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Emerging Sites of HCI Innovation: Hackerspaces, Hardware Startups & Incubators

Silvia Lindtner[1,2], Garnet Hertz[1], Paul Dourish[1]

[1]Department of Informatics
University of California, Irvine
Irvine, CA 92767-3440 USA

[2]School of Computer Science
Fudan University
Shanghai 201203, China

{lindtner, hertz, jpd}@ics.uci.edu

ABSTRACT

In this paper, we discuss how a flourishing scene of "DIY makers" is turning visions of tangible, mobile and ubiquitous computing into products. Drawing on long-term multi-sited ethnographic research and active participation in DIY maker practice, we will provide insights into the social, material, and economic processes that undergird this transition from prototypes to products. The contribution of this paper is three-fold. First, we will show how DIY maker practice is illustrative of a broader "return to" and interest in physical materials. This has implications for recent HCI research that has begun investigating questions of materiality. Second, we shed light on how hackerspaces and hardware incubators are experimenting with new models of manufacturing and entrepreneurship. We argue that we have to take seriously these bottom-up maker practices, not just as hobbyist or leisure practice, but as a professionalizing field functioning in parallel to research and industry labs. Finally, we end with reflections on the role of HCI researchers and designers as DIY making emerges as a site of HCI innovation. We argue that HCI is positioned to provide critical reflection, paired with a sensibility for a deep engagement with materials, tools and design methods.

Author Keywords

Make, DIY, hackerspace, materiality, critical making, China, manufacturing, IoT.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Throughout its history, HCI has employed radical envisionment of future technologies as part of its research program. Many of the resulting visions have become landmarks in both research and industry, and have set directions for major research and industry programs [12]. Amongst them, we might count Alan Kay's writings on the Dynabook [22], Apple's "Knowledge Navigator" video, Sun's "Starfire" envisionment, Weiser's Scientific American article on ubiquitous computing [46], and Ishii and Ullmer's CHI paper on "tangible bits" [20].

These visions largely arose during a period when interaction design and the user interface were somewhat neglected topics in system design. Indeed, HCI as a discipline and a professional field developed not only a systematic body of knowledge around user interface design and evaluation, but also advocated for the importance of the user within the broader system design process [9]. Today, HCI conceptions of user experience and interaction design are at the heart of new product development and the technology transfer process. HCI, then, has been remarkably successful in shaping technological innovation. However, because of this greater prominence of interaction design and user experience in both the technology industry and the popular consciousness, HCI is no longer the only place where new interactional visions arise.

Take, for instance, Weiser's vision of a world of seamless, embodied experience of digital devices embedded into the fabric of everyday life. While this vision originally might have been devised in the corridors and meeting rooms of Xerox PARC several decades ago, it is a vision that is being developed, extended, and shaped not just by engineers in other companies, but by tinkerers, hackers, and hobbyists. In particular, a flourishing DIY ("do-it-yourself") or "maker" community is expanding HCI visions, methods and insights into commercial products. A quick glance at the crowd-sourced funding website Kickstarter makes this clear: examples include products like the Spark Core, an Arduino-compatible Wifi-enabled prototyping platform that raised over 500,000 USD in crowd-sourced funding on Kickstarter earlier this year. What the Spark Core does is seemingly simple: it turns a standard household appliance into a "smart" one. Once embedded, it brings to life what has long been the vision of ubiquitous computing: the coffee machine that brews the morning coffee when your

alarm clock on your mobile rings, the refrigerator that emails you the missing ingredient for dinner right when you leave the office, and the lamp that welcomes you with a warmly-lit living room when you finally arrive at home after a long day of work. The vibrancy of efforts like Spark Core marks an important shift in the way that a DIY maker ethos and new interactive products are connected.

DIY making is no longer just a hobbyist movement driven by a loose collective of computer enthusiasts, artists, designers, geeks, and developers. Central to this development is the confluence of crowd-funding websites such as Kickstarter, the proliferation of hackerspaces on a global scale and publications such as MAKE magazine. The combination of new economic funding models, physical spaces and publications is crucial here. While MAKE magazine helps spread an understanding of DIY making as a form of creativity, innovation and popular engagement with science and technology, hackerspaces provide the physical space and tools to bring people together in implementing these ideas in practice. These developments suggest taking DIY making seriously as a site of technology innovation that emerges alongside professional fields and disciplines like HCI.

In this paper, we examine DIY maker productions like the Spark Core as emerging sites of HCI innovation. Our particular interest is in the ways in which DIY making has extended beyond tinkering and hobbyist practice and become a site of industrial innovation. Drawing from long-term ethnographic research and active participation in DIY maker communities, we will examine the role hackerspaces, hardware incubators, and hardware startups play in this transition. They into innovation practices that were traditionally associated with research universities, large corporations, and research labs.

