Presenter Symposium

3D Printing and Beyond: Digital Innovation in a Physical World and its Implications

Short Title: Digital Innovation in a Physical World
Submission Number: 14031

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Technology frames and industry control in emerging industries: the development of the 3D printing industry

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The Software and Hardware Side of Digital Entrepreneurship: The 3DPrint Venture

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Navigating Through the Fog of Discovery in Accelerated R&D Processes: Course Setting or Continuous Tacking?

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3D Printing our Imagination?
Organizing Digital Innovation in Healthcare

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Digital Density: The Interplay of the Digital and Physical World in a 3D Printing Design Community

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Type of Symposium: Presenter
Time Requested: 90 Minutes

Potential Sponsor Divisions: Organizational Communication and Information Systems (OCIS); TIM; ENT;

SYMPOSIUM OVERVIEW

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Technologies such as 3D printing blur the lines between the physical and the digital and shapes how people organize, collaborate and innovate. 3D printing enables innovators to rapidly adapt, share, combine and test their creations. A reciprocal relationship between physical and digital artifacts is increasingly facilitated by digital technologies, providing opportunities for low cost, nearly everlasting experimentation. These technologies are often pervasive and impact the trajectories of digital ventures by changing the core offerings of organizations, often leading to the emergence of new industries.

The democratization of digital technologies enables new innovation processes, such as hackathons, and can lead to the acceleration of new product development endeavours. The implications of such technologies extend well beyond the traditional view of organizations, affecting how work can be orchestrated, as these technologies enable the rapid assembly of teams outside formal organizations which have been shown be capable of outperforming incumbent firms.

The purpose of this symposium is to bring together a set of papers from various research groups working toward making sense of how pervasive technologies such as 3D printing affect organizations, through the emergence of new forms of organizing, new product offerings, and new industries. Even though most of the work presented in this symposium is related to emerging and pervasive digital technologies, the authors have made a conscious effort to extend their focus beyond a particular technology and present the broader impact of increased digitization on organizations.

The work presented examines the changing nature and globalization of work, as well as how digital technologies enable new digital business models. In sum, the papers presented in this symposium examine the duality between digital content and physical material, explore new ways of organizing innovation processes under high degrees of uncertainty, and seek to increase awareness of the impact of such technologies to management research and practice, such that their benefits can be realized.

Presentations

In the first paper, Zeijen and Brusoni use technology frames as a theoretical lens to explain how pervasive technologies lead to the emergence of new industries. Their study sheds light on the evolution of the 3D printing industry while examining how the focal application of the industry shifted from prototyping to direct manufacturing applications. In addition, they examine the interactions between the three incumbent developers of the technology and lead users, contributing to literature that sought to explain why firms face difficulties to adapt in rapidly changing environments. Their results provide evidence that factors beyond product features determine the performance of incumbent firms in meeting customers' needs.

In the second paper, Tumbas, Hukal, Seidel and Berente examine how digital technologies impact trajectories of digital ventures by enabling organizations to change internally. In addition, digital technologies support entrepreneurial organizations in changing their product offerings. Their grounded-theory-inspired study combines computational and manual analyses to investigate i) how changes in hardware trigger changes in software and vice versa, and ii) how these changes impact the development trajectory of the organization. Due to high degrees of uncertainty, digital ventures are often forced to adapt, leading them to continuous experimentation and often on trajectories that significantly differ from the initial intend of the organization. Their findings suggest a complementary, yet often competitive relation between digital content and physical material. Their study draws on the process view of entrepreneurial activity and the modular layered architecture view of digital technologies, informing the literature on digital technology based entrepreneurship and digital innovation.

In the third paper, Lifshitz-Assaf, Lebovitz and Zalmanson examine how new innovation processes, namely makeathons, accelerate R&D processes. The paper combines the theoretical temporal perspective with the sociomaterial one in order to investigate the emergent innovation work practices and processes associated with successful or failed new product development. Specifically, they study makeathons, as temporary forms of organizing, during which participants were able to produce new assistive technology products for disabled individuals within 72 hours. Their work provides insights on how to rapidly assemble effective teams outside traditional organizational boundaries and sheds light on innovation work processes. Their findings suggest that navigating the “fog of discovery” by tolerating ambiguities and adapting to emerging outcomes is critical for developing a working product.

In the fourth paper, Polykarpou and Barrett examine how integrating an emerging technological innovation can affect the coordination of work. In particular, they focus on how emerging technologies can be used as a way to expand the jurisdictional boundaries of work groups over time, as well as when work groups may feel under threat in light of organization change. While 3D printing is a technology that bridges the digital and physical domains and one might expect the importance of the physical domain to be weakened due to the increased digitization of innovation, their research highlights how the materiality of place is implicated in the innovation process. Using a practice lens and data systematically gathered over 24 months at a hospital implementing 3D printing, their work offers unique insights into the role of place when organizing for digital innovation.

In the fifth study, Kyriakou and Genc examine digital artifact attributes that facilitate or impede the reciprocal relationship between the physical and the digital world. By examining the largest open source hardware community to date, they aim to provide insights on how digital innovation may affect the future of manufacturing, insights relevant for both scholars and practitioners focusing on digital innovation. Their results include the effects of shape and functional novelty on the manufacturing of digital artifacts. Specifically, their results suggest that digital artifacts which were novel in terms of their shape, as well as digital artifacts that were novel in terms of their functionality, would be selected by users for manufacturing. Somewhat surprisingly though, designs that were novel both in terms of shape and in terms of their functionality would be less likely to be manufactured.

