsumed earlier handicrafts, as represented by Etsy, an online marketplace dedicated to selling handmade items (Abrahams, 2008). As the Maker Faire attendees suggested, it also included new forms of electronic experimentation — with new circuit design facilitated by open source hardware projects such as Arduino (Powell, 2012).

Perhaps one of the most dramatic changes of the 21st century was the availability of computer-controlled fabrication. The widespread dissemination of PC-hosted software design tools — along with Internet-enabled online communities and common file format — allowed amateurs to design and fabricate tangible objects (Anderson, 2012: 21; West & Kuk, 2016).

In some cases, individuals created these designs to share them (Anderson, 2012). For example, the Thingiverse online community attracted more than 13,000 user-contributed digital representations of physical objects in its first five years. Such representations both enabled consumer experimentation and also created demand for 3D printing manufacturers and service bureaus (West & Kuk, 2016).

In other cases, the users utilized the technologies to speed products to market, as when Silicon Valley startups DodoCase and Square utilized the TechShop lab in Menlo Park to rapidly iterate prototypes and speed their products to market (Chen, 2013). A recent study of 3D printer startups suggested that 80% of the investigated companies were started with help from local maker spaces (Greul et al 2014); these include Ultimaker which originated in FabLab Utrecht (Walter-Herrmann & Büching, 2014: 199) and MakerBot which came from a New York city maker space (West & Kuk, 2016). Many of these entrepreneurs are commercializing solutions to their own needs – as when Square founder Jack Dorsey was unable to accept a credit card sale — following the model of user-entrepreneurs described by Shah & Tripsas (2007).

Maker Labs and Makerspaces

Most makerspaces provide shared fabrication equipment at a physical location, with formal or informal instruction available from the operator, contract teachers or fellow hobbyists. For example, Mortara and Parisot (2014) identified 73 makerspaces in Europe and the US in 2013: using a cluster analysis of their equipment, business model and other attributes, they identified 13 distinct categories: eight different groups run by for-profit businesses, three types of community-run labs, and two types run by government or university libraries.

An early antecedent of these spaces would be found in the hacklabs that began in Europe around 1995. These labs provided access to recycled PC hardware running Linux and other free and open source software[2], as well as training in computers and electronics. They differed from later maker spaces in their lack of digital fabrication — and also in a strong political orientation tied to anarchist and other anti-capitalist movements that rejected proprietary software business models. By 2008, they had begun to evolve towards an emphasis on physical production in facilities now referred to as "hackerspaces" (Maxigas, 2012).

2 The hacklabs emphasized the "free" software of the Free Software Foundation rather than the open source software of the Open Source Initiative. While they overlap in IP policies and production processes, these two differ in their emphasis: "free" software was more political and ideological and "open source" software was more utilitarian and commercial (Dedrick & West, 2008).

The idea of a local workshop organized around shared fabrication tools originated at MIT's Center for Bits and Atoms and with its first director, associate professor Neil Gershenfeld. After teaching a fabrication class at MIT since 1998, Gershenfeld had a vision of empowering individuals by making tools widely available to individuals. With NSF support, he organized the first Fab Lab in Boston in 2002. The center defined a standard configuration and a charter that emphasized open access to labs, free knowledge dissemination and protection of IP rights. Building on this, over the next decade the concept was spread to more than 100 sites on five continents (MIT, 2001; Walter-Herrmann & Büching, 2013). In 2009, the center created the Fab Foundation as an independent non-profit with four major goals: "the creation of new Fab Labs, training for fabbers around the world, the development of regional networks [of Fab Labs] and the development of international projects [between these networks and labs]" (Fab Foundation, 2015).

Finally, a small but highly influential for-profit makerspace was TechShop, which opened its first location in October 2006 in Menlo Park near Stanford University. It later moved that site further north and opened locations in the Bay Area's two largest cites — San Jose and San Francisco. It also opened seven other locations outside California (including locations in Portland and Raleigh, NC that later closed) and announced plans to open two more locations (Hurst, 2014).

The Fab Lab and TechShop represent two competing approaches towards the same goal. The minimum Fab Lab configuration is simpler and less expensive, and the decentralized organization and ownership has brought more than 500 sites on six continents. Meanwhile, the TechShop model has a larger, more elaborate configuration that (the company reports) costs more than $1 million per location. As such, it has fewer but more sophisticated sites (Table 1).

