Why Place Still Matters in Digital Innovation: Organizing 3D Printing in a UK Hospital

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Completed Research Paper

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Abstract

This paper examines the importance of place in organizing digital innovation that bridges the physical and digital domains. We explore this through an illustrative case of digital innovation, 3D printing, at a clinical innovation department of a major UK National Health Service (NHS) hospital. Using ethnographic, archival and interview data spanning a three-year period, and by employing a practice-based perspective and the concept of place, we find that the actors organizing 3DP enacted place making practices that raised identity tensions, thwarting 3DP collaborative work. While one might expect place to lose its significance when digitizing innovation, our findings highlight the importance of place for practices which constitute collaborative work as a key organizing practice for 3DP. We contribute by demonstrating that places still play an important role in the digitization of innovation and provide an understanding of how the materiality of place is implicated in the development of digital innovation.

Keywords: *digital innovation, materiality, organizing, 3D printing, practice lens, identity, place, healthcare*

Introduction

In this paper, we examine how a UK hospital organized for the deployment of 3D printing (3DP) as a service. 3DP is an illustrative example of digital innovation, which utilizes digital design models to directly fabricate end-use products by 'materializing' information, layer-by-layer. As such it provides the opportunity to extend our understanding of the phenomenon of the digital innovation which bridges the physical and digital domains. For example, the case of 3DP requires both digital modelling and physical 3D printers situated in particular places to transform digital models into customized, tangible artifacts. Our fieldwork study, which focused on how a clinical innovation department organized around the digital innovation of 3DP, uncovered findings which were both surprising and somewhat unexpected. 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.

We adopt a practice perspective to approach our study, drawing in particular on practice theory, which views organizing is an ongoing accomplishment which is enacted and reinforced through situated practices (Feldman and Orlikowski 2011; Nicolini 2012; Schatzki 2005). 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. By taking this approach, we hope to offer novel insights into the role of place when organizing the digital innovation of 3DP. We make two contributions to the literature. First, we show that places still matter with the digitization of innovation and provide an understanding of how the materiality of place is implicated in the innovation process. Second, we highlight how the materiality of place and 3D artefacts is entangled with and enacts identity tensions that are thwarting 3DP collaborative work. Third, we contribute by building on and extending the emerging stream of identity and innovation by responding to a recent call to study the professional workers' level of analysis (Anthony and Tripsas 2016). In the next section, we introduce the phenomenon of 3DP, followed by an account of our practice theory informed theoretical framework. We then present our research methods and setting, followed by our analysis and discussion. We conclude by highlighting the contributions of our study and their implications for research and practice.

3DP as a Digital Innovation

Otherwise called additive manufacturing (AM), 3DP is an emerging technology that transforms digital models into physical objects, by 'materializing' information, layer-by-layer. There are several AM processes, differentiated by the manner in which they create each layer (Campbell et al. 2011). For example, the main AM techniques are selective laser sintering (SLS) – using a laser to selectively melt metal or polymeric power, stereolithography (SLA) – using an ultraviolet laser to harden a photosensitive polymer and finally 3DP – jetting a binder into a polymeric powder. 3DP builds physical objects in contrast to the predominant 'subtractive' manufacturing technique, which involves cutting blocks of material into the right shape, and assembling them into more complex products (Campbell et al., 2011). What is particularly salient for the phenomenon of 3DP is the combination of model customization and open source repositories for 3D printing novel physical objects. For example, Kyriakou et al. (2017) note that 3DP communities not only build models, but also build more abstract models called metamodels, which are interactively modified to produce different 3D models, leading to truly customized physical objects. The authors argue that examining the metamodels in the 3DP context can enrich our understanding of how digital innovation can change design and manufacturing processes. Building on this emerging stream of research, we examine the application of 3DP in a sector that has not been examined before, the medical sector.

3DP has numerous applications and has gained much interest in the medical world. Applications vary from anatomical models mainly intended for surgical planning to surgical guides and implants (Tack et al. 2016). For instance, doctors previously mostly worked with two-dimensional X-ray images, computed tomography (CT) images or magnetic resonance (MR) scans to gain insight into pathologies. With 3DP, they utilize a multitude of 3D renderings of CT and MR images to reconstruct and design a 3D model through computer-aided design (CAD) software, that they can then 3D print with a variety of materials and tactile qualities. The need for improved visualization and surgical outcomes has given rise to 3D-printed anatomical models, patient-specific guides, and 3D-printed prosthetics. The technology is expected to bring about a new era of

medical innovation, with claimed benefits such as the quick customization of drugs for unmet patient needs, recent advancements such as tissue and organ fabrication, as well as the creation of customized prosthetics (Ventola 2014).

Conceptualizing 3DP as Bridging Physical and Digital Domains

Jones and Rose (2016) distinguish between two distinct types of digital innovation: those that bridge the digital and physical domains, and those that operate solely in the digital domain. An example of the former might be innovations associated with the digitalization of automobile control systems in which digital technologies enhance the capabilities of a physical product. Regarding the latter, this concerns innovation in the software industry, in which the product itself is digital. We consider 3DP as a digital innovation that bridges the digital and physical domains, in that innovation occurs both in the software (e.g. digital modelling of objects) and physical domains (e.g. innovation in printing technique and materials). One of our study informants exemplified this during a conversation:

"Many people think that 3DP is about a machine that 3D prints an object. While that may be the physical manifestation of 3DP, the process starts much earlier… 3DP objects, such as medical devices, are digitized and rely on digital imaging - the currency of 3DP […] without it there would not be any 3DP"

3DP Practitioner, Global 3DP Summit

As the quote above demonstrates, 3DP is considered to be bridging 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. Our review highlights that the literature has not yet developed theoretical sensitivity around digital innovations that bridge the physical and the digital. Previous studies have focused on the design and management of innovations in the service-layer (Yoo 2010), where there is seemingly endless flexibility, and on the materiality of digitization within innovation processes and outcomes (Boland et al. 2007; Jonsson et al. 2009; Lee and Berente 2011). Less attention has been paid to the importance of the physical domain 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 introduction of a new digital innovation of 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, they do not theorize explicitly the role of place in digital innovation.