The Spark Core is illustrative of a whole series of hardware startups committed to embedding into new products aspects of the 1960/70s hacker ethos*, i.e.* the commitment to designing technologies that are modifiable by others, the open sharing of knowledge, and peer production. When DIY makers turn their open ideas into products, do they still practice "DIY" technology production? What concessions have to be made in regards to the openness of a product that is aimed at reaching a mass market? We will analyze in this paper, both the opportunities and the tensions that lie in this transplantation of the hacker ethos into a commercial endeavor of hardware production.

The rest of the paper is structured as follows: first, we discuss related HCI literature on DIY making. After describing our methods, we delve into discussing the findings from our research, with a particular focus on the role of hackerspaces, hardware startups and hardware incubators in contemporary DIY maker practice. In the discussion, we will examine, in light of our empirical cases, the changing relationship between DIY maker communities and HCI through the three lenses of amateur expertise, critical making, and materiality.

RELATED WORK: DIY MAKING & HACKING

Over the last half decade, there has been a growing interest in DIY maker and hacker practice within HCI [6. 16, 17, 25, 26, 27, 35, 36, 39, 40, 42, 44 45]. This prior work has explored DIY making as site of 1) novel forms of engagement with diverse materials including electronics as much as fabrics, wood, plastic, paper, etc. [6, 36, 39, 42], 2) community formation around lay expertise and open sharing [27, 35, 39, 45], and 3) in terms of its impact for research, design and teaching [25, 26, 27, 44]. Taken together, these works have shown that DIY making is a productive site for HCI research, design practice, and for teaching HCI as well as technology design more broadly.

Hartman *et al.* [17], for instance, illustrate that DIY maker practices such as mashing, hacking, and gluing can be understood as "opportunistic design." By this, they refer to a practice of design that integrates existing artifacts and site-specific tools to target a particular user or small community. The authors suggest that this development approach leads to increased fulfillment for the designer and allows for rapid prototyping. In addition to an altered relationship between prototype and product design, DIY maker practice has also been explored as a productive site for teaching and learning. Kolko *et al.,* for instance, demonstrate that DIY hacking is useful in teaching especially non-STEM students science and engineering skills, because of its hands-on and interdisciplinary form of engagement [26]. While this prior work has demonstrated the impact of DIY making in areas of prototyping, education, and learning, it is presented as a practice that takes place mostly outside of professional design and development. Tanenbaum *et al.* [40] reflect on this and argue that HCI researchers tend to portray DIY making as a recreational activity or as a hobbyist practice, e.g. [45].

In this paper, we are extending from these earlier efforts by focusing on contemporary efforts from within DIY maker movements toward entrepreneurialism, professionalization, and marketing. DIY making is more than just a novel form of material engagement. It is an emerging site, where technological visions are crafted into tangible products and alternate models for industrial development and design. In our fieldwork, DIY makers did not just utilize 3D printers and laser cutters in hackerspaces; they collaborated with manufacturers to scale up prototypes and reach mass markets. They worked with governments to set up educational programs and platforms, and partnered with venture capitalists to develop models of R&D. These developments call upon us to take into account how DIY making is extending into product design, industrial development, and manufacturing.

METHODS: WORKING WITH AND AS MAKERS

For our discussion, we draw from long-term research with DIY maker communities. This work includes ethnographic

research over the last 4 years and active participation in the maker scene through hands-on projects over the last 10 years. In total, we have conducted participant observation as well as formal and informal interviews at over twenty maker-related events such Maker Faires, Dorkbots, Start-up Weekends, Arduino workshops, and Barcamps throughout North America, Europe, Asia and South America. We have also conducted in-depth participant observation at four hackerspaces in China and two in the United States and at one of the first hardware incubators [18, 19, 30, 31].

This distributed nature of our inquiry is a key element of our research and of this community. DIY making and start-up culture has traveled beyond core innovation hubs such as Silicon Valley or New York City. This global context makes it increasingly important to ethnographically examine the mobilization of DIY making in relation to varied political and cultural structures. This paper, then, draws on our long-term engagement with DIY makers across regions. We will draw out findings from specific cases and sites, in particular from our long-term with

We organized and gathered data at eight workshops that investigated larger concepts and ideologies of contemporary maker culture through hands-on practice. Each event brought together scholars and practitioners concerned with DIY making and from diverse backgrounds, including but not limited to: HCI, the arts, design, engineering, and manufacturing. These workshops proved to be productive sites to distill themes or questions that had remained unclear throughout the ethnographic research [15]. Workshop topics included educational aspects of making, global questions of maker culture, and the role of future visions in the professionalization of maker practice.