Collectively, these five presentations demonstrate how pervasive technologies such as 3D printing blur the boundaries between the physical and digital and shape how people organize, collaborate, and innovate. Following the presentations, Pamela Hinds (discussant) will facilitate an interactive discussion between the presenters and members of the audience.

RELEVANCE TO DIVISIONS

This symposium is being submitted for consideration to the Organizational Communication & Information Systems (OCIS), Technology & Innovation Management (TIM), and Entrepreneurship (ENT) divisions.

Organizational Communication and Information Systems (OCIS) Division.

All papers presented are related to digital innovation, a topic of high interest to the members of the OCIS division. The research presented tries to address issues pertinent to, digital innovation and entrepreneurship, changing nature of work, and sociomateriality, all issues of high interest to OCIS scholars. Tumbas et al. present a novel qualitative method that is likely to attract the attention of participants. Kyriakou and Genc present a novel computational method for comparing digital artifacts to extract their similarity in an objective way.

Technology & Innovation Management (TIM) Division

All papers presented are related to digital innovation, a topic that is at the heart of the TIM division. The interactive discussion (both structured and open format) is specifically designed to share the accumulated collective knowledge from the presenters' experiences regarding the potential implications of such emerging technology for innovation theory. Lifshitz-Assaf et al. present how new innovation processes can accelerate R&D processes. In addition, Polykarpou and Barrett examine how an emerging technological innovation can affect the coordination of work. This symposium will provide a forum for researchers who have experience working with and for researchers who are interested in potentially conducting research on the impact of emerging technologies on innovation processes, work, business models, organizations and industries.

Entrepreneurship (ENT) Division

Many of the potential advantages of studying emerging technologies and the interplay between the physical and the digital world are related to the interests of the members of the Entrepreneurship division. The work by Tumbas et al. examines how digital technologies impact the trajectories of digital ventures and how digital technologies support entrepreneurial organizations in changing their product offerings. In addition, Zeijen and Brusoni examine how pervasive technologies lead to the emergence of new industries. All papers presented focus on digital innovation, a core topic in entrepreneurship research.

PROPOSED FORMAT OF SYMPOSIUM

Length: 90 Minutes

To begin the session, Harris Kyriakou will provide a brief overview (5 minutes) of the symposium. Following the introduction, a total of 60 minutes will be allocated for the five presentations (12 minutes each). Following the presentations, Pamela Hinds (discussant) will facilitate a structured discussion (10-15 minutes) with the presenters to enable a dialogue for the presenters to share their experiences, as well as implications and insights from their research with audience members. Lastly, the discussant will open the floor to the audience and moderate questions from the audience to the presenters for the remainder of the session (10-15 minutes). Questions and comments can be directed to a specific presenter or as a general question to all presenters.

Tentative Schedule

Minutes 0 – 5: Welcome and introduction to the symposium

Session chair: Harris Kyriakou

Minutes 5 – 65: Paper presentations (12 minutes each)

Technology frames and industry control in emerging industries: the development of the 3D printing industry, *presented by Axel Zeijen*

The Software and Hardware Side of Digital Entrepreneurship: The 3DPrint Venture, *presented by Sanja Tumbas*

Navigating Through the Fog of Discovery in Accelerated R&D Processes: Course Setting or Continuous Tacking?, *presented by Sarah Lebovitz*

3D Printing our Imagination? Organizing Digital Innovation in Healthcare, *presented by Stavros Polykarpou*

Digital Density: The Interplay of the Digital and Physical World in a 3D Printing Design Community, *presented by Harris Kyriakou*

Type of Symposium: Presenter
Time Requested: 90 Minutes

Minutes 65 – 90: Interactive Discussion

PRESENTATION SUMMARIES

Technology Frames and Industry Control in Emerging Industries: The Development of the 3D Printing Industry

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Many new technologies have the potential to (re)shape industries—but relatively few actually do so. Historians of technologies have extensively discussed, for example, long waves of economic development that build on broad, pervasive technologies to generate new paradigms of production and consumption (e.g. Freeman & Louçã, 2001). They have identified a few characteristics (e.g. pervasiveness of applications) that, in the long term, lead to the emergence of new industries and leaders. Yet, without the benefit of hindsight, managers and strategy scholars alike still struggle to predict which technologies will deliver truly disruptive effects, or say how to benefit from them before they become established.

One technology that has been heralded as revolutionary for manufacturing industries in particular is 3D printing, or additive manufacturing (e.g. Hopkinson, Hague, & Dickens, 2006). While the technology emerged in the 1980s, and applications for end-use manufacturing (such as making parts for airplanes or engines) have been recognized as early as 2000, the technology has so far not found manufacturing applications on a large scale.

This study sheds light on the development of the 3D printing industry as its target application shifted from prototyping applications to direct manufacturing applications. In particular, we study the interaction between the developers and (lead) users of the technology. On the developer side, we examine the three leading original equipment manufacturers (OEMs) that have developed 3D printing technologies over the past 30 years, but that surprisingly have seen their dominance threatened while the range of potential applications of the technology grew. We analyze the development of their products, strategies, and their interaction with user industries and lead clients, in response to both internal developments (endogenous factors) and external events (exogenous factors).

Within the broader field of industrial development, this study uses technology frames and innovators’ choices as a theoretical lens. In studying industrial emergence and change, scholars have emphasized that technologies develop in parallel to its applications in adopting markets (Clark, 1985; Grodal, Gotsopoulos, & Suarez, 2015). Both sides can be subjected to shocks (technological developments or demand discontinuities), creating pressures for incumbent firms to respond and providing opportunities for new entrants. This process has been the focus of many studies that sought to explain the observed difficulties in firms to adapt to changing environments and resulting inertia (e.g. Gilbert, 2005; Tripsas & Gavetti, 2000).