Both have three common fabrication devices: a lathe and CNC mill for metal work, and a 3D printer using fused-deposition modeling (FDM[3]); TechShop also has the corresponding tools for working in wood and fabric. Both have computer-controlled machines for cutting 2-dimensional vinyl sheets (for making signs) and a 3-D laser cutter (for cutting plastic, wood and some metals). The Fab Labs include a recommended inventory of software and electronics parts, specifically (as of Aug 2015) the Arduino and Raspberry Pi open source embedded circuit boards.

Global Diffusion of Makerspaces

To estimate the worldwide population of makerspaces, in August 2015 we analyzed lists of local sites as provided by online directories at three websites:

- **FabLabs.io[4]** listed 531 Fab Labs, of which 249 are in Europe, 150 are in the Western Hemisphere and 132 are in Africa, Asia or Oceana (Table 2).
- **TechShop.com**: the company had eight sites open thus far, with three in the San Francisco Bay area, and one each in Arizona, Michigan, Pennsylvania, Texas and Virginia

3 FDM is the least expensive and most common technology for consumer-level 3D printers (West & Kuk, 2016).

4 Although not part of the official Fab Foundation website, the foundation's website references FabLabs.io as the authoritative list of local Fab Labs around the world.

- **HackerSpaces.org** listed 1,185 active "hackerspaces"[5] worldwide, with 287 in the United States. The largest concentration are 39 hackerspaces in California, including 13 in the San Francisco and 11 in Los Angeles metropolitan regions. These 39 include three TechShops and one Fab Lab; of the remaining 35 hackerspaces, 30 appeared to be independent makerspaces with tangible fabrication equipment such as a CNC machine or 3D printer.[6]

Table 1: Comparison of two prominent multi-location makerspaces

Source: FabFoundation.org, TechShop.ws (August 2015)

Makerspace		**Fab Lab**[7]	**TechShop**
First location		2002	2006
Organization		Nonprofit franchising independent locations	Chain of for-profit subsidiaries
Number of global (US) sites		531 (93)	8 (8)
Representative size		320 m^2 (3,444 ft^2)	"15,000+ ft^2" (1,400+ m^2)
Estimated cost		$106,000-$122,000	"over $1 million"
Selected tools	Metal	Metal lathe CNC mill	Metal lathe CNC mill (2) Welder (3) Plasma cutter (2) Tubing bender
	Plastic	3D printer (FDM) Resin and plaster casting kits	3D printer (FDM) Injection molder Vacuum forming station
	Wood		CNC router Lathe Table and band saw Compound miter saw
	Electronics	Oscilloscope Function generator Power supply Inventory of digital, analog components and circuit boards	Oscilloscope Signa generator Power supply Frequency counter Multimeter
	Fabrics		Sewing machine Serger Computer-controlled embroidery machine
	Other tools	Vinyl cutter Laser cutter	Vinyl cutter Laser cutter

5 The website offers this definition: "Hackerspaces are community-operated physical places, where people share their interest in tinkering with technology, meet and work on their projects, and learn from each other."

6 The original list of 39 California sites includes four groups without such facilities and a fifth group now defunct. It did not include six facilities we could identify — five additional sites on the FabLabs.io website (one independent Fab Lab and four private labs at educational institutions) and an independent lab (Vocademy in Riverside) that we visited as part of the field study described below. Thus 31 of 40 (or 78%) of the maker spaces in this one sample were independent labs.

7 Combines both "Ideal Lab Layout" and recommended "Fab Lab Inventory"

Table 2: Fab Lab locations by country, August 2015

Source: FabLabs.io

France	51	US	93
Italy	51	Canada	7
Benelux	40	Latin America	50
UK	21		
Germany	19	Russia	15
Spain	15	Japan	12
Scandinavia	14	India	10
Switzerland	11	China	6
Central Europe	11	Taiwan	5
Rest of Europe	16	Korea	4
Africa	20	Rest of World	60
		Total	531

3. Field Study of Makerspaces

To better understand the nature and motivations for the increasing popularity of makerspaces, we conducted an observation- and interview-based field study. The primary data from active makerspace members regarding the benefits of physical over virtual communities served as a supplement to the secondary data presented above.