We draw upon this long-term engagement with DIY makers to trace the ongoing transformation from hobby to entrepreneurial practice, manufacturing and product design. We begin by briefly discussing some of the origins of the hacker ethos and how DIY makers are reworking it into product design. We uncover this development as part of a broader transition from hacking to making.

FROM HACKING TO MAKING

Our contemporary landscape of information technology production has been profoundly influenced by the emergence of so-called "hacker culture" in the 1960/70s. Its members were committed to peer production, the open sharing of knowledge, and to designing technologies that were open and modifiable by users [21, 29]. From Mac OS X to Android, from Amazon.com to Google Chrome, the technology landscape is full of products that depend upon this alternative model of technology production, variously known as "open source," "peer production," "open innovation," and the like.

Fifty years later, we find ourselves in the middle of a new hacker movement that both draws from this history and departs from it in significant ways. It is rooted in a growing network of hackerspaces that expand the ideas of the Web generation into hardware. Hackerspaces are shared social studios that bring together people engaged in building creative technical projects through the free and open sharing of equipment, tools, software and hardware code. A typical hackerspace is equipped with computing tools that allow for experimenting with the physical/digital boundary—computer controlled laser cutters, 3D printers, and open microcontroller platforms such as the Arduino. The origins of the hackerspace movement developed in Europe, where the first hackerspace *C-base* opened in 1995 [3]. Today, with an estimated 700 to 1,100 active spaces in existence worldwide, hackerspaces are a significant global phenomenon [31].

The contemporary movement extends and in part remakes earlier hacker practice. While earlier generations invented the production and use of digital things and software, makers today are shaping the production and use of physical things and hardware. More importantly though, just as Web startups and the Bay Area counterculture drove aspects of new technologies and IT culture, so is the contemporary culture reinventing manufacturing and innovation in hardware. In other words, we are witnessing a parallel between the developments in the 80s, when the countercultural movement turned into the software industrial complex of Silicon Valley we know today [41].

Hackerspaces are crucial sites in this contemporary movement as physical spaces that provide social and technological resources for people to collaborate on the production of new technologies. Across the hackerspaces we visited, many people drew inspiration from the hacker movement of the 1960/70s and its impact on the broader IT culture. They were driven to bring the hacker ethos of earlier generations to the masses by designing and developing open hardware products. And they believed that this has the potential to lead to a significant transformation in current economic, social and political processes of industrial production by bringing the hacker ethos of earlier generations to the masses. One maker, for instance, put this as follows: "*if you look back into time, you see what's happening in the 60s and 70s. The 60s brought advances in computing. Its pioneers were people like Wozniak and Steve Jobs. They were makers, hackers, academics, and entrepreneurs. But this time around it's different. You have Kickstarter and VCs… Hardware startups today can really make anything possible. Everyday startups build new products, from biotech all the way to video games, new shoes, clothing, toys, vehicles, you name it. It's an exciting time to be in. Because of this the meaning of DIY changed. Today, DIY means that anyone can take a product to the market, with the support from the crowd.*"

This idea that the very essence of what DIY making means has changed is crucial here. It describes what many makers are strongly committed to: the democratization of technology production, enabled by the concerted effort of

startups that develop products that are modifiable by their users, new educational programs and funding infrastructures such as Kickstarter. The ultimate goal for many is to enable others – in particular those less tech-savvy – to become producers of technologies.

Attitudes and reasons for participation in a hackerspace or DIY maker practices, however, are undoubtedly diverse. While some individuals are inspired by a countercultural ethos to tinker and play to alter society's status quo, others actively participate in start-up initiatives in their regions, collaborate with government officials, or even large corporations. Despite often heated debates about these differing approaches, what many nevertheless agree upon is the belief that "making" technology leads to individual empowerment that is essential in times of increased global economic uncertainty and social upheaval. Making, here, is conceived of as a new form of citizen engagement. It is seen as a pathway to move passive consumers into active participants in state affairs and the market. As an Arduino developer told us: *"Our society renders us as customers. The maker movement is really about making us citizens again, so that we can truly own something – truly understanding how a thing works. I am thinking what computer to get my 9-year-old son for his birthday. First I was thinking tablet, but it's too passive. Then I thought Linux, and how it's really about this idea of turning customers into citizens. So I want to give my sun a Linux PC. I want him to open the console and understand what's going on inside. I know it will be hard at first, but I want him to understand it."*

Hackerspaces are perceived by many in a similar vein; as spaces that encourage people to experiment with alternative modes of citizenship. A hackerspace "evangelist" that has been central in spreading such beliefs across different hackerspaces is Mitch Altman, the co-founder of the San Francisco Hackerspace Noisebridge. Over the last half decade, Altman has toured around the world to visit hackerspaces, share his own insights and experiences of working in and making a living off of DIY making. In an interview we conducted, he described his take on hackerspaces as follows: *"Hackerspaces are a fantastic way for people to explore their creativity in a supported environment… You might find that if you love what you are doing, you can make a living off of it.,, the Internet is all fine, it's a great tool, but it's not real community. When people come together in hackerspaces and share what they love, magical things happen."*