These studies suggest that a crucial factor in organizational adaptation is the set of assumptions and beliefs held by organizations about technologies and their applications, which are reflected in routines, capabilities and the features of the products that are produced. These sets of assumptions have been described as technology frames (Kaplan, 2008; Kaplan & Tripsas, 2008; Orlikowski & Gash, 1994). However, despite the realization of the broad range of important features of these assumptions (from industry logic or recipes, to organizational emphasis on the level of technological subsystems,Leonardi, 2011; Porac, Thomas, & Baden-Fuller, 1989; Spender, 1989), previous studies of technology frames and organizational adaptation have focused mainly on resulting product features as the place where frames can be observed (e.g. Benner & Tripsas, 2012). Furthermore, both conceptual and empirical work suggest that industry development entails the resolution of tensions in understanding between supply and demand side, as technologies become crystallized as dominant designs and become understood as categories (Benner & Tripsas, 2012; Garud & Rappa, 1994; Grodal et al., 2015; Kaplan & Tripsas, 2008).

This emphasis on product features becomes problematic in explaining many of the choices that firms have to make in developing industries. These choices include not only the products themselves, but also choices on the scope of the market and industry to operate in altogether (Santos & Eisenhardt, 2005, 2009). Moreover, they include choices on how to operate in these markets, for example by purposefully dividing tasks in the industry (Jacobides, Knudsen, & Augier, 2006) and selecting a business model. Such choices are constrained, though not fully determined, by managers' assumptions about the technology and its applications, and intra-industry tensions in sensemaking might be deliberately created or upheld.

In this study, we seek to further understand how technology frames affect organizational choices in an industry under development. It departs from an empirical setting that is hard to explain through the current operationalization of technology frames as operating mainly through product features: the development of additive manufacturing technologies through the shift from prototyping to manufacturing applications. The 3D printing industry makes for a particularly relevant setting because 3D printing is a very versatile (in some sense general-purpose) technology that can target many different applications (Shane, 2000), highlighting the importance of framing and positioning choices.

Our study has a qualitative and longitudinal design, tracing the actions of the three pioneering OEMs, especially in their positioning towards user groups. As these organizations experienced shocks, first in the form of a radical change in applications driven by users, and later in the form of severely increased competition, we observe how their choices changed, and how their behavior affected the development of the industry. It is based on interviews with the OEMs (the focal firms and competitors), lead users (in automotive, aerospace, and engineering industries) and industry experts (N = 9), and secondary data sources (annual reports and press releases, product descriptions and brochures, website histories, complete for the focal firms, plus industry journals, reports, books, and two conferences).

3D printing was developed in the mid-1980s, with three main firms emerging as technology pioneers (3D Systems and Stratasys in the US, and EOS in Germany). The first application found for 3D printing was rapid prototyping, where 3D CAD models were produced as physical objects for form, fit and function testing or as design aids. An additional application was found in the 1990s with rapid tooling, where 3D printed objects were used in the production process of other parts. In 2000, Boeing found a first application for direct manufacturing of end-parts in printing the entire air duct system for a jet fighter avionics system. This event was a shock to both the technology developers and users, in that "*it proved to the world, and certainly to the aerospace community, that these technologies aren't just restricted to doing concept models and functional prototypes with a limited lifespan*" (interview quote from the project leader).

Following this shock, the OEMs started targeting explicitly direct manufacturing applications, yet the machines remained largely the same. What they initially struggled to realize was the extent to which 3D printing *for manufacturing* entailed different requirements than 3D printing *for prototyping*, both on the level of the physical objects and the relationship between developer and user. 3D printing until then had been designed essentially as black boxes, with limited choices in settings and material, to be used as standalone devices. 3D printers as machine tools in production environments, in contrast, required full control and transparency over the machine, for a number of reasons. They needed to be able to certify the production process, develop intellectual property in parts specifically designed for 3D printing, and integrate the 3D printer in a larger production environment. Furthermore, design of the 3D printing process became dependent on capabilities that were less relevant before, such as material science and thermal control.

While the OEMs did focus on improving their machines to meet higher demands, they did not deviate much from the black box-model of a 3D printer. What is more, in some cases they scaled back users' control over the technology, expecting that this would lower the complexity of operating the machines and reduce the room for error, and thereby lower the barriers to adoption. The persistent mismatch between the offered technology and users' needs led to increased competition among OEMs in the last decade, where fast followers differentiated themselves on production-friendliness, and new and diversifying entrants leapfrogged the required technological capabilities, to enter the market with radically open systems and business models. In 2016, General Electric acquired two fast followers to become an equipment manufacturer itself. Until that moment, General Electric had been a lead user of the technology, working actively together with the main OEMs to meet the requirements of its applications. The main OEMs, in the meantime, have all replaced their leadership to alter their ways to pursue direct manufacturing applications through more open systems integrable in production environments.[1]

Our findings contribute to the literature on technology frames, as well as the broader literature on industrial dynamics. While previous literature on technology frames and sensemaking focus on products and product features as embodying the envisioned use, our

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[1] EOS replaced its TMT around the CEO in 2010, 3D Systems and Stratasys replaced their CEO in 2015 and 2016, respectively.

results suggest that it was factors beyond the product features that determined the performance of the OEMs in meeting their customers' needs. We propose an extension to the technology frame concept towards capabilities underlying the technology and the functional relationship between producer and user of technology or more generally the assumed industry architecture (Jacobides et al., 2006; Von Hippel, 1982). Furthermore, they show how different shocks affected the OEMs' technology frames in different ways. The recognized opportunity of more advanced applications affected mainly the interpretation of required product features, while the threat of competition and lost control affected the features of the extended frame, the assumptions about required capabilities and industry architecture surrounding 3D printing technology. One especially interesting finding in terms of industry emergence is what we would call a *control trap,* where the OEMs chose to limit the users' control of the technology in response to the emergence of a broader set of potential application, expecting that this would ease adoption and would keep control over the 3D printing industry with the suppliers of the machines. Our findings suggest that this choice is what has made them vulnerable, both to competitors in the OEM market and to user industries vertically integrating backward.