We followed the guidelines of purposeful sampling when selecting the participants for the interviews (Miles, Hubermann, & Saldana, 2013). A total of 32 semi-structured interviews were conducted face-to-face at makerspaces and firms in Southern California; these were supplemented by face to face and telephone interviews of makerspace users and managers elsewhere in the US and Europe (Table 3). Some of the users were clearly hobbyists, others had already started a business based on their makerspace utilization, while others appeared to be nascent entrepreneurs (cf. Carter et al, 2003) contemplating a potential startup.

These 32 interviews — with an average length of 28 minutes — were recorded and transcribed for subsequent analysis. Our interview protocol focused on the makers' motivation to join and stay in a local makerspace, the benefit of physical vs. virtual communities, and the reasons why people start a makerspace.

Table 3: Interview sample

	Role in makerspace			
Location	*Founder*	*Employee*	*User*	*Total*
Southern California	3	2	21	26
Other U.S.	1	1	2	4
Scandinavia	1	-	1	2
Total	5	3	24	**32**

To analyze the transcribed interview data, we followed an inductive coding strategy with the aggregated constructs emerging during the data collection process (Miles et al., 2013). We initially coded the user and founder interviews separately, but found that (not surprisingly) the two groups had similar views on the benefits of having makerspaces — so we then performed our coding on the combined sample. Based on the data, the 10 first order categories of motives were grouped into three second order themes.

Three themes represent the major factors that distinguish online communities from makerspaces: the availability of tools, the empowerment of individuals and the face-to-face interaction within the community. As discussed below, these motives and themes are consistent with the precepts of the maker movement and highlight the strong linkage between physical presence and tangible fabrication.

Access to Tools

One theme that emerged from the interviews is the benefit of the wide availability of tools makerspaces offer to individuals. This access to a wide variety of professional and expensive equipment is the stated reason for creating such makerspaces, and is proffered as the main reason why makers should (and do) join these spaces (Table 4).

Availability of diverse and expensive tools. By analogy to personal computers, Walter-Herrmann and Büching (2013) claim that fablabs enable people to access digital fabrication devices and will similarly be used in everyday life. In line with this, we found that makers value the unique access to diverse and expensive tools that are otherwise only available to larger organizations. Makerspaces enable individuals — without the financial resources to purchase expensive machines like 3D printers or laser cutters — to work on their ideas and realize their projects. This access empowers people to pursue their ideas independently from established service companies. Without the access to those tools makers are constrained to utilize special companies which offer production as a service.

Opportunity to experiment. Another benefit that emerges from the diversity of tools is the chance to test different machines and experiment with them before committing eventually to a purchase (Table 4). Makerspaces often function as a showroom for new and cutting-edge technologies, enabling makers to view the machines in a real-life environment and experience them personally. Makers and founders see in makerspaces a chance to uncover new talents and skills by being able to try different kinds of machines and production styles.

Joy of making. Makerspaces also provide members an environment that enables them to work with physical things and create real tangible objects. In times where more and more aspects of our daily lives are driven by electronics or digital technologies, makers are fascinated by mechanical movements and the haptic feeling of parts when working on physical projects. Makerspaces and fablabs represent a playground where people can play, experiment, and learn. This finding is consistent with other studies that found that — independent of age — fun plays a major role for members to participate in makerspaces (Walter-Herrmann & Büching, 2013).

Incubating a startup. With their diversity of tools, makerspaces also provided entrepreneurial hubs where early-stage entrepreneurs can realize their business ideas, test their prototypes, and start production. Founders and makers describe the entrepreneurial spirit and atmosphere that provides a foundation for new business ideas. Members with different background provide valuable feedback both in technical and business related topics.

Table 4: First theme: access to tools

Motives	Exemplary quote
Availability of diverse and expensive tools	*"[…] the Makerspaces have tools available that are inaccessible. You know, the big thing is like laser cutters or CNC machines [...] if you want to play with that stuff or use it and not go to a big company to have something done for you, this is the place to be."* - Sam (Maker) 22 Oct 2014
Opportunity to experiment	*"So I know that Makerspaces is one of the places that people go […] sniff it out if they don't know, besides online."* - Mark (Maker) 29 Oct 2014
Joy of making	*"I think basically I've been a maker all my life. I've always been tinkering and curious about building things. And I mean I started with electronics, then I got into software and then I got bored with software so then I got into hardware and that led me to, you know, things that moved and things that can talk to each other like networking. So then I got into CNC machines because of that."* - Arman (Maker) 18 Nov 2014
Incubating a startup	*"[…] we found out that they had an office space for rent so we decided to move here."* - Paul (Maker) 31 Oct 2014 *"Blue Eagle Labs […] were in the middle of production for their 3D printers and they're hoping to use our space in hopes of lighting their load of production. […] They had done the crowdfunding and […] were trying to catch up on the fulfillment"* – Dannie (Maker) 12 Nov 2014 *"There were people in makerspaces that were no longer just hobbyists. They had ideas for products, but they had no idea how to take those products to market."* - Travis (Maker) 12 Nov, 2014