Altman's articulation of hackerspaces as providing a relatively safe environment to explore an alternative life- and work-style is something we found to be shared amongst many makers. Indeed, over the last years, a series of successful startups has spun out of this environment of exploration; Altman himself, for instance, invented "TV-B-Gone," a device of the size of a TV remote control that allows the user to turn on and off publicly display televisions in her or his vicinity. Embedded in the device is a countercultural ethos that critiques the passivity of technological designs such as the TV. Although toing with the idea to disrupt a particular kind of status quo, Altman stressed that building a disruptive device does not entail that he can't make a profit by selling it to others. That the commitment to countercultural ethics was not perceived as antithetical to structures of the market economy is what we would like to emphasize here. Many, similar to Altman, did not see a contradiction in critiquing the status quo and sustaining one's livelihood through fruitfully merging social critique, industrial production, and product design. On the contrary, many consider such alignments essential in order to move DIY making beyond a hobbyist practice. Many believe that DIY making could work from within the system and alter what they consider problematic aspects of contemporary capitalist structures such as passive consumption, top-down and test-oriented education systems, and hierarchical politics.

"Making is going Mainstream"

One of the most powerful supporters of this idea that individual makers can reposition themselves in a world dominated by large and powerful corporations is MAKE magazine, a key publication in the field of DIY making. MAKE magazine is a compilation of electronic hobby projects and tutorials that use clever physical construction, open source microcontrollers, robotics, and physical computing. Founded by O'Reilly Media and spun off into its own company in 2013, MAKE is also organizes and operates Maker Faire, an outlet for individuals and companies to exhibit their projects as well as a source of inspiration for the "maker" ethic. MAKE magazine marks a broader transition from "hacking" to "making." For instance the magazine's founder Dale Dougherty had initially proposed to title the magazine "Hacks." Reflecting on these earlier days, Dougherty described to us how when he proposed the name "Hacks" to his children, they were not convinced, but suggested: *"why don't you call it Make? Everyone likes to make things."* He goes on: *"So, I started using the word makerspaces, because I was interested in getting them into schools, and I didn't want to get into the semantics of hacking versus making."*

MAKE magazine is aimed at signaling inclusivity to the wider public, schools, and potential sponsors as well as an active distancing from "hacking" as a practice to subvert computer security systems for malicious or criminal purposes, also known as "cracking" [11, 30]. The publication, in this way, has transformed a principle at the heart of the HCI discipline – that technology production can or even should be the site of user participation – into a profitable undertaking [30]. Or in other words, the concept of user participation has become a powerful marketing language that brands an emerging industry of hardware design as technoscientific expertise shared with families, children and other tech novices [33] – or in Dougherty's

words: *"making is going mainstream and is positioned to impact culture, innovation, and education."*

Not just MAKE magazine, but also hackerspaces are deliberating carefully how to position their work in ways that wouldn't render their work in association with illegal or "black hat" hacking. For instance, as stories of Chinese hackers breaking into Google servers circulated widely in national and international mass media outlets in 2010, the Chinese term *heike* 黑客 became the widely used term to describe this illegal practice of hacking into a system. Makers working in China were anxious to come up with a term that did not have any immediate associations with *heike* or hacker. The co-founders of the hackerspace in Shanghai settled, after several weeks of deliberation on a hackerspace mailing list, on the Chinese word *chuangke* (creative professional). *Chuangke* has the advantage of connoting *chuangyi* (creativity) and *chuangxin* (innovation), which are employed in positive terms in political and public discourse in China that emphasize creativity as a way to foster social change and technological innovation [31]. *Chuangke* subsequently became the term widely used in China's DIY maker scene. Similar to the decisions made at MAKE, a central focus, here, was on spreading the word of the maker ethos by rebranding hacking and softening the tone of its language.

We will now discuss how such efforts to turn DIY making into a mainstream practice have been accompanied by new partnerships between makers, manufacturers, VCs, and the start-up of new educational and state-run initiatives.

FROM MAKING TO MANUFACTURING

We now zoom in on the role hackerspaces and hardware incubators play in the move of DIY making into industrial production and manufacturing. We will show that both seed and support the growth of hardware startups that bring DIY maker ideas to the market.