Theoretical Perspective: A Practice Lens

In order to address our research question in the context of digital innovation, we adopt a practice perspective (Feldman and Orlikowski 2011; Nicolini 2012). For the purposes of this paper, we emphasize two aspects of practice theory that are particularly helpful in examining how the hospital organizes around the digital innovation of 3DP. First, a practice approach does more than just describe activities or just what people do. Practices are meaning-making, identity forming and order-producing activities (Chia and Holt 2006; Nicolini 2009). Second, our practice-based approach accounts for both social and material elements in the organizing practices for digital innovation. Following the critique of both deterministic (under-socialized) and voluntaristic (over-socialized) accounts of technology (Leonardi and Barley 2008), an increasing attention to materiality is warranted (Orlikowski 2007; Orlikowski and Scott 2008). The practice lens examines how organizing practices are bound up with the material forms and places through which humans act and interact (Orlikowski 2007). In this way, we conceptualize organizing as the different sets of discursive, material and bodily practices that are situated and enacted.

To this end, to produce insights into the digital innovation of 3DP that bridges the digital and physical domains, our study also focuses on spatial aspects in relation to digital fabrication, by utilizing the concept of place. Scholarly research has described the relationship between place and space in a variety of ways. A consistent theme relates to the association of space with abstraction, indirect experience and as being boundless, and place with bounded locality and concrete experience (Giddens 1990; Schultze and Boland Jr 2000). Generally, places can provide "raw material for the creative production of identity" and "creative social practice" (Cresswell 2004, p. 39). Following previous research that recognizes the value of introducing place as a distinct concept to space (Lawrence and Dover 2015), and in attempt to address the largely absent concept of place in innovation studies, we use place as an analytical tool. 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 implicate each other in the context of a wider network of places when organizing the digital innovation of 3DP.

Methodology

Research Setting and Site Selection

We performed a fieldwork study at a clinical innovation group of a UK, NHS hospital (henceforth CIG), spanning a period of three years. The health care sector is an important one to examine the organizing of 3DP, as hospitals will need to revisit their organizing practices for leveraging the potential of the technology, with considerable implications for reconfiguring care practices, jurisdictions, relations and identities (Barley 1986; Barrett et al. 2012; Barrett and Walsham 1999). This is especially the case in healthcare, which is characterized by strong social boundaries between health care workers from different professions (Ferlie et al. 2005), created in part by strong professional and occupational identities (Abbott 1988).