Personal Locus of Control

The second theme that members and founders pointed out in regards to makerspaces was the personal locus of control. Makerspaces empower individuals to help themselves by providing hands-on training and developing technical skills over time. Contrary to conventional educational institutions, makerspaces turn individuals from passive knowledge consumers into active participants in the educational process.

The interviews with founders of makerspaces revealed that their main vision for creating the local space was to contribute to society by educating people and providing them with technical skills. At the same time, prior research showed that such empowerment increases the likelihood of entrepreneurial activity by nascent entrepreneurs, who differ from non-entrepreneurs in their desire for self-realization and independence (Carter et al, 2003).

We found three categories of motives in this theme (Table 5).

Practical vs. academic training. Both makers and founders perceived an imbalance between academic and functional education in society, one that led to young people targeting academia rather than practical training. This absence of practical education was the major reason for people to found a makerspace.

Skill development. The makers' motivation to work in a makerspace is to learn how to apply the tools to realize their individual purpose and vision. Through extensive experience with different tools, they gain hands-on experience and can eventually become expert users. Hence, makerspaces serve also as an educational institution that conveys skills and knowledge away from academia.

Self-empowerment. Prior research defines the empowering process as the belief in one's own capability and competence (Duhon-Haynes, 1996). By developing their technical knowledge, members become independent and gain self-confidence.

Table 5: Second theme: personal locus of control

Motives	Exemplary quote
Practical vs. academic training	"In this country everybody is [in] academia. Well we're failing a lot of people. We're telling people that it's either college or you're a loser. Well no you're not a loser. You have a different intelligence. Not more or less, it's different." - Gene (Founder) 28 Oct 2014
Developing technical skills	"Basically to, initially it was to learn about 3D printers but I learn pretty quick and so it wasn't long before I was probably one of the experts there then." - Doug (Maker) 25 Nov 2014
Self-empowerment	"Ah, because we have so many friends who kept asking us for advice on how to do stuff. Because, we have so much, between Ben and I, we have so much maker knowledge, and then, you know, people would be like 'oh that's way too hard', and we'd be like 'no, you just use a glue gun'. And then one of my girlfriends actually said to me, 'how do you use the glue gun?' And I was like, 'oh no!' [laughs]. I was like, 'there's a need?'" - Lori (Maker) 17 Nov 2014

Social Interaction

While the original goals of the makerspaces were defined by the technology — as with hackerspaces and other similar groups — a major benefit for participants came in working side-by-side with others of similar interests. The participants identified both transactional benefits (solving a specific problem) and relational benefits (building ties that advanced their personal or professional goals).

By allowing participants to meet and work face-to-face, makerspaces provide a personalized interaction that contrasts with the more anonymous interactions in the virtual world. At the same time, face to face interaction provides for both qualitatively (richer) and quantitatively (higher bandwidth) improved interpersonal communications, engaging the senses of sight, hearing, smell, taste, and touch (Nohria & Eccles, 1992). The verbal and non-verbal communication enables four valuable outcomes to the members (Table 6).

Technical support. The direct interaction facilitates more effective support between the members as issues can be communicated without the need for long verbal explanations. While it is common also in virtual communities that members support each other with their experience and skills, participants in our interviews describe the interaction in makerspaces as faster and easier than in a virtual environment, where most social-context clues are filtered out. The makers in the interviews mentioned the different quality of support and expert tips they experience in the makerspace.

Learning from others. Besides concrete support and advice for specific issues, the aforementioned face-to-face interaction builds also the basis for long-term learning and build-up of knowledge and experience (Nohria & Eccles, 1992). Members learn from each other combining their own experience with the knowledge they get from others. The face-to-face interaction enables peoples' self-empowerment as already mentioned in the previous section.

Generating and sharing ideas. A third benefit that emerges from the interaction between members with interdisciplinary background is a lively environment in the makerspaces, which builds the seed for mutual inspiration and new ideas among the makers.