Hackerspaces: drivers of economic & societal change

Prior work has traced three waves of hackerspaces [34]; hackerspaces like *L0pht* that were started covertly in the 1990s and only provided access to selected few characterized as first wave; hackerspaces like *C-base* in Berlin, that started with a more public profile and a strong commitment to ideals of Internet freedom, as second wave; and hackerspaces like *Noisebridge* in the Bay area, committed to a global hackerspace movement, as third wave. We add a fourth wave, here; the hackerspace as incubation of startups and functioning in the realm of research and development.

Several of the hackerspaces we worked with began to function – even if informally – as incubator programs for hardware startups. Many cited as motivation prominent examples of companies that emerged from hackerspaces such as the Pebble Watch (a programmable watch whose team is the recipient of the largest Kickstarter campaign in history) and MakerBot (a low-cost 3D printer that has become a key symbol for an industrial revolution via DIY making), and Square (a convenient payment system enabling small businesses to collect credit card payments easily worldwide). In our interviews with founders and members of hackerspaces, we found that many considered hackerspaces as new sites of innovation, research and development. Many stressed that hackerspaces, because of their focus on experimentation with an array of materials, open collaboration, and rapid prototyping, were prone to seed innovation. They presented this in contrast to established R&D labs, which many described as slow moving and caught up in patent wars.

While many hackerspace members stressed that a hackerspace shouldn't be reduced to its potential to seed new entrepreneurial practice, many were nevertheless instrumental movers and shapers in local or international start-up scenes. For instance, members of a hackerspace in Shanghai, which did not house any startups per se, actively participated in the organization of events such as Startup Weekends, Barcamps, and Hackathons. The underlying motivation was that these events introduced others in China through a hands-on manner to concepts and practices of technology production and innovation that they perceived as less common in China.

Other hackerspaces, however, centrally incorporated incubating practices and/or industrial production. The founder of a hackerspace in Shenzhen, for instance, describes this as follows: *"We have a maker concept here that a hackerspace could also be the place that people can exhibit and even sell their products. You can see there are a lot of maker products, and we also provide 3D printing services… It's a very good entry point: people don't need to own printer, but they can come over and print it by grams. We also sell the printed objects. We have memberships, we have routine workshops and meet-ups. I foresee there will be many more people – not only engineers but everybody – to come up with great ideas and make them reality."*

The hackerspace in Shenzhen is ideally located for such an endeavor. In the heart of a former manufacturing site that has been turned into a trendy scene of art boutiques, design loft studios, bars and cafes, it functions as an interface between China's emerging creative industry and the region's long-term expertise in manufacturing. Just a subway ride away, its members can access the heart of China's enormous industrial fabrication industry, ranging from small craft workshops all the way to large-scale contract manufacturers. Shenzhen has long been a particularly unique environment in China: declared a Special Economic Zone (SEZ) upon its inception, it was designed and built with the goal to encourage foreign investment and economic growth. Foreign corporations, for instance, receive tax reductions and other benefits when they open a production site in the regions. According to Zhang – the founder of a startup housed in the hackerspace – this is a strong motivator to startup a company in

Shenzhen over other places in China or abroad. The 28-year-old designer originally registered his company in Shanghai. He now debates to move registrars. Since March 2013, the local government has released a new regulation that significantly lowers barriers to start up a business in the Shenzhen region. *"Shenzhen feels much more open than any other city in China,"* Zhang explained, *"it's a place where lots of people begin to think about starting up a business. That's why we like to be here."*

This alignment between making and other spheres of economic and social development is also visible in a recent government initiative: in 2011, the Shanghai government endorsed hackerspaces as so-called "innovation houses" to be supported by government funding. The official document described this initiative as part of a larger effort to build a citywide platform for supporting widespread science work and innovation. This support of DIY making by the Chinese government contributes to a larger nation-wide effort of moving China's economy away from its image of copying products or manufacturing for others towards a hub of creativity and innovation [31]. In other words, the Chinese government sees hackerspaces as pivotal in transitioning the economy from a "Made in China" model to a "Created in China" model.

One year later, the first of these innovation houses was built and is today in active use as a Junior makerspace, *i.e.* a 20-square-meter room located in a public community building, equipped with miniature machines for children to learn how to solder, CNC, and 3D print. Members of China's hackerspaces are not opposed to this. On the contrary, one of the co-founders of China's first hackerspace, for instance, works with the government to host educational workshops to introduce DIY making to a wider public. Such collaborations between makers and official institutions are certainly not unique to China.

Take for instance the announcement by O'Reilly Media that they received significant funding by DARPA (Defense Advanced Research Projects Agency) for an educational program aimed at bringing *"the practices of making into education and* [to] *extend the maker movement into schools"* with a target of reaching 1,000 schools by the school year of 2012-13. The announcement lead to a considerable controversy in maker circles over the official support for what many still wanted to see characterized as a grassroots and countercultural movement. Mitch Altman, for instance, had publicly criticized O'Reilly for tying the maker movement to the goals of the defense industry and US military.

