Infrastructuring and the Challenge of Dynamic Seams in Mobile Knowledge Work

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ABSTRACT
Highly mobile knowledge workers spend a large portion of their time traversing within and among different infrastructural configurations as they move through space. These dynamic configurations are experienced as either technological or contextual constraints, which range from forms of technological exclusion and infrastructural disconnection to divides caused by both spatial and organizational boundaries. The workaday nature of these constrained environments force mobile workers to engage in a type of articulation work that involves the construction of bridging, assembling, or circumventing solutions to repeatedly negotiate these impediments. Engaging in these 'infrastructuring' practices requires that workers develop 'infrastructural competence'—knowledge of the generative possibilities of infrastructural seams. In effect, this renders mobile workers as infrastructural bricoleurs. We discuss the implications of this required competence and speculate regarding its origin, maintenance, and differentiation among professions.

Author Keywords
Knowledge work; mobile technology; infrastructure; ubiquitous computing; sociotechnical

ACM Classification Keywords
K.4.3 Organizational Impacts: Computer-supported collaborative work

INTRODUCTION
It is no longer notable to claim that a vast majority of work practices are mediated by information and communication technologies (ICT) [54]. Nor it is contested that the Great Recession and an expanded global economy had a hand in establishing the increasingly modular and project-based characterization of most work today [2,61]. What is also obvious, though less fully explored in the discourses of work and technology, is fact that there is an increased physical dynamism in today's work styles—people can be, or must be, mobile whether within their large office complexes, their client regions, or other types of work sites [65]. Today's white-collar workers are rarely fixed to a particular location by virtue of task or technology, rather they have begun to approximate professional satellites, using mobile infrastructures and tools to orbit around clients and co-workers across paths that expand and traverse multiple temporal and spatial zones. A recent survey by Forrester Research confirms this fact: between 2001 and 2012 across Europe and the United States the population of mobile knowledge workers grew from 15% to 29% of employees [9].

Historically, work was defined primarily by its "atom" or manufacturing nature [3], identified by its processing and production of large-scale physical items; now, the United States is fast being defined by its dominance in "bit" or knowledge work--the creation and manipulation of ideas or data [54].

Knowledge work differs from its earlier, more mechanistic sibling in several notable ways. First, it is an inherently cognitive (as opposed to physical) type of labor that generates information or knowledge as its primary output [6,23]. Second, it is often project- rather than function-based [2,31,61], a characteristic that affects not only who involved in it (i.e., specialists vs. generalists), but also how long it typically lasts (i.e., terminal vs. ongoing work). Third, as with many other developments of late, it is increasingly digital or computational in its character [1,15,17,45]. Finally, because knowledge work is typically untethered from specific material conditions (e.g., factories), it easily dislocated and allows for 'anywhere, anytime' production patterns [20].

As the rise physical mobility as a part of knowledge work is occurring across many industries and professional domains, the analyst must delimit their focus not by professional jurisdiction but at the level of practice. Previous research has employed this approach in investigations of offroaders [29], on-site-movers [49], and digital nomads [18]. 'Nomadic' practices have been particularly well studied within the CSCW community [13,17,70], providing foundational details about how workers travel long distances, work without stable workplaces or fixed organizational anchors, and manage a kit of resources during their time on the move [21,58].

Of these empirical insights, one particularly important strand of the conversation is the contention that the increased dynamism of work via physical mobility introduces infrastructural challenges for workers. Infrastructure here refers both to large-scale systems such as electricity and transportation [33], as well as knowledge and information infrastructures that variably comprise many knowledge work domains [34]. As Su and Mark [70] suggest, mobility puts a 'nomadic worker' into a persistently visible and active relationship with infrastructural arrangements because the likelihood of a breakdown, either in workflow (i.e., social) or technological connectivity, is heightened by the continuous encounter with barriers and boundaries as he or she moves. For example, employees using mobile devices are regularly frustrated in their attempts to securely access, store, scan, or print information because of an incompatibility with foreign print drivers, borrowed network access rights, and other localized protocols [55]. Beyond access, workers also become dependent on specific devices and applications, which can become difficult when mobility forces the need for non-preferred or non-integrated use patterns [21,74].

In short, to be mobile, particularly as a professional, is to be engaged in a constantly changing relationship to infrastructure. Because different infrastructures are typically less than ideally, if at all, integrated with one another, workers must constantly focus their attention on identifying, managing, and working through or across infrastructural gaps and disconnects [25]. Mobility, in this sense, is synonymous with a lack of access to centrally organized resource-allocation mechanisms (prevalent in stationary forms of work) and a concomitant requirement to navigate multiple installed bases of situated infrastructures, nearly all of which are organized independently [71]. This said, we acknowledge the increasing role that cloud services play in allowing workers to bring together disparate parts of an infrastructural ecosystem to address the contingencies of a particular work situation.