Submission #14031

Hardware and Software Innovation in Digital Entrepreneurship: The 3DPrint Venture

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Digital ventures are young, entrepreneurial organizations whose infrastructures, products, and services rely on the modular layered architectures of digital technologies (Yoo, Henfridsson, & Lyytinen, 2010). Digital technologies provide flexibility to entrepreneurial organizations and render the operations of digital ventures(Nambisan, 2017). Confronted with uncertainty, digital ventures are often forced to adapt, leading them on new trajectories beyond the initial intent of an organization (Henfridsson & Yoo, 2013; Singh, Mathiassen, & Mishra, 2015; Svahn, Mathiassen, & Lindgren, 2017). Because digital technologies are malleable and re-programmable, they enable digital ventures to pivot—that is, to rapidly change their organizational activities and thus rapidly *shift* their trajectory. Trajectory shifts are often referred to as swift transformation (Huang, Henfridsson, Liu, & Newell, 2017), pivoting (McDonald & Gao, 2016), changes of activity paths (Henfridsson & Yoo, 2013), or experimentation (Kerr, Nanda, & Rhodes-Kropf, 2014). We refer to the trajectory of a digital venture as manifested in changes to resources, processes, and products over time.

Digital technologies enable scaling of the user base (Huang et al., 2017), internalizing digital capabilities in a stepwise manner (Tumbas, Berente, Seidel, & vom Brocke, 2015), and creating entirely new businesses (von Briel, Davidsson, & Recker, 2017). Broadly, digital technologies impact trajectories of digital ventures in two ways: First, they allow the organization to internally change, often in response the external dynamics; second, they support entrepreneurial organizations in changing their products and service offerings.

Previous work in the field of digital innovation (Yoo et al., 2010) and digital entrepreneurship (Huang et al., 2017) has, by and large, focused attention on digital technology as software components and has treated hardware to large extent as stable and given (von Briel et al., 2017). However, there is an increasing number of digital ventures that span both, software and hardware domains, that is, they offer both services and associated hardware. Understanding the role of digital innovation in shaping the developmental trajectory of digital ventures thus requires an understanding of how both hardware and software innovations, as well as their interactions, influence the trajectory of young, entrepreneurial organizations. Yet, what is the specific role of hardware and software innovations in shaping the development trajectories of digital ventures? We thus ask:

RQ: *How do hardware and software innovations influence trajectories of digital ventures?*

To seek answers to this question we conduct an exploratory, grounded-theory-inspired study of the development of a digital venture from the 3D printing industry—3D Print, a medium sized company that grow into a leading provider of soft- and hardware for professional usage of 3D printing. The company innovates their software services and hardware through a mixture of proprietary and open source developments.

Our study combines qualitative analyses with computational approaches to trace date in order to generate novel insights (Berente, Seidel, & Safadi, 2018). We aim to analyze how the product offering of 3DPrint has changed in terms of both software and hardware, and how these innovations have impacted the venture’s trajectory over time. Specifically, we investigate (a) how changes in hardware trigger changes in software and vice versa, and (b) how these changes impact on the development trajectory of the organization. 3DPrint is a medium-sized company with a market-leading position in providing 3D printing solutions.

We incorporate several data sources, including a) interviews with key informants as well as b) development trace data of changes made to the software components used to operate the physical printers, and c) archival data such as documentation material and product version change logs. 3DPrint's history is marked by considerable market and technology uncertainty that lead to substantial changes to the organizational and technological set up of the venture. The case was chosen because the company innovates both hardware and software components. The trajectory of 3DPrint is thus marked by dynamic interrelations between digital content (models, data, software), and physical material (filaments, printing devices).

Our study draws on a process view of entrepreneurial activity (Davidsson, 2015) and the modular layered architecture view of digital technologies (Yoo et al., 2010). These models provide the lens for the theory building process. During data collection and analysis, we view digital technologies as consisting of multiple layers. This allows a finer granular analysis of the process starting from 3DPrint's inception until the latest product release.

The malleable and generative nature of digital technologies enables the decoupling of form from function and medium from content. Accordingly, the diffusion of digital technologies into physical products paves the way for a layered modular architecture of digital artifacts (Kallinikos et al. 2013; Yoo et al. 2010). The layered architecture represents different design hierarchies, where decisions on one layer can be made mostly independent from the other layers (Yoo et al., 2010). The layered modular architecture of digital technologies comprises four layers (illustrated as a lens for the vignette in Figure 1). For example, the contents layer refers to diverse types of content and associated metadata. Then, the service layer encompasses application functionality the users of digital technologies interact with. Finally, the device layer incorporates the computer hardware and the operating system the other layers act upon.