Broadly, we observed that many makers strongly believed that the work of hackerspaces and hardware startups could support the development of their respective local economies. The euphoric rhetoric of making as an industrial revolution has spread far beyond such efforts. For instance, in the US, making is tied to economic recovery, rendered as providing the grounds for a return to a "made in America" brand. President Barack Obama, in a State of the Union Address, lauded a manufacturing innovation institute in Ohio for its work in open-source 3D printing as *"carrying the potential to revolutionize the way we make almost everything."* He also announced plans for building new manufacturing hubs, where businesses will partner with the departments of Defense and Energy *"to help create a network of 15 of these hubs and guarantee that the next revolution in manufacturing is made in America."* Obama, here, echoes the former Wired Editor-in-Chief Chris Anderson, who suggested in his prominent book publication 'Makers" that today's makers are driving forward the "third industrial revolution" – a generation of technology producers that expands from the earlier Web 2.0 techniques to innovate industrial production.

To sum up, hackerspaces are sites where people actively explore new approaches to what constitutes a tech organization, research and development. We suggest that this development requires attention from HCI researchers, not just as a new subject for research or as an engagement with novel materials, but as a model of interaction design and technology production that evolved in parallel to research labs and design studios.

Hardware Incubators: from prototype to product

From January through April of 2013, we conducted ethnographic research at a hardware incubator in Shenzhen, China. The 15-week-long program, backed by a European Venture Capital firm, that has taken place twice a year since 2011, each time investing in 10 selected open hardware startups. The aforementioned Spark Devices, for instance, was amongst the selected to turn their DIY maker ideas into products by taking advantage of Shenzhen's vast manufacturing expertise. While each startup focused on developing a unique product, they shared a strong commitment to making products that allowed others, in particular lay experts and novices, to become themselves makers. They envisioned liberating individuals from the confines of capitalist modes of production that render citizens as mere consumers of technologies.

On the marketing slides of the incubator one reads: *"we are a new kind of accelerator program. For people who hack hardware and make things."* DIY making, here, is rendered as a new take on Silicon Valley tech production. The program manager describes DIY as a business approach to bringing a product to the market. He stressed that what was before shaped by only a couple of "professional" designers or privileged few is now in the hands of the masses. DIY making is the marketing spin of mass production. What lurks underneath is the promise that today's kludge can be tomorrow's million dollar start-up company. Quite in contrast to the language of openness that typically pervades rhetoric in MAKE, the language takes another turn. Makers are rendered as risk takers who are willing to quit their daytime jobs are encouraged. Others, the program manager made clear, do not necessarily fit: *"If you have a product or*

if you have a project and it doesn't look like it can be turned into a product, it gets filtered out. Ultimately, it is a commercial endeavor so we are looking for people that want to do a business around some marketable product."

The accelerator program is illustrative of a broader trend we observed in our research: a drive toward mass production accompanied by a degree of black-boxing, *i.e.* the concealing of the inner mechanics of technologies to make them easier to use or more modular. For instance, the startups that participated in the incubator had to make a series of trade-offs. While committed to the production of open technology, they soon realized that the requirements of a consumer product differed significantly from a prototype. Working with factories in China, the startups learned about specific affordances and limitations of the machines used for mass production including mills, drills, lasers, and molds. Their original designs often changed significantly after having gone through long and involved interactions and material tests with their manufacturers.

This process made many of the startups revisit the concept of openness means when merged with industrial product manufacturing. They debated if it was even possible to remain "truly" open source, if this entailed sharing with the consumer the source of each and every single component, from LEDs and PCBs to the physical materials used for the product enclosures. Many agreed that when moving into product design, it came down to a selective form of openness, rather than an "all time" openness. One of the program managers for the hardware accelerator put it as follows in a conversation with us: ***"****I think that's the dirty secret in open-source hardware: everybody has something that they keep closed, or secret, whether it's their suppliers, or whether it's their testing, or things that they just haven't released yet."*

What we observed across such processes of spreading DIY making beyond a hobbyist practice was also a move away from what was at the heart of some of the original hacker ethos. We see this perhaps best exemplified by one of the earliest and most successful open hardware startups: MakerBot Industries. In 2012, MakerBot announced that they went closed-source with their new printer models of the Replicator 2 and Replicator 2X, in addition to changing the terms of use in the open hardware repository website Thingiverse. Many of their fellow makers and even one of their own co-founders heavily critiqued this decision as "decidedly moves away from the openness that MakerBot was evangelizing in the past." Bre Pettis, one of the co-founders, characterized the closing of Replicator 2's source as a challenge of building a sustainable large business with more than 150 employees, and being *"as open as we possibly can"* instead of retaining a strict adherence to open source. Pettis characterized open hardware as being sustainable for small educationally-oriented businesses such as Evil Mad Science and projects funded by Kickstarter, but incompatible with large hardware production.