We selected this research setting for purposes of explorative richness, as little theoretical precedent exists for inquiry in this domain (Pettigrew 1990). CIG is a multidisciplinary center that supports and accelerates the development of innovative medical technologies with the aim of addressing unmet patient needs, while improving patient safety. 3DP requires organizing across diverse occupational communities of practice within the hospital, hence CIG has comprised of heterogeneous experts at different points in time throughout our fieldwork. Figure 1 visualizes the main actors involved in 3DP, such as biomedical engineering (comprised of mechanical engineers and R&D), as well as professionals, including consultants, technicians, radiologists and surgeons, who work collaboratively to design, develop and implement innovations using 3DP, at a centralized services lab (3DPLab).
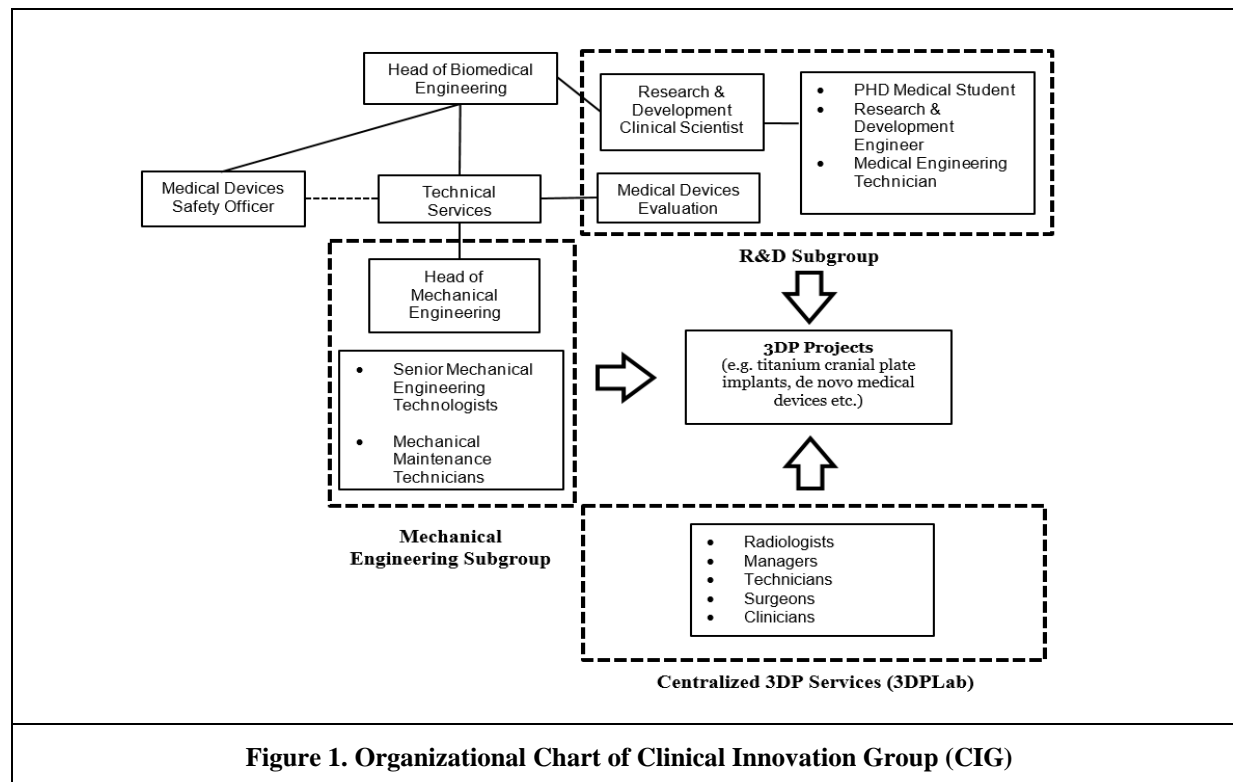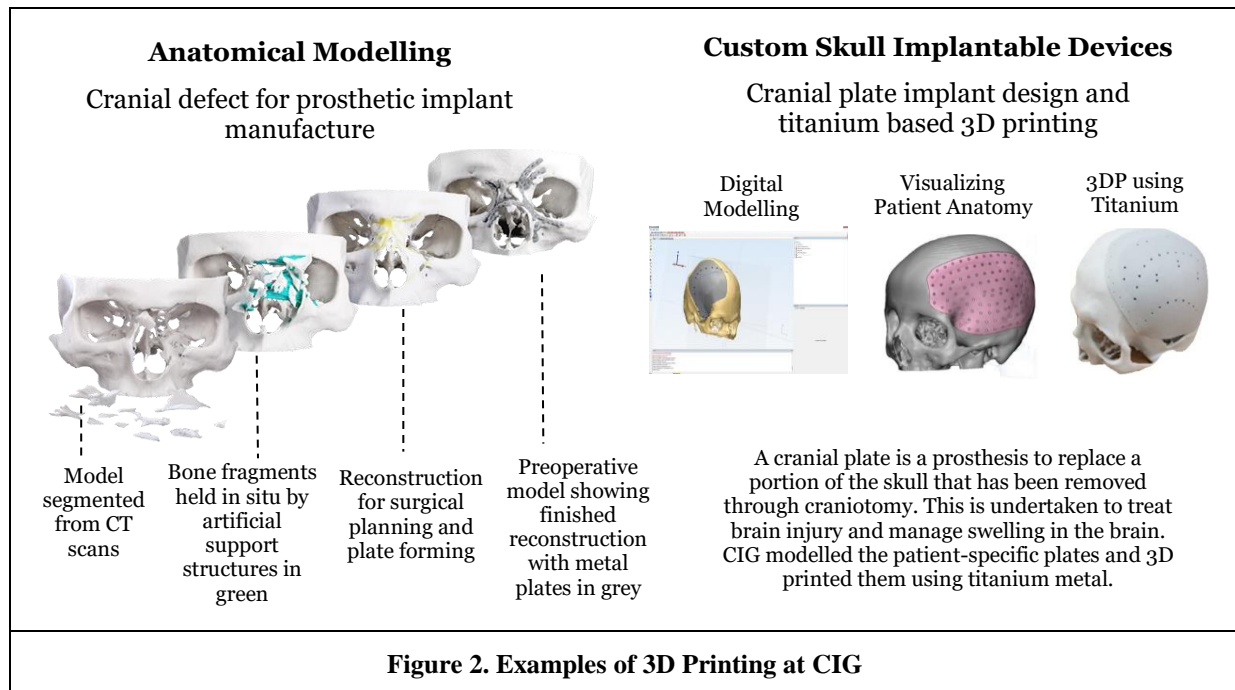

Figure 1. Organizational Chart of Clinical Innovation Group (CIG)

All three groups were located in different places within CIG, though they worked collaboratively on diverse 3DP projects. The technical services of CIG maintain approximately 33 thousand medical devices with a value of £50 million. The R&D subgroup is a team of healthcare and clinical scientists that address unmet clinical needs through the application of science and technology. The 3DPLab produces a range of 3D anatomical models for a variety of clinical specialties, with applications ranging from surgical planning, pre-bending of surgical plates, to anatomical visualization and the creation of customized implants for surgery, all for enhancing patient care. This includes the specialties of orthopaedic surgery, neurosurgery and transplant surgery among others. Figure 2 shows key examples of CIG's 3DP work.

Anatomical Modelling

Cranial defect for prosthetic implant manufacture

Custom Skull Implantable Devices

Cranial plate implant design and titanium based 3D printing

Digital Modelling

Visualizing Patient Anatomy

3DP using Titanium

Model segmented from CT scans

Bone fragments held in situ by artificial support structures in green

Reconstruction for surgical planning and plate forming

Preoperative model showing finished reconstruction with metal plates in grey

A cranial plate is a prosthesis to replace a portion of the skull that has been removed through craniotomy. This is undertaken to treat brain injury and manage swelling in the brain. CIG modelled the patient-specific plates and 3D printed them using titanium metal.