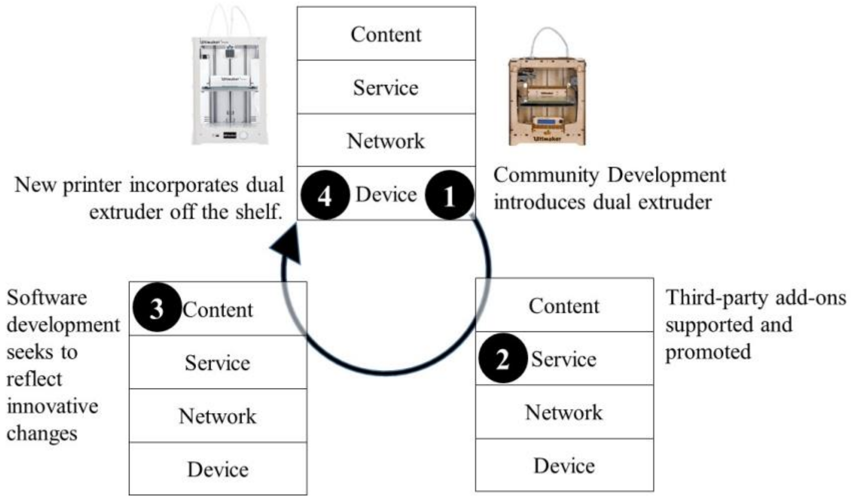
Drawing on this view of digital technologies, we describe a vignette (Figure 1) where hardware innovations triggered changes in software layers. 3DPrint's open source community developed a hardware add-on called "dual extruder" (step 1). The online community played an integral role in shaping the early trajectories of 3DPrint as described by the R&D Manager:

> *"We gave the community our drawing and the parts they needed to improve our machine and in turn, we talked to them and took some of the improvements back into the next iterations"*

Dual extrusion is an important feature of a 3D printer and allows the users to alternate between multiple filaments or materials. Initially, concerns over quality prevented 3Dprint from providing a proprietary solution for dual extrusion. Reacting to considerable demand from the user community, the venture eventually decided to endorse a community upgrade that allows to retrofit 3Dprint's own machines with a second printing head. To facilitate this innovation, the 3DPrint team subsequently needed to work on upgrading the software (see step 2 and 3) to ensure smooth operation with upgraded devices. Overtime, operation dual extrusion was deemed satisfactory as a number of crucial operations could now be undertaken with two printing heads. Consequently, 3Dprint decided to incorporate the feature by incorporating it into the next product release of off the shelf 3D printers (step 4).

Figure 1. Vignette Illustration: Hardware triggers Software Innovation

(modular layered architecture adapted from Yoo et al. 2010)



Here we describe one path in which software and hardware changes mutually shape the digital venture's trajectory. By studying the process and the role of software as well as hardware components, we aim to contribute a micro level process theory of digital venture trajectories. We thereby inform the nascent body of literature on digital technology based entrepreneurship (Nambisan, Lyytinen, Majchrzak, & Song, 2017) and contribute to the digital innovation literature. Our study indicates that in the development process of entrepreneurial organizations there are innovations that relate to either hardware changes, software changes, and sometimes the co-occurrence of both.

Navigating Through the Fog of Discovery in Accelerated R&D Processes: Course Setting or Continuous Tacking?

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Scholars have argued that our society has become an “acceleration society” (Agger, 2004; Rosa, 2003; Wajcman, 2008), whereby technological changes are leading to “speed space” (Virilio, 2010) and “time-space compression”(Harvey, 1990). The perception and enactment of time are going through unexplored changes (Hassard, 2002; Tavory & Eliasoph, 2013). This study explores “makeathons,” a new innovation process that aspires to accelerate traditional R&D processes into 72 hours, morphing the temporal landscape (Tavory & Eliasoph, 2013) of new product development process from an innovation journey into a sprint. Makeathons have emerged from the grassroots “making” movement, using freeform fabrication technologies and open-source software and hardware platforms to build solutions for a wide variety of problems, ranging from everyday use to biology and robotics (Halverson & Sheridan, 2014; Nascimento & Pólvora, 2016; Upcraft & Fletcher, 2003). The making movement has been described as the “third industrial revolution” (Anderson, 2012), as do-it-yourself (DIY) technologies threaten to disrupt traditional industrial manufacturing (de Jong & de Bruijn, 2013; Su & Pirani, 2013) and perhaps return to individualized production. We investigate how it is possible for makeathon participants to produce new assistive technology products for disabled individuals – a process that traditionally requires weeks, months or even years – in just 72 hours. For that purpose, we combine the theoretical temporal perspective with the sociomaterial one in order to investigate the emergent innovation work practices and processes associated with successful or failed new product development (Hernes, 2014; Langley, Smallman, Tsoukas, & Van de Ven, 2013; Orlikowski & Yates, 2002).

The ability to develop new products in a makeathon is particularly puzzling as this setting raises the ambiguity of the innovation process to a degree that, according to previous literature, would impede outcomes. Beyond the time pressure induced by the severe time constraints, makeathons are also temporary forms of organizing (Bechky, 2006; Klein, Ziegert, Knight, & Xiao, 2006; Valentine & Edmondson, 2014), assembling individuals to solve and innovate on specific problems and then disassemble. Understanding the nature of “flash” organizing is critical to the changing nature of work, as work increasingly occurs outside traditional organizational boundaries in ad hoc assemblies of individuals (Valentine, 2017). Furthermore, temporary groups are based on “self-organizing” principles (Benkler, 2006; O’Mahony & Lakhani, 2011), whereby the work process is fully emergent and not pre-defined. As such, the traditional ambiguity embedded in innovation processes is amplified, and the work practices developed to cope with it become central. We therefore closely examine the practices that enable engagement with the enhanced ambiguity induced by this accelerated and temporary process.