Folding all these pieces together yields a setting for computer-supported work that is both dynamically changing and, as of yet, not well understood. To pursue this gap in knowledge, we draw on work by pioneering cyberinfrastructural researchers (e.g., 57, 58, 69], particularly research on 'infrastructuring practices' [52,67], to explain the empirical phenomena we see out in the field. As Vertesi [73] showcases the artful dexterity of scientists, we document the 'infrastructural competence' [25] of mobile knowledge workers as they successfully (and usually rapidly) adjust and concatenate multiple infrastructures to accomplish their work. In so doing, we seek, like an evolving infrastructure itself, to graft [59] ourselves to the larger conversation within infrastructure studies with new data and, potentially, new insights. Our contribution to the conversation will extend prior infrastructural thinking into new empirical domains and simultaneously expand our understanding of infrastructural practices when these practices are not dominated by the (creative) use of a single installed base common in scientific settings [30, 73].

RELATED LITERATURE

This paper is situated at the nexus of two streams of scholarship: first, the discussion of how mobile technologies are influencing and changing the way that modern workers do their work, and second, the discussion of how users/workers engage in workaround practices to bridge or extend knowledge infrastructures when infrastructural design(s) constrains desired usages or activities. We consider the extant research in each of these discussions briefly before turning to the mainstay of our study.

Mobility Practices in Knowledge Work

The 1960s has been identified as the moment when knowledge work began to define the future character of the American economy [39,76]. Indeed, as mentioned, much of the work that is popular today (e.g., software engineering, data science, design, etc.) springs from this initial root and, in so doing, bears certain recognizable characteristics: 1) producing and transmitting knowledge, 2) involving intellectual skill and manipulation of abstractions, 3) requiring problem solving tied to creativity, or 4) necessitating theoretical and technical knowledge, formal education and continuous on-the job learning [20,53,62]. This emphasis on intellectual endeavors makes it clear to see how easily knowledge professions can be decoupled from specific locations or times [51]—so long as a network connection is available.

CHI and CSCW researchers have been on the forefront of documenting how ubiquitous networks and mobile devices have begun to shape the extension and expansion of knowledge work over the last quarter century [e.g., 17,50,70]. Popular themes in this collective body of work include, only as a small example, the assembling of tools or 'kits' for professional nomadism [e.g., 14], the extension of work into the home environment [e.g., 17], heterogeneity of technological resources that enable mobility of work across several locations [e.g., 21], and the effects that constant availability by way of mobile devices have on the identification and psychological well-being of modern professionals [e.g., 16,40,41]. Complementary work of note, but of less central concern to our thesis herein, centers on the use of mobile devices to attend to emergencies [e.g., 32,38] and health care maintenance [e.g., 4,12]. This paper seeks to be in conversation with this cumulative body of scholarship in presenting another grounded example of the integrated sociotechnical nature of mobile practices for the consideration of both researchers and designers alike.

Infrastructures and Seams

Knowledge workers' increased dynamism, as noted above, is made possible by a combination of expanded ICT networks, the development and adoption of mobile device systems designed to support enterprise tasks, and the social

evolution of mobility as an integral, if not normative, component of both individual and organizational identity [54,61]. This set of sociotechnical arrangements comprises what we consider a *knowledge infrastructure* [24]. Knowledge infrastructures can be described as comprising multiple, heterogeneous sub-infrastructures that have been grafted [59] or merged [56] together to achieve a particular professional or scientific end. Infrastructures grow in an evolutionary manner, beginning as a primary *installed base* [30] and morphing across time with the introduction of new participants and tasks to accommodate additional features, capabilities, and arrangements.

As an infrastructure takes shape as a collection of technological systems, devices, and interfaces, it also facilitates and is facilitated by people's relationships with and around these artifacts [34]. Thus, to be understood completely, an infrastructure must include the human habits, norms, politics, standards, and temporal rhythms that animate and surround it. This sociotechnical nature is what enables infrastructure to evolve into the immutable ecosystem we typically recognize it to be [34]—an arrangement that is long-lasting and highly durable [34,42]. Because of this evolutionary characteristic, Hughes [33] once famously suggested that the study of infrastructural ecosystems should span across time and space rather than focus on narrow, isolated instances of technologies in use.