Figure 2. Examples of 3D Printing at CIG

Data Collection

We have collected data through multiple methods. Table 1 provides a summary of the study's data sources. The first author spent at least 3 days a week, on average, over two years, within the research and development (R&D) function of the group, directly examining and following how hospital actors organized around 3DP. Our primary data sources include zooming in and zooming out on 3DP practices (Nicolini 2009), ethnographic observations (343 hours) and detailed field notes (400 single spaced) of how 3DP projects are negotiated and transformed over time, as well as in-depth, semi-structured interviews with participants from various hierarchical levels and disciplines (55), supplemented by archival data (20GB of project progress documents, emails, technical specifications and design files of 3D printed medical devices, spanning a period of three years.

Interviews

In addition to the spontaneous, informal interviews that regularly occurred while observing work, we also arranged semi-structured interviews with informants from different hierarchical levels and functional areas involved with the process of 3DP. Almost all interviews were digitally recorded to facilitate analysis and lasted 30 to 120 minutes, producing 750 pages of single spaced, transcripts. Our initial interviews were exploratory; we collected rich data on the organizing practices of the 3DP projects CIG were working on over time by using an open and flexible interview design. We carefully considered and rephrased questions with interviewees so that they could discuss how they experience their work world, what is meaningful to them and what their practices involve, while remaining open to emerging themes. This facilitated the emergence of unexpected themes, such as the importance of the materiality of place for 3DP, which guided our consequent data collection efforts.

Table 1. Overview of Data Sources		
Data Collection	**Informants/Material**	**Total**
Semi-structured interviews	**Formal (#55) with 48 participants, including:** Hospital Divisional Directors, Managers, Clinical Scientists, Clinical and Mechanical Engineers, Technicians, 3DP healthcare professionals, Surgeons, Radiologists **Informal (#90) with participants above during fieldwork**	60 hours 5 interviews conducted over Skype 250 hours 17 months of observation
Participant observation	**Meetings** • Design review • Establishing and updating 3D projects **Biomedical engineering** • Rapid prototyping • 3D modelling • Repairing and maintaining equipment **3DPLab Practices** • Anatomical modelling • 3DP of medical devices	40 hours 150 hours 50 hours 400 pages of fieldnotes, single spaced
Observation at key 3DP conferences	**3DP Innovation conference - practical use of 3DP CAD software for medical modelling (Europe)** • 3DPCo Headquarters **3DP network (UK) – research dissemination** **Global 3DP Summit (Europe & Globally)** • Observation and informal interactions with more than 2 0 clinicians and 3DEquipCo staff	48 hours 7 hours 48 hours
Archival sources	**Emails** • Evolution of practices between 2014-2017 (through bran ding material, plans, logos, roadmaps, interactions)	100
	Internal documents • 3DP device technical specification files • Design drawings • Project review documents • Group presentations of 'who they' are and 'what they do'	150
	Public documents • Medical regulation and legislation directives • 3DP Reports • 3DP blogs	100

Participant Observation

In addition to gathering interview data, the first author conducted participant observation and took detailed field notes (Emerson et al. 2011) of the practices of the different groups involved in 3DP in real-time, as well as at several project meetings, where audio-recording was not allowed. As a participant, the first author was granted access to the hospital as an honorary researcher and was physically located at the R&D subgroup, regularly interacting with members of the team and developing several close informants. The honorary researcher role was a natural one to conduct participant observation because the first author was an accepted, yet temporary, member of the organization.

The first step in assembling a day's field notes was to expand the running notes taken in the field into full narratives that someone who had not been on-site could understand. Similarly, we indexed screenshots and photocopies of documents at the point in the field notes where they were used. We paid particular attention to "reproducing the sensation of being there, captur(ing) the nuances of that moments and render(ing) these meaningful (Jarzabkowski et al., 2014, p.276). Weaving together actions, conversations, and images allowed us to capture and better understand our informants' "native point of view" (Van Maanen, 2011) and their regimes of sayings and doings (Nicolini, 2009). We also collected archival data related to CIG's collaborative projects to further specify and refine events from the interviews and meetings. We received, for example, internal reports, newsletters, emails between all the different actors involved, internal organization documentation such as project specifications, product designs, memos and strategy reports. Complementary to these, we collected public 3DP regulation reports and blog entries from key medical 3DP organizations. These archival sources helped with obtaining historical and reference points for 3DP project dynamics across the hospital and wider 3DP technology updates.

Finally, in addition to zooming in on the practices within the hospital, we also shadowed the practice of 3DP in real-time at different conferences, meetings and gatherings where the practice of 3DP was debated, considered, sanctioned and legitimated (Nicolini 2009). Studying the configurations of practices requires empirically localizing "complex and global formations which are simultaneously taking place at different sites" (p. 13). Although the field study was initially focused on observing and understanding the organizing practices of heterogeneous actors in the digital innovation process at CIG, the study was later extended to other centers and locations that had become relevant in understanding 3DP practices. The observation was preceded by, and later integrated with, semi-structured interviews with 3DPrintCo, a leading medical service 3DP organization. Finally, we held regular meetings with key participants to share findings and further develop our understanding of key insights which emerged over the research process of ongoing data collection and analysis.