We have little research on the emergent work processes in such new forms of organizing for innovation (Faraj, Jarvenpaa, & Majchrzak, 2011; Yoo, Boland, Lyytinen, & Majchrzak, 2012). We have multiple studies on the motivations to participate in such new forms of organizing (see Von Krogh & Von Hippel, 2006), yet little understanding on the work process itself (Lifshitz-Assaf, 2017; Majchrzak, Griffith, Reetz, & Alexy, 2017). Such “open” forms that started in software have spread to a variety of fields including hardware, robotics and biology (O’Mahony & Lakhani, 2011) and are especially critical in fields such as healthcare and medical device development where the manufacturing companies do not satisfy many segments of the individuals in need (Aungst, 2015; Von Hippel, 2017). Scholars have suggested that do-it-yourself (DIY) assistive technologies can empower individuals to adapt existing designs to fit their custom needs at a low cost and in a short time (Boland, Lyytinen, & Yoo, 2007; Hurst & Tobias, 2011). We study makeathons that use new DIY technologies in order to solve assistive technology challenges.

In this study we emphasize the need to investigate the use and impact of materials and tools to understand the temporal change in accelerated R&D processes. Makeathon participants in this study used new freeform fabrication technologies and materials (such as 3D printers and laser cutters) and open source software and hardware platforms (such as Arduino, Raspberry Pi and other electronic kits) to enact the accelerated new product development process. These technologies and digital platforms are fueled by online communities of individuals who voluntarily post and retrieve information and instructions about how to create physical artifacts, making development faster and more accessible (Aldrich, 2014; Austin, Devin, & Sullivan, 2011; Dougherty, 2012). Scholars have called to further explore how 3D technologies and other novel representations constitute effective boundary objects (Boland, et al., 2007; de Jong & de Bruijn, 2013; Kyriakou, Nickerson, & Sabnis, 2017; Su & Pirani, 2013). The use of materials in R&D processes has been studied and shown to play multiple roles in facilitating work (Nicolini, Mengis, & Swan, 2012). Material representations such as sketches (Henderson, 1998), blueprints (Ewenstein & Whyte, 2009) and computer-aided design (CAD) drawings (Carlile, 2002), which are commonly used in development work to conceptualize ideas, function as “boundary objects” (Star & Griesemer, 1989), helping individuals communicate to achieve shared understandings (Bechky, 2003a; Carlile, 2002), enlisting support (Bechky, 2003b) and coordinating work (Henderson, 1998; Swan, Bresnen, & Robertson, 2007). Moreover, prior literature has shown that the same materials can be perceived in distinct ways (Faraj & Azad, 2012; Fayard & Weeks, 2007; Garud & Rappa, 1994; Leonardi, 2011). For example, Mol illustrated in “body multiples” (2003) how different healthcare professionals, in treating the same disease of the same body organ, view and enact the same organ completely differently. In this study, we observe distinct ways of when and how the freeform fabrication and digital materials are used, and we illustrate how they are related to different underlying assumptions regarding the role of materials in the new product development process.

We investigate how new assistive technology products are developed in such accelerated, temporary and self-organized processes. For that goal, we study 13 projects across two assistive technology makeathons where participants voluntarily came together to build working solutions for individuals with disabilities, under a severe time constraint of 72 hours. Participants received a defined problem, access to material resources (3D printers, DIY mechanical and electrical equipment and material supplies), and an explicit goal of building a working product in 72 hours, with no guidance on the process or expected structure. At the end of the 72-hour period, each project presented its end product, marking a discriminant time point at which we compare each project’s level of success in developing a working product. At the end of these 72 hours, six projects were able to develop working assistive technology products and some even delivered them in person to individuals with disabilities. A 13-year-old girl took home a lightweight, portable prosthetic arm to help her with everyday activities. An academic professional received a remote control device to ease her difficulty managing her portable oxygen device. A fashion designer acquired a simple kit to upgrade his mechanical wheelchair to operate electronically. Beyond easing the challenges for these specific individuals, the makeathon products’ designs became publicly available, providing individuals with similar challenges affordable solutions.

Our findings shed light on two divergent innovation processes that emerged at the makeathon, continuous tacking and course setting – which led to discrete successful or failed products. Six projects followed a continuous tacking process and successfully produced working products in 72 hours, while seven projects followed a course setting process and were unsuccessful under these conditions. We observe that engaging in continuous tacking, navigating the “fog of discovery” by tolerating ambiguities and adapting to emerging outcomes, was critical for developing a working product. We illustrate how these two innovation processes relate to underlying assumptions regarding the very nature of the innovation process and hence the role of tools and materials in the innovation process. To this end, we suggest continuous tacking projects and course setting projects utilized tools and materials fundamentally differently, enabling the former to experience successful innovation trajectories and outcomes while the latter were unable to do so within the constraints of the makeathon.

Submission #14031

3D Printing our Imagination?

Organizing Digital Innovation in Healthcare

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"Brain surgery is changing. Surgeons are using 3D printed titanium plates to replace parts of patients' skulls… before 3D printing, metal plates were hammered out by hand and adjusted during surgery, but their fit was not perfect, and up to one in 10 patients developed infections. One of the first patients to have a 3D printed plate fitted, who collapsed with an aneurysm and needed emergency surgery to fix blood vessels in her brain, shared that "I don't feel like I am sort of a monster [chuckles], I am very pleased with the way it looks and the way it feels" (BBC, 2017)

3D printing (3DP) is an emerging technology that transforms digital models into physical objects. Heralded as the third industrial revolution (Economist, 2012), the technology has gained much interest in the medical world, as it has the potential to improve patient lives as seen in the quote above, with applications ranging from 3D printed anatomical models for surgical planning that reduce operating time and save costs(Tack, Victor, Gemmel, & Annemans, 2016), implantable medical devices such as titanium cranial plates that can improve patient outcomes, and even 3D bioprinted structures that could be used to replace injured, missing, or diseased tissue in patients (Murphy & Atala, 2014). Integrating such a technological innovation into the workplace is an important area for both organization theory and IS scholars.