While the developments at MakerBot lead to significant controversy in the maker scene, it is nevertheless celebrated as one of THE success stories of a DIY maker project that began as a small start-up in a New York City based hackerspace and that is today changing the conversation and practice around industrial production. The recent merger between MakerBot Industries and the professional 3D printing company Stratasys for several hundred million USD further fuels such visions of DIY making as a new tech revolution. The efforts of such open innovation models out of hackerspaces and incubator programs, as discussed in this section, have generated a broader imaginary of DIY making as simultaneously the savior of the American economy by rebuilding a "made in America" brand and the driver of new economies in so-called developing regions.

DISCUSSION

The relevance of DIY making to HCI has been articulated to date in terms of four broad trends: the call for more open and participative forms of design, *e.g.* [24], the relevance of tinkering and experimentation to engagement with digital tools, *e.g.* [6, 16, 32, 36], the emergence of new forms of material as interaction sites [6, 39] and the move towards forms of HCI design practice that are more critically engaged [36]. However, as we have documented here, DIY making is at a moment of transition, which in turn motivates a new framing and engagement in HCI. We will consider three aspects here: amateur expertise, the move towards critical making, and materialiaty.

Amateur Expertise

DIY making has extended beyond a practice of a cluster of nerds hacking away on the weekend, aimed at reaching beyond the hobbyist market and an audience that isn't technically minded. We have shown in this paper that hackerspaces, hardware start-ups and incubators are turning the computational vision of ubiquitous computing, user participation and engagement into products; and one might begin to ponder, then, whose vision it is anyway. Especially because, in this move from vision to product, hardware startups coming out of hackerspaces and incubators largely sidestep the traditional pipeline of HCI R&D that generally follows the path of academic or industry research labs. In doing so, hackerspaces introduce a model of open innovation not dissimilar from earlier generations of open source software developers.

Open source software productions have long been incorporated by corporations, *e.g.* as an "open innovation" strategy that treats open source as a form of external knowledge source [28, 43, 47]. For example, Chesborough [7] illustrates how, in contrast to the more traditional innovation models that house research and development internally as is common in well-known labs such as Bell AT&T and Xerox PARC, open innovation refers to a firm's endorsement of external channels such as spin offs, ventures, licensing, but also individual inventors and startups. Large corporations such as IBM, Intel and Procter

and Gamble utilize open source development as "test site" to assess their direction in R&D [7].

Seen in this light of both entrepreneurial practice and open innovation, DIY making also shifts the ground on which HCI's own technical legitimacy rests. Just as open source software production was at the heart of shaping the technological and social means of Internet technology today [21, 23, 41], so has now open hardware efforts engender a shift in HCI innovation and research practice.

HCI has long argued for the ability of information technology to support the creativity of end users, and for the importance of allowing people to be creatively and productively engaged with digital tools. However, distinctions are still maintained between different spheres of expertise; for instance, that of the HCI professional and that of the end-users who, while expert in their own domain, depend upon the HCI professional for intercession and guidance [10]. Prior work has tackled this question of the relationship between "expertise" on the one hand and "legitimacy" on the other [9]. Collins and Evans, for instance, argued that expertise (as a matter of practical knowledge) and "expert-ness" (as a matter of power and influence) are tightly linked. Or in others words, when people demonstrate expertise, they also exert claims of authority. For instance, they present particular forms of knowledge and practices as central to the discipline or domain. It is in this context that the transformation of DIY practice documented here becomes especially relevant and problematic for HCI, because it is embedded in a similar shift of legitimacy – what we might loosely frame as the legitimacy of the laboratory and the legitimacy of the marketplace. That is, one source of legitimacy of HCI work lies in scientific inquiry, theoretical elaboration, and academic deliberation; another likes in commercial production, engineering practice, and marketplace valuation.

So, when we examine new models of manufacturing, and consider alternative forms of industrial practice, we also shift the grounds on which HCI's own technical legitimacy rests. If the relationship between theory and design has long been a source of tension within HCI, then the relationship between design and manufacturing, or between design and entrepreneurship, might also become a site of contests of authority and a place for new forms of authority to arise. In what follows, we outline how prior work in HCI on critical making can be applied, here, to begin tackle such tensions, rather than putting them aside as mere political meanderings.

Critical Making

As we have shown in this paper, DIY making is the site of a highly politicized discourse around economic recovery and innovative development. What do these contemporary developments mean for our engagement with DIY making in HCI? While governments and media have mostly taken up the overtly enthusiastic tone behind publications such as MAKE, we believe that HCI has something valuable to offer: a repertoire of deep engagement and critically reflectiveness toward technological design.