Data Analysis

We paid attention to the longitudinal nature of our data and adopted a process research approach (Langley 1999), with the aim of tracking the flow of events and practice enactments over time. The analysis consisted of multiple readings of the interview transcripts, field notes and documentation, the open coding of discursive and other practices, as well as issues related to everyday work at CIG. This led us to employ a multitude of strategies for analyzing the data, such as narrative strategy (Langley 1999; Pentland 1999), zooming in and zooming out (Nicolini 2009) to surface the "effects produced by different nexuses of practice" (Nicolini 2012, p. 234), and a grounded theory strategy (Strauss and Corbin 1990). Parallel to data collection, we began our first round of analysis with the coding process and category building practices of grounded theory. Our open coding focused on zooming in on the practices of the multidisciplinary groups at CIG, such as the R&D practices of rapid prototyping, designing, mechanical engineering practices of equipment management and repairing and the 3DPLab practices of anatomical modelling, while remaining alert to emerging ideas. At the same time, we wrote extensive theoretical memos on our emerging findings and created an event list (Poole et al. 2000) based on our interviews, fieldnotes and archival date. This enabled us to maintain an integrated database of evidence in Atlas.Ti, throughout the fieldwork, which helped us construct a detailed story from our data and identify linkages and patterns between different types of events and practices.

Through this process and over time, we were sensitized to the emerging importance of place when organizing the digital innovation of 3DP. For example, in their descriptions of work, our participants repeatedly referred to the importance of the mechanical engineering workshop place and its role in

developing the 3DPLab service. This was further corroborated by participant observations, where we observed identity tensions and challenges enacted through the practices of the R&D and mechanical engineering subgroups at the workshop place, as well as 3DPLab, and what outcome that brought about for the development of the 3DP innovation. Once the materiality of place started to emerge as a topic of interest, we went back to our data and mined our fieldnotes, interviews and documents for relevant clues and meaningful events. In this second round of analysis, we therefore focused our attention on documenting, exploring and unpacking the place making practices of each of the subgroups organizing 3DP and with what consequences for the development of the 3DP innovation. To do so, we knitted our findings together as rich vignettes; "vivid portrayals […] of specific incidents that illuminate [the] theoretical concepts" that emerged from our analysis (Jarzabkowski et al. 2014, p. 280). Namely, how the materiality of artifacts at the mechanical engineering workplace used by different subgroups enacted identity tensions when organizing (vignette 1), and how the deliberate strategy of CIG leaders to renovate the mechanical engineering workshop place into an innovation hub backfired (vignette 2).

At the same time, when zooming out of CIG, we focused on our emerging findings and paid attention to identity tensions and place considerations at key 3DP conferences and gatherings (see Table 1 for details). This approach corroborated our emerging findings and improved the trustworthiness and transferability (Morse et al. 2002) of our theoretical insights with 3DP practitioners, engineers, clinical scientists, and managers, at sites other than CIG. Our second-order coding (Strauss & Corbin, 1990) was being reconfigured throughout the fieldwork while incorporating both findings from CIG and observation at key conferences, while iterating between interview transcripts, observations, our event list and the literature. In the next section, we provide composite narrative theorizing and vignettes demonstrating our theoretical insights.

Findings

We begin our analysis with the process of establishing a centralized 3DPLab at CIG and how the hospital was organizing around the innovation at different places, through the situated practices of different CIG actors. We have organized our narrative to highlight our emerging fieldwork insights of the importance of the materiality of place and identity tensions when organizing 3DP innovation.

Establishing an in-house 3DPLab Service at a Centralized Place

In 2015, CIG secured funds to establish an in-house, centralized 3DP services lab, with the aim of enhancing patient care. The project brought together a diverse range of specialties across the hospital, with the common goal of establishing and developing the benefits of 3DP. During the initial stages of development, the service was comprised of a 3DP lab technician, radiologists, surgeons, and clinicians. Initially, these actors enacted practices of anatomical modelling to facilitate surgical planning. Table 2 summarizes their anatomical modelling practice. Discussions around centralizing the 3DP service at a 'neutral place' were key, as the place where the 3D printers would be physically located played a crucial role in the process of innovation. There was debate for where to place the 3D printers, with options for centralizing the place as a hospital wide service, or departmentalizing the printers at discipline-specific departments (e.g. Craniomaxillofacial surgery). CIG decided to place the 3D printers at a 'neutral place', that is, a place where no hospital division, surgical specialty or departmental politics would influence the use of 3DP. Thus, CIG placed the 3DP service at the 3DPLab which was equipped to cross-charge medical specialties for services both within and outside the hospital.

By taking advantage of recent technological advances in MRI and 3D ultrasound, 3DPLab utilized 3D images of human body structures to create 3D models of patients' anatomy. A digital infrastructure was setup for the 3D printing practices of the service. The imaging datasets were obtained from radiology in their raw format (DICOM data) and were imported into specialist software packages. The structure was identified and turned from sliced imaging into a 3D structure, by engaging in segmenting practices, which could be rotated and edited on screen. The software then produced a stereolithographic (stl) file, required to communicate with the 3D printer software. Once modelled using CAD software, further adjustments could be made in terms of coloring and sizing, and the finished file was sent to the 3D printer.

Table 2.3DPLab Practices		
Practice	**Activities**	**Empirical Material**
Anatomical Modelling	Segmenting CT or MR images	*[the lab technician] loads the 3D model of the patient skull on his large iMac screen, with what seemed to be a fractured mandible, taken directly from CT scans and modelled instantly. After a period of deliberation, the technician comments that "now I need to remove the parts they [referring to maxillofacial surgeon] are interested in (showing the green areas of the CT scan layers of the model as the bone).* Fieldnotes, January 25th, 2017
	Consulting human anatomy books	*"I consult the books all the time. It is very challenging, but usually the end user (surgeon etc.) will sit here with me to help me do the model and explain what they want",* Fieldnotes, January 25th, 2017

As 3DPLab expanded their service offerings within the hospital within the next 12 months, they required further collaboration with the hospital's biomedical engineering department. For example, the R&D and mechanical engineering subgroups of the biomedical engineering department were collaborating to 3D print customized and implantable cranial plates as part of craniectomy surgery. 3DPLab proposed collaborating with biomedical engineering, as their medical device designing practices and documenting the technical details necessary to design personalized medical devices under ISO certification was necessary to ensure regulatory compliance with medical device legislation.