Organizing 3DP is challenging endeavour. It requires coordinating work among occupational groups with specialized expertise and knowledge boundaries(Carlile, 2002; Carlile, 2004; Okhuysen & Bechky, 2009), and has the potential to reconfigure boundary relations amongst them(Barrett, Oborn, Orlikowski, & Yates, 2012). At the same time, 3DP innovations highlight the need to pay attention to both digital modeling practices as well as the materiality of spaces to locate the 3D printers within hospitals.

Our research focuses specifically on how hospitals are organizing 3DP as a service and how this is consequential for occupational dynamics. In particular, we studied the role of the materiality of place, and how occupations mobilize and protect their jurisdictional boundaries when a new technology creates upheaval. We explore these areas of inquiry through a practice lens (Feldman & Orlikowski, 2011; Nicolini, 2012). In particular, our analytic approach recognizes the constitutive role of everyday practices in bringing the world into being and accounts for both social and material elements in digital innovation. Additionally, the concept of place sensitizes us not only to localized practice enactments that are identity and meaning making (Nicolini, 2012), but also to the relations between multiple lived places that are infusing experience in one place with the evocation of other events and other places. In this way, we holistically examine and illuminate how specific places where 3D printers are located at are part of a wider network of places when organizing the digital innovation of 3DP. By taking this approach, we hope to offer novel insights into the role of place when organizing the digital innovation of 3DP. At the same time, we view boundaries as relational, dynamic, and in a state of becoming (Tsoukas & Chia, 2002). In this way, we examine how situated practices are configuring, maintaining, and extending boundary relations through jurisdictional claims.

3DP is an innovation that bridges 3DP the digital and physical domains, as it requires both digital modelling and physical 3D printers located in particular places to transform digital models into customized, tangible artifacts. Previous work examines digital innovations where there is seemingly endless flexibility and focuses on the materiality of digitization within innovation processes and outcomes(Boland, Lyytinen, & Youngjin, 2007; Jonsson, Holmström, & Lyytinen, 2009; Lee & Berente, 2011). Less attention, however, has been paid to the importance of the duality of digital and physical domains in digital innovation, and the case of 3DP is exemplary to explore this area. An exception is Barrett et al., (2012), who examine the importance of place (implicitly), by showing how the materiality a dispensing robot in a pharmacy context influenced the work practices, interests and relations of three interdependent occupational groups. However, by focusing on the robot's hybrid materialities and shifting boundary relations, the role of place is not explicitly theorized.

By foregrounding how hybrid materialities are entangled with groups' status, control and autonomy, Barrett et al., (2012) demonstrate the consequentiality of digital innovations for occupational dynamics. As such, they join prior research reporting how technological innovations play an important role in reorganizing work among different occupational groups, for instance, by serving as an occasion for social reorganization, triggering jurisdictional disputes and renegotiations (Barley, 1996) and shifting occupational roles, relations, identities and boundaries (Bailey, Leonardi, & Barley, 2012; Zuboff, 1988). Occupational groups may resist collaborating when their jurisdictional boundaries are under threat in light of organizational change (Truelove & Kellogg, 2016) and draw on their knowledge and expertise to establish and maintain authority over which tasks to perform (Abbott & Forrest, 1986; Anteby, Chan, & DiBenigno, 2016). Research in this tradition emphasizes how particular occupation members may reinterpret and enact their roles, status, and autonomy in the face of new technology implementations, or through the constitutive role of multiple materialities. As Anteby et al., (2016, p.211) argue, however, the question remains, "why and how occupational members take on or yield new tasks, or how they support new organizational initiatives and technologies"?

Our study is based on data systematically gathered over 24 months at a hospital implementing 3DP, with a longitudinal focus on how different occupational groups have used the technology. Our empirical materials come from a variety of sources, including ‘zooming in’ on practices (Nicolini, 2009), ethnographic non-participant observations (343 hours), detailed field notes (400 single spaced) of how 3DP projects were negotiated and transformed over time (Emerson, Fretz, & Shaw, 2011), in-depth, semi-structured interviews with participants from various hierarchical levels and occupational groups (55), informal, in-situ interviews that regularly occurred while observing work (90), and finally, archival data (20GB of project progress documents, emails, technical specifications and design files of 3D printed medical devices).

First, our research highlights how the materiality of place is implicated in the innovation process. While one might expect place to lose its significance with the digitization of innovation, we observed the opposite. Places, even the ones where the innovation of 3DP was not explicitly unfolding, were constitutive of the practices of the actors involved in the innovation process. Further, the materiality of place played an important role in both enabling and constraining the development of the digital innovation. Our findings show that the materiality of the places where each of these groups work is constitutive of their practices, thwarting or enabling collective collaborative work in the innovation process. This points to an ecology of places and practices; in our case, practices unfolding in places other than the 3DP Lab – where digital innovation seemed to be unfolding, can influence the development of the innovation process.