We have shown in this paper, that many makers believe that acting outside of traditional institutional frames such as the large corporation allows alter contemporary modes of capitalist production. While certainly not all DIY maker products are aimed at cultivating critical awareness amongst users, critical reflection is nevertheless central to the practice: Think, for instance, of the ongoing debate around MakerBot Industries going partially closed source or around the announcement of O'Reilly Media to accept funding from the US military agency DARPA. Or, Altman's TV-B-Gone, as discussed earlier, can be seen as an interventionist and critical design that is not divorced from production.

Such projects and ongoing debate in the maker scene, provide new models for critical reflection. As Bardzell and Bardzell have shown, HCI tends to render critical approaches in design in opposition to "affirmative" or "opportunistic" design [4]. We propose, then, a form of critical making that doesn't oppose production, product design and designed artifacts. This is in line with and simultaneously extends Ratto's work on critical making, intended to bridge the gap between creative physical and conceptual exploration [36]. With a focus on a process of making prototypes to expand the social study of technology, Ratto's critical making comes from a perspective of injecting DIY making into the process of critical thinking. We see value in extending Ratto's criticality into manufactured products. While Ratto's emphasis is not on what is produced through the process of critical making, we argue to include the releasing and analyzing the implications of built devices into critical practice.

Materiality of Making

An interest in the materials of design has been central to HCI for several years. Buechley's work with the Lilypad Arduino –a prototyping platform for responsive systems in fabric and clothing – is a particularly salient example [6]. This has in turn prompted recent discussions at venues like CHI around the topic of "materiality" – not just of new materials but of modes of analysis that proceed from a material foundation [5, 12, 37, 38]. These efforts tend to focus on the small-scale making of craft practice or the research lab.

Our investigations into the entwining of DIY practice, professionalization, and commercial endeavors points to another critically important consideration in HCI's study of materiality, which is the materiality of manufacturing. That is, manufacturing and its own materialities shape the kinds of interactive devices that might be produced through DIY practice in a number of ways. We have shown that materials and material forms of production that are effective for prototyping are frequently not effective for larger-scale

production. The shift from building something in a 3D printer of a research lab to producing a version on a milling machine on a factory floor tests material limits in different ways. However, HCI has explored DIY making foremost as a method to scale-up and speed-up prototyping [16, 17].

We stress, here, the importance for HCI to take into account how hackerspaces and incubators are already scaling into manufacturing. This requires revisit the concept of "openness" as it is traditionally defined – meaning access to schematics, designs, and electronic formats such as source code or 3D models. Such aspects are only part of the equation when considering manufacturing, at which point suppliers and supplier relationships and manufacturing partnerships also matter. As we have shown in this paper, the realization of an open hardware product in Shenzhen involved in various capacities diverse actors, sites, values and machines, ranging from new funding websites such as Kickstarter, the affordances of manufacturing machines, the workings of venture capitalist firms alongside those of hackerspaces. The question of materiality, then, pertains not only to the making of an object, but to social, economic, and material infrastructures enlisted in its production.

CONCLUSION

It is a measure of HCI's success that user experience and the importance of interaction design are now central parts of new technological visions. One consequence of this, though, is that, since HCI concerns are so foundationally entwined with new models of technological innovation, new fields and disciplines are involved in developing, designing, and prosecuting visions of interaction. HCI is no longer simply happening in interaction-oriented research labs and HCI-centered academic programs, in user experience groups or at HCI conferences. It is also happening at emerging sites of technical invention – at hardware incubators, at hackathons, and in hackerspaces.

Our goal in this paper has been to document the design and innovation practices arising at some of these sites, with an eye towards understanding the implications for HCI. Our work suggests that we need to understand the broader contexts within which these emerging sites of HCI innovation are embedded. To draw an analogy with open source software, open source is both a form of collaborative programming and a new institutional form, with all its regional, technological, organizational, and political consequences. Similarly, when we turn our attention to hackerspaces, we see not only a space experimenting with new sorts of fabrication tools, but also a community that reshapes the very meaning of technology innovation. Our research suggests that we need to see the hackerspace not just as a place that amortizes the cost of a lasercutter and a 3D printer across hundreds of people. It is a place where people are experimenting with new ideas about the relationships amongst corporations, designers, and consumers. It is from this perspective that we approach in this paper questions of expertise, materiality, and criticality – topics which increasingly also define the relationship between HCI as a discipline and the other cultural groups with which HCI interacts.

HCI will continue to produce radical visions of the future of human engagement with information technologies. What we need to do beyond this, though, is to be equally visionary about what our relationships might be to other sites of technological innovation that are involved in bringing these visions to fruition.

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