However, in the process of organizing the innovation of 3DP across different occupational communities, their practices as situated in different places within the hospital, other than the 3DPLab, brought about identity tensions that inhibited their working relationships when organizing. We unpack these below, by turning our attention to the situated practices of two other biomedical engineering groups involved in 3DP, mechanical engineering and R&D subgroups, as they are enacted in their respective place, the mechanical engineering workshop. To understand the emergence of the identity tensions, it is important to contextualize the groups' place making practices over time.

Identity Tensions Enacted in Practice when Organizing 3DP

Place-Making: From Enacting Manufacturing to Servicing Practices

In 2014, the mechanical engineering team were manufacturing bespoke, novel medical devices on request across the hospital, at the mechanical workshop place. They were enacting practices of medical device designing and manufacturing consulting, through such activities as using two-dimensional design tools and communicating with clinicians and surgeons. The mechanical engineers were skilled instrument makers having trained through on-the-job apprenticeships.

However, over the next year, they shifted their practices to repairing medical equipment, as shown in Table 3. This shift gradually came due to the changing strategic priorities of CIG, for instance when biomedical engineering took on the repairing of medical equipment such as beds and scales, which were considered medical devices. Hence, the mechanical engineering team were enacting repairing and managing equipment practices, bringing income to the biomedical engineering department through external contacts. Another consideration that shifted the practices of the mechanical engineering team was the introduction

Table 3. Mechanical Engineering Subgroup Practices			
Practice	**First-order activities**	**Empirical Material**	**Leading to**
Repairing and Managing Equipment	Repairing medical devices	*"we've taken on contracts regarding the overhaul of hospital beds, scales, hoists, chairs, couches"* Interview, Head of Mechanical Engineering *"I spend probably 90-95% of my time working on surgical instruments, repairing them"* Interview, Mechanical Maintenance Technician	• Erosion of job satisfaction
	Generating spare equipment orders	*"On a yearly basis, we check all our equipment out and then if spares are needed, we have to source those and generate orders"* Interview, Senior Mechanical Engineer	• Feeling devalued

of regulatory technical documentation as part of the ISO quality system for manufacturing. The materiality of the regulatory documenting practice was significant in sidelining mechanical engineering as they no longer manufactured medical devices without this documentation. Related to this, they did not have the skills (e.g. 3D modelling) to engage with the technology. The mechanical engineering team did not like the shift in their practices, as they considered their skills were better suited to manufacturing medical devices. They often noted that they are not utilizing their instrumentation skills and that this led to diminished interest in their work, feeling devalued and with their job satisfaction and status eroded.

Re-appropriating the Mechanical Workshop Place: R&D Practices

The shift in mechanical engineering team's practices was also associated with a partial re-appropriation of the mechanical workshop place, specifically with the introduction of the R&D subgroup. According to a member of the R&D subgroup, "the design room [located in the mechanical engineering workshop] used to be the mechanical engineers' office, and one day, the head of CIG would come in and plainly announced 'you have to empty the room', R&D is coming in'". Another interviewee reflected on the gradual re-appropriation of the mechanical workplace:

"The workshop used to be useful before, but not now. In the past, a lot more manufacturing took place than currently, but now R&D took over. There's a lot more documentation involved ... so it's really a struggle because R&D are heavily involved in the innovation process, they have a scientific framework of thinking, they critically ask questions about why they are doing things and they strategically use their time and resources, while mechanical engineering don't really understand the documentation R&D go through"

Fieldnotes, Medical Devices Evaluator, July 1st, 2016

The R&D subgroup engaged in designing and innovating practices, with such activities as project briefing for 3DP projects and rapid prototyping of medical devices using scientific principles, hence securing 3DP projects with clinicians from different departments. They also had a 3D printer in situ which they used to rapid prototype their designs, further facilitating their practice. Table 4 summarizes their innovation practice.

Table 4. R&D Subgroup Practices			
Practice	**First-order activities**	**Empirical Material**	**Enacting Identity**
Designing & Innovating	Project Briefing	*"We create project briefs for 3DP projects, their market potential and design 3D models for review, which guide our practices"* Interview, R&D Clinical Scientist	• Broader professional identity than equipment managing practices of biomedical engineering • Regulatory and risk gatekeepers • Medical device designers
	Designing and Rapid Prototyping of Medical Devices	*"At the core of our work is medical device design, applying rigorous scientific principles to approach healthcare problems"* Interview, Medical Engineering Technician	
	Technical File Documenting for 3DP	*"we do technical file evaluation for medical devices… going through this process minimizes the chances of something going wrong"* Fieldnotes, March 17th, 2016	

Throughout the course of our fieldwork, we observed identity tensions between the R&D and mechanical engineering subgroups that thwarted their organizing of 3DP. The occupational identity were exemplified during a 'breakdown event' when organizing around the innovation of 3DP, such as when CIG was assigned with a new 3DP project. We illustrate our theoretical insight of identity tensions in the organizing of 3DP as enacted in practice using composite vignette 1 below, crafted through our fieldnotes, interviews and archival analysis. The vignette takes the reader in the middle of organizing a new 3DP project between the mechanical engineering and R&D subgroups. We use the vignette to demonstrate how the materiality of the artefacts used by the subgroups' practices enacted identity tensions.