Second, our study shows how jurisdictional boundaries between multiple occupations are reconfigured when 3DP creates upheaval. Different occupational groups yield new tasks using 3DP as a way of expanding their jurisdictional boundaries over time. Our longitudinal findings provide granularity as to the boundary work practices four occupational groups (mechanical engineering technicians, 3DLab - comprised of radiologists and 3D technicians, clinical engineering R&D and neurosurgeons) enacted, and documents how inter-jurisdictional group boundaries were relationally reconfigured through such practices as extending task jurisdictions, resource spacing, and knowledge devaluating.

Submission #14031

Digital Density: The Interplay of the Digital and Physical World in a 3D Printing Design Community

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Digital innovation is based on the malleability of digital representations (Zittrain, 2008). These representations can be changed, edited. The facilitator of this process, the operant resource (Nambisan, 2013), is information technology, which provides persistence for the shifting digital artifact, and provides the means by which these representations can be transformed.

Much of the study of digital innovation has focused on digital artifacts as the target state of the process. Since these objects are always subject to further editing, they are perpetually unfinished, and ontologically ambivalent (Ekbia, 2009; Kallinikos, Aaltonen, & Marton, 2013). However, digital innovation is often the precursor of physical innovation. For example, practitioners of architecture, engineering, and industrial design produce designs that manifest in the physical world(Boland et al., 2007; Lynn, 1998). Digital technologies such as 3D printing are now in the hands of consumers, hobbyists and tinkerers, permitting some of the malleable characteristic of digital innovation to permeate to physical artifacts.

The physical objects created no longer have ontological ambivalence. But because they are represented by digital artifacts, and these artifacts can be used to drive additive manufacturing machines, objects can be mass produced while still exhibiting differences. That is, with additive manufacturing processes – such as 3D printing, differences can be produced as a matter of course. As an example, a manufactured spoon is no longer only an end product, as it can be digitized through scanning, personalized for a guest, and transferred back to the physical world through 3D printing. The resulting objects of non-standard additive processes exhibit non-standard seriality (Carpo, 2011; Migayrou, 2003) , i.e. personalized spoon. Objects can exhibit this nonstandard seriality, but they may not. They may remain perennially incomplete, drifting (Ekbia, 2009). Understanding these processes may help us understand the effect of particular digital artifact attributes that facilitate the permeation to the physical world, an important insight for both the research and practice of digital innovation.

We define the ever-increasing permeation of the digital world to the physical world as *digital density*. Digital density permits the creation of metamodels that in turn lead to the ability to rapidly alter products and services based on individual preferences and needs (Kyriakou, Nickerson, & Sabnis, 2017). This is apparent in examples such as easy-to-customize 3D designs, the creation of highly personalized recommendations, and service offerings such as customized t-shirts to personalized insurance quotes.

Currently, the transition between digital and physical is somewhat slow, as the physical products produced are nothing more than instantiations of the digital world. However, as digital density increases, it is perhaps safe to assume that this reciprocation will soon become much more rapid. Physical elements will instantaneously be disassembled and reshaped to give way to completely new forms in the physical world, in a similar way that software is dynamically altered to give way to new or enhanced renderings of software. It is a period of malleability and an era of ever-increasing digital density.

The transition between digital and physical is arguably affected by the attributes of the digital artifact. For example, the incompleteness of digital artifact leads to generativity, as designers seek closure (Ekbia, 2009; Zittrain, 2008). Generative designs breed unoriginal derivatives (Hill & Monroy-Hernández, 2012) and it has also been argued that the more derivative a work, the less likely it is to be further reused (Cheliotis, Hu, Yew, & Huang, 2014). These pessimistic findings are in sharp contrast to generally optimistic prior work about the value of open communities, in which shared knowledge was seen as a way of speeding innovation (Benkler, 2006). This is particularly important as often, even in communities specifically created to encourage remixing and variation, designs are not reused (Cheliotis & Yew, 2009), let alone instantiated to the physical world

This study examines *the digital artifact attributes that affect the reciprocal relationship between the physical and the digital world*. Specifically, we examined the differences and commonalities of digital versus physical artifacts and how each of these parallel spaces can inform, support and improve the other as digital density increases. We employed computationally intensive theory discovery methodologies (Berente et al., 2018), examining the choices of users and their sequence in an open source hardware community.

Open hardware digital innovation communities provide features that encourage the sharing, modification and recombination of designs that are eventually instantiated as physical objects. These communities provide a way to gain insight into how digital innovation may affect the future of manufacturing. In addition, digital innovation communities provide opportunities to better understand the interplay between the physical and the digital world, as well as how attributes of digital artifacts may facilitate their eventual use.

The activity of more than 10,000 users and more than 53,000 designs were analyzed from an open source hardware community called Thingiverse. We collected data between January 2009, date of creation of the community, and June 30, 2013, the date that we concluded our data extraction. The dataset employed here was constructed using Thingiverse Application Program Interface (API).

Empirical studies on this issue are rare. Studies on physical form have focused on architecture, or on product design. Several groups of scholars are studying additive manufacturing (Lipson & Kurman, 2010; Mota, 2011; Piller, Harzer, Ihl, & Salvador, 2014), and in particular online 3D printing communities (Kuk & Kirilova, 2013; Kyriakou, Englehardt, & Nickerson, 2012). Many other scholars have focused on digital rather than physical form: for example, studies of remix communities (Benkler, Shaw, & Hill, 2015).

In our analysis, we controlled for the potential effect of the experience of the artifact creator, the community involvement of the creator, the availability of the design in terms of number of days and whether a design had been featured in the first page of the online community. Our results suggest digital artifacts that were novel in terms of their form, as well as digital artifacts that were novel in terms functionality would be selected by users for manufacturing. Somewhat surprisingly though, designs that were novel both in terms of shape and in terms of their functionality were less likely to be manufactured.

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