Entrepreneurial recruiting. Makerspaces introduced nascent entrepreneurs to local experts with overlapping interests, at a time when they were seeking partners or workers for their potential ventures. The interactions both allowed them to vet the skills of these potential founders or employees, and also to shop for skills that were complementary to their own.

Table 6: Third theme: face-to-face interaction between members

Motives	Exemplary quote
Support & help	"They would be able to say this one is really much easier than that one or you might get stuck here but you just have to fiddle with this thing, you know, those sort of tips you can't really online. " – Graham (Maker) 24 Nov 2014
Learning from others in the community	"You cannot imagine how people here are learning from each other. If it's not a class we teach, you're welcome to teach someone something you know. In other words, I won't let you teach the machines we have here but if you have a skill, share it. And that's what happens here and people become friends." - Gene (Founder) 28 Oct 2014
Generating and sharing ideas	"So it is a really open and friendly environment where people come together and are very prone to share their ideas." - Erik (Entrepreneur) 06 June 2014
Recruiting entrepreneurial partners and employees	"[This makerspace was] the second most important resource, since I found my people that work here now." – Diego (Entrepreneur) 01 May 2014

4. Conclusions

Makerspaces demonstrate the ongoing importance of physical presence and interaction in an increasingly digital world. As might be expected, much of the value realized by participants is tied to the access to specific equipment that allows physical fabrication of new objects — and also the learning that comes about through use of this equipment.

These spaces empower individuals to create digital designs and realize them as physical objects. In many cases, they are using tools such as 3D printers that were originally available only to large or medium-sized industrial firms; with falling prices and the shared costs of a community space, this equipment — and tangible creation capability — is now affordable and accessible for individuals, whether consumers or nascent entrepreneurs.

At the same time, bringing people of similar interests to a physical location creates stronger interpersonal ties than the virtual alternative. Part of this is because of the greater richness and capacity of mutual exchange made possible by face-to-face interaction (cf. Nohria & Eccles, 1992). But part is also because of the natural desire of humans — as social animals — for personal interaction and group identity (cf. Putnam, 2001). Even as interpersonal interactions move increasingly online, 21st century humans seek to build (or reinforce) social capital and a sense of community engagement through face to face interaction (Foth, Hudson-Smith and Gifford, 2016).

The urgency and efficacy of this face-to-face interaction is even greater for would-be entrepreneurs, who need to acquire both social and human capital (Davidsson and Honig, 2003). These nascent entrepreneurs seek to build their social capital by identifying potential customers, suppliers, employees and managers of their new enterprise. At the same time, they seek to build their human capital — the knowledge and skills relevant to their new ventures — by developing the nascent entrepreneur's own human capital, or by acquiring new human capital in the form of cofounders and employees. For new ventures making tangible goods, these skills relate to the design and production of such goods.

The Future of Makerspaces

What is the long-term future of these makerspaces? It seems necessary to examine this both in terms of the direct impact of the spaces as enduring institutions, and their indirect impact on individuals and the nature of tangible creation.

The first question is whether these makerspaces will become a permanent social and economic institution. Many have argued these spaces are the successors to the legendary Homebrew Computer Club (e.g., DiResta et al, 2015). However, the HCC only lasted from 1975-1986 as entrepreneurial member left to start their own companies — and the window for entrepreneurial entry into the PC industry began to close — while ordinary users could buy fully supported Apple, IBM and other model PCs from retail stores.

Conversely, model railroad clubs continue to thrive around the world, more than a century after the first club was founded in London in 1910. At this point, it would be difficult to predict whether makerspaces will continue to play a vital role in providing hands-on access to tools and face-to-face interaction (as do woodworking clubs and classes) or fade away as did local PC and open source clubs.

This latter issue suggests that researchers examining hobbyist and other local face-to-face clubs need to situate their studies in two broader external contexts. The first is the specific point in the diffusion of innovations from innovators and early adopters towards the late majority (Rogers, 1995), as the diffusion of technology fuels the democratization of innovation (von Hippel, 2005).

The second is the secular trend towards richer and more immersive virtual interaction, supplanting face-to-face interaction for many (but not all) interpersonal interactions.

Even if they do disappear, that does not mean that their importance is limited to helping a few people make a few objects during a brief period of time. Their potential long-term impact can be considered in terms of the entrepreneurial entry enabled by these spaces, as well as the changes in consumer attitudes towards making tangible objects.