Vignette 1 – The Material Enactment of Identity Tensions Through 3DP Artifacts

A new 3D printing project opportunity arrived at CIG, an order for 3D printing fifty mobile phone cases that would provide additional mobile phone battery for a departmental trial study, with the aim of improving interactions with patients. The project was first delegated to the mechanical engineers, who attempted to manually machine the phone cases using traditional drilling and computer numerical control machines. The R&D group, however, seemed skeptical about the approach adopted by the mechanical engineers. Andrew, a clinical scientist with the R&D group, commented that "manually machining fifty mobile phone cases as per specification will take ages for the mechanical engineers". He further explained why the clinical scientists thought of the mechanical engineers' practices as inadequate for using 3D printing. "Although they can do very finessed machining using 2D drawings, it is not the way we engineer in the 21st century […] yes, you can manually mill bits of plastic but you are probably talking about 2-3 days of work […] in order to speed the process of delivering design, we use 3D modelling in 3-4 hours and 3D print it, whilst you are getting on to the next project, and the cost would be a third of our hourly rate, so it's a no brainer really". For the R&D group, the occupational identity of the mechanical engineers enacted through practices such as repairing medical equipment and designing 2D models,

conflicted with their practices of 3D modelling and 3DP. This tension between R&D and mechanical engineering subgroups persisted for most of the fieldwork.

The vignette demonstrates how the materiality of the artefacts each of the groups uses in their practices enacted tensions when organizing 3DP. For example, the mechanical engineers use 2D drawings and operate traditional machining tools that require craftmanship and manual precision. In contrast, R&D used 3D modelling techniques to 3D print medical devices de novo. The repairing practices of the mechanical engineers enacted in the situated place of the mechanical engineering workshop enacted an identity as 'equipment fixers', which was at odds with the R&D subgroup identity of designing and innovating medical devices using 3DP.

3DPLab Place Expansion Fails

The identity tensions examined above led CIG trying to stretch their identity beyond that of 'equipment fixers'. To do so, they envisioned the enactment of a new identity around service oriented 3DP work, to extend the anatomical modelling practices at 3DPLab. Consequently, they proposed the redesign of the mechanical workshop place to enact new, service-oriented 3DP practices, thereby enabling them to stretch their identity beyond equipment fixing. Their deliberate strategy to "stretch" their identity as innovators and renovate the mechanical engineering workshop place backfired, however, with unintended consequences. We illustrate this through the vignette 2 below.

Vignette 2 – The Materiality of Place Prevents Identity "Stretch"

The leadership at CIG recognized the strategic need to "stretch" the identity of the biomedical engineering department with the aim of projecting 'an innovators identity' to the hospital. CIG wanted to develop the 3DPLab service further by renovating the mechanical workshop place into a future proof, in-house prototyping and 3D printing facility that complemented 3DPLab, in the hope of scaling up innovation work within the hospital. The R&D subgroup prepared an innovation project brief to gather investment for updating the existing mechanical workshop place, which, as they phrased it, had some outdated and redundant kit that could be removed, providing space for rapid prototyping facilities, quality controlled manufacturing areas and meeting spaces. In other words, R&D advocated place renovation for "inspiring innovation through building a creative and safe environment for design, prototyping and manufacture of medical technology". The R&D subgroup frequently commented that as part of their vision of inclusive design thinking and proactively meeting unmet patient needs, they "wanted this to be an inclusive design project and source everyone's views on redesigning the instrumentation place".

Their deliberate strategy to "stretch" their identity as innovators and expand the 3DPLab services, however, backfired with unintended consequences. Although R&D aspired to design this collaborative place, CIG faced the resistance of the mechanical engineering subgroup. The innovation project brief resulted in discursive practice tensions between the R&D and mechanical engineering subgroups, based on their different practices, and eventually the project was not approved. After consultation with the technologists and technicians in the group, the head of mechanical engineering concluded that the project was only addressing the desires of the R&D subgroup. Mechanical engineering wanted to maintain the space they had for their repairing and equipment managing practice, for which they were invested in as to how they added value at the department and across the wider hospital. The materiality of the mechanical workshop included an array of milling, drilling and computer numerical control machines, along with trolleys and other medical equipment for repair, as seen in Figure 3 below. Specifically, mechanical engineering signaled the need for maintaining the group's equipment repairing practice and hence, their identity as 'equipment fixers'. The discursive practice tensions around the vision, artifacts and practices of the instrumentation workshop stalled and thwarted the innovation process for advancing 3DP use in the hospital, by means of developing the services of the 3DPLab.

Figure 3. The Mechanical Engineering Workshop at CIG

Discussion

Our study focused on the question of how hospitals are organizing around the digital innovation of medical 3DP over a three-year ethnographic fieldwork and by employing a practice-based approach. Our findings show that when the heterogeneous actors were organizing 3DP, they enacted occupational identity tensions through their practices that thwarted their collaborative work in the process of digital innovation. For example, when CIG was assigned a new 3DP project, we observed a 'breakdown event', that showed how the materiality of the artefacts and practices of each of the subgroups (in our case mechanical engineering and R&D) enacted identity tensions for how to do 3DP work. Even though the mechanical engineering group enacted practices of medical device designing and manufacturing, changes in regulation (the use of the technical file orientation for medical device design) and changing hospital strategic priorities shifted their practices towards repairing medical equipment which left them feeling devalued and marginalized. Intrinsically related to the identity tensions, our study demonstrates the importance of the materiality of place for digital innovation. The mechanical workshop place may be seen as constitutive of these tensions. We observed how the mechanical workshop as a place played an important role when organizing 3DP, through their situated spatial practices which were identity-making (Nicolini, 2012). As the mechanical engineering workplace was re-appropriated from a manufacturing place to a place of fixing and repairing, the mechanical engineering group shifted their practices to repairing, enacting an identity of "equipment fixers". The generalized identity of the biomedical engineering department as "equipment fixers" seemed to foreshadow the innovation practices of the R&D subgroup, whose practises included 3DP project briefing and rapid prototyping of medical devices.

When CIG attempted to expand the 3DP service of the 3DPLab by recognizing the need to redesign the mechanical engineering workplace into an innovation hub, we observed the resistance of mechanical engineering that eventually blocked the redesign, as their repairing practice enacted an identity of "equipment fixers". In other words, the mechanical workshop place may be viewed as constitutive of the mechanical engineers' identity by what that place needs to have materially for their identity to be purposed. We further theorize that places other than where the 3DP innovation seemed to be explicitly unfolding, relationally influenced the overall development of 3DP. Specifically, the mechanical engineering workplace was constitutive of the practices of the groups involved in the 3DP, leading them to block the redesign of the place into an innovation hub. Given the emergent findings around identity tensions and the materiality

of place, we discuss and elaborate below the implications of our study for how these two different areas are related.

Implications for Research and Practice

The Materiality of Place and Digital Innovation

Our study suggests a number of implications for research regarding the organizing of digital innovations, a question that is critical for organizations which operate increasingly in a world that is permeated with digital technology (Yoo et al. 2012). First, it shows that places are important despite the digitization of innovation and provides an understanding of how the materiality of place is implicated in the innovation process. 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 (e.g. by blocking CIG efforts to "stretch" their identity and redesign the mechanical workshop into an innovation hub), to strengthen the 3DP offering of the centralized 3DPLab. Digital innovation scholarship can pay more attention to the materiality of place, related to the view of places as "active ingredients" in organizing practices of digital innovation.

Second, and relatedly, our study also has implications for the emerging focus on materiality in digital innovation (Barrett et al. 2012; Cecez-Kecmanovic et al. 2014; Leonardi and Barley 2008; Orlikowski and Scott 2008). While studies have focused on the digital materiality of technological artifacts, such as remote diagnostic systems (Jonsson et al. 2009) and the digital and mechanical materialities of robots (Barrett et al. 2012), we show that digital innovation is necessarily enacted through situated practices at particular places. This is a bounded locality experience which is both a sociomaterial performance and an active ingredient in the development of digital innovation.

Identity and Digital Innovation

Third, our study has implications for research examining the role of identity in innovation. There has been increasing interest among management scholars on the role of identity for enabling and constraining innovation (Fiol 2002; Schultz and Hernes 2012; Tripsas 2009). Recent work has proposed an identity-based categorization of innovations, where innovative activities such as technological change fall on a spectrum from identity-enhancing to identity-stretching to identity-challenging (Anthony and Tripsas 2016). Interestingly, however, this emerging stream of research is silent about the role of identity in digital innovation. We contribute by building on and extending this emerging stream by responding to a recent call to study the professional workers' level of analysis (Anthony and Tripsas, 2009). As the authors note, how professionals incorporate and relate to technologies is a missing link that is important to understanding the role innovation plays in threatening professional and occupational identity, which can impact organizational outcomes. Specifically, we highlight the challenges of "stretching" identity in practice. For instance, we show that as reflexive practitioners, CIG recognized the importance of how they were viewed (e.g. their external identity) and attempted to shift their practices by redesigning the mechanical engineering workplace to expand the 3DPLab offering. This points to the importance of considering holistically how shifting identity in practice is intertwined with negotiating new practices and reconfiguring the materiality of place, which can be challenging for members of multidisciplinary collaboration in the process of digital innovation.

In addition, we join previous research in healthcare that demonstrates the importance of identity for innovation in IS research (Mishra et al. 2012). However, we depart from this line of research by demonstrating the importance of examining the dynamics of practices for enacting identity tensions. For example, we show that the materiality of place and 3D artefacts is entangled with and enacts different subject positions as seemingly distinct and somewhat fixed when performing identity work, thwarting 3DP collaborative work. Previous work shows that spatiality is intertwined with identity-making processes (Dale and Burrell 2008). Our empirical data supports the notion that the materiality of place is identity making, shaping mechanical engineers' identity as "equipment fixers". This points to the importance of examining place dynamics in the process of innovation, especially when a new identity is required to shift practices towards service-oriented work. Such considerations include redesigning the place, removing the traditional

machining and introducing different materialities to allow user-facing interactions and to develop over time a new identity. We believe that paying attention to the dynamics of practices in identity work provides a fruitful lens to examine innovation processes generally and those more specifically around digital innovation.

Finally, our study has additional implications for practice. In particular, our study provides insights for digital innovations bridging physical and digital domains, and suggests that practitioners should pay attention not only in the immediate place that innovation is unfolding, but also the other places where actors collaborating in 3DP are working in. This is especially the case with the digital innovation of 3DP, as it usually requires multidisciplinary collaboration and spans diverse boundaries in organizations.

Conclusion

In this paper, we investigated how a hospital was organizing around the digital innovation of 3DP. We found that the practices of multidisciplinary groups were enacting identities that led to irreconcilable tensions when organizing around the medical innovation of 3DP. Our fieldwork study, which focused on how CIG organized around the digital innovation of 3DP, uncovered findings which were both surprising and somewhat unexpected. 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. From our findings, we extend the role of materiality of place in the digital innovation process. Our study is limited to the extent that we only examine one specific digital innovation in a particular organizational context, but we believe our theoretical insights are valuable and generative. Future research is needed to verify and elaborate on these insights, as well as to examine the role of identity tensions and place in other contexts and with other digital innovations.

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