To continue with the HCC analogy, the club is gone, but Apple — the company founded by former members Steve Jobs and Steve Wozniak — was recently the world's most valuable company, and continues to drive technological and market change in the consumer electronics, Internet and computing industries. Makerbot (acquired in 2013 by Stratasys) is only one of dozens of 3D printer companies formed out of local makerspaces (West & Kuk, 2016; Greuel et al, 2014). While these companies are likely to be combined through mergers and acquisitions over the next decade (as happened with PC makers 30 years earlier), the product category they created seems destined to remain and become more widely adopted.

In another parallel to the PC era, the experiences of these early makers could also enable the democratization of maker technology. The reality is that today's tools and training materials for digital fabrication are a long way from being ready for a mass market. As with any complex technical innovation (such as those described by Rogers 1995), improvements in ease of use are an essential prerequisite to market growth, while the revenues generated by such growth will enable firms to invest in making the necessary improvements. In that regard, the early makers who utilize today's makerspaces could become both the vanguard and the potential test audience for the widespread diffusion of digital fabrication technologies to the eventual mass market.

Makers and Artisans in the 21st Century

Ironically, a wildly successful personal 3D printer industry (spun off from makerspaces) that put a 3D printer in every home could potentially eliminate the need that most consumers have for a local makerspace. Conversely, shared fabrication spaces could continue, not as a nonprofit institution but as an Internet-enabled commercial service bureau such as Shapeways or Materialise (West & Kuk, 2016).

Whether through large centralized facilities that offer Amazon-style rapid delivery or through local 3D printshops, increasing demand (and falling cost) of tangible fabrication will certainly attract the entry of firms providing fabrication services. In some locations, digital fabrication could become part of the public infrastructure — housed in libraries or other city offices — much as cities provide water, electricity or other infrastructure services (cf. Mortara and Parisot, 2014). Will these devices or services continue to support social aspects of creation (as have makerspaces) or merely be a means to achieving a utilitarian end?[8]

[8] Exactly 100 years ago, sociability was an important attribute of the diffusion of telephone service in the U.S. through the use of the "party line" to share local telephone infrastructure (Fischer, 1988). However, the sociability provided by such shared access was later designed out of the system in the interests of increasing capacity and privacy.

How will the widespread availability of such fabrication change how individuals view creation and tangible objects more generally? One possible impact would be continuing growth of the maker movement, which would include not only fabrication but markets for sharing or selling designs (such as Thingiverse and Shapeways). This optimistic view is held by Michel Bauwens — an activist for peer-to-peer production and founder of the P2P Foundation — who said:

> What are the fablabs and hackerspaces, in my opinion? They are the reinvention of the artisanal regime for the digital age. In the industrial regime, there was a division of labor between workers and designers-managers. As I see it, what is most interesting about fablabs is that they take us back to the [artisanal] knowledge regime. For me, a "faber" [latin for 'maker'] is a thinker who makes and a maker who thinks. So, it really is a reunion of those two aspects of human work that had become separated. But it is a post-industrial artisanal regime, one that still has all the advantages of the industrial regime. Thus, knowledge and know-how can now be shared globally, rather than just between neighboring artisans. (Cassely, 2015; translation by Xavier Olleros)

In that regard, this technology would bring to digital design of physical objects the sort of creativity and experimentation that has been available with information goods for decades, thus furthering the democratization of innovation. It would also bring such digital design closer to more longer-standing forms of physical production — the artisanal design of the pre-digital era — such as woodworking or the handicraft markets represented by Etsy.

Finally, even if there are solutions for who and how individuals can become digital artisans, there is still the question of what they will be making and why they would want to do so. Smartphones were around for almost a decade before the "killer app" became obvious — access to the public internet (West & Mace, 2010). Today, the killer app for 3D printing (and digital fabrication) is not immediately obvious. Will it come from individuals creating their own digital designs and producing tangible instantiations, much as digital photography fueled demand for color printers at the beginning of this century? Or will it be driven by consumers fabricating the designs of others, just as photocopiers enabled the duplication of textbooks and other printed materials?

These questions of who, what, why and how these fabrication technologies will be used will determine whether makers become a movement that goes mainstream, or a small niche application of these fabrication technologies. The answers to these questions will help determine where the fabrication is done — whether at makerspaces, commercial services bureaus, public infrastructure or in the home. Together, these questions about the future of the maker movement and makerspaces will provide opportunities for further research for many years to come.

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