Infrastructure is also typically invisible and transparent in the background; to experience infrastructure knowingly, it has often been said, is to experience it when it is not working [57,72]. This framing aligns with Weiser's original conception of ubiquitous computing, in which users were envisioned to move across a space without technological breakdown or disruption—'seamlessly' [75]. For Weiser, seams, or recognized gaps or points of breakdown, represented a failure on the part of infrastructure designers because they force users to become cognizant of and engaged with the design limitations of the infrastructural environment.

Recent infrastructure studies scholarship presents a different take on infrastructural seams, however. Dourish and Bell [22, p. 29], for instance, acknowledge that "…<seeing> infrastructure as stable, uniform, seamless, and universally available is clearly problematic." Vertesi [73], in a similar spirit, claims that seams, while not necessarily welcome, provide opportunities for actors to bridge infrastructural gaps 'artfully', to perform infrastructural workarounds that accord with the sociotechnical relationship(s) present at any one seam's edge. These acts of infrastructural alignment and navigation are called 'infrastructuring' [7,36,37,52] and occur when actors construct—either individually or collectively—a bricolage of material, mental, social, and cultural resources to adapt to seamful situations and advance accordingly.

Infrastructuring is nearly always needed because the complex, messy, and unevenly distributed nature of infrastructure requires that individuals be in continuous negotiation with it [22], such as in .response to an infrastructural impediment or at a moment of infrastructural breakdown [57]. These sites of engagement are particularly appealing for analysis because they illuminate the dependencies among the comprised components (or the lack thereof [44]) as well as the competence or ingenuity of actors. Thus, seams, in addition to outlining a more accurate understanding of the technical configuration of an infrastructure, also impart insight into our ongoing negotiations with it [22].

RESEARCH STUDY

We report on the infrastructuring practices of mobile knowledge workers as part of a larger study that centers on exploring the sociotechnical relationship(s) between workers and digital infrastructures. Our interests in conducting this research are exploratory—we are striving to inductively identify new types of practices and data patterns by which to classify workers and infrastructural ecosystems in the service of organizational scholarship and design research. This is not, nor has ever intended to be, a study that looks at a particular set of workers, a particular industry context, or a particular set of infrastructural tools in an evaluative manner. As such, it should be considered as a prelude to more targeted investigations in the future.

Theoretical Framework

The theoretical framework we bring to this work is *practice theory*—an analytical lens that draws on Orlikowsi's investigations of technology-in-use in organizations [48]. Practice is defined as a 'recurrent, materially bounded and situated action engaged in by members of a community' [48, p. 256]. Central to a practice lens is the notion that social life, including its sociotechnical components, is an ongoing production; in this vein, researchers focus on when and how actors engage in repeated patterns of activity as well as why certain activities are produced and reinforced the way that they are [26]. For example, Orlikowski [47] famously showed that the practices of consultants in a multinational consulting firm revealed a different usage and different intention of use for Lotus Notes than did the practices of the technologists within the same firm—an insight that helped to usher in a constructionist era of technology analysis, especially within workplace studies.

Practice theorists [e.g., 43,47]—like infrastructure scholars [e.g., 44,57]—often focus on moments of breakdown or challenge because these help to reveal otherwise transparent activities or institutionalized values and norms; waves on an otherwise calm sea of activity create an opportunity to contrast the new with the given, the odd with the normal. We adopt a similar orientation in our examination of physically mobile knowledge work, namely seeking insight into the practices and motivations these workers by looking at how they address challenging or unknown events in the course of their work.

Data and Analysis

The data that informs this analysis is comprised of interviews and observation fieldwork. Eight interviews and 10 hours of observation (with one subject) were conducted in person by the first author in New York City between January 2014 and June 2014; sixteen interviews were conducted (11 in person; 5 remotely) by the second author between February 2014 and March 2015, primarily in and around Research Triangle Park, North Carolina. Interview subjects were identified in one of two manners: via snowball sampling using email and social media or via cold-calling nomadic workers who publically identified themselves online. The initial snowball sample was seeded from the personal networks of each of the authors.

Subjects were selected for inclusion in the study on the basis of their professional engagement with digital infrastructures: 1) they were required to be engaged in knowledge work of some kind, 2) be more than occasionally mobile (i.e., physical mobility was a core component of their working practice, not something that occurred rarely), and 3) possess the agency to handle a disruption or challenge on their own (i.e., their use of infrastructure had room for customization and was not prescribed totally by their organization). Of the total twenty-four subjects, 12 were women and 12 were men. While we did not collect specific demographic information per subject, it is fair to generalize the sample as ranging in age from mid-twenties to mid-sixties. All subjects shared a technical competence that enabled them to maneuver ably throughout a physical space while maintaining a sufficient type of connection to their work. Individual variations in this competency will not be discussed here, but form the basis of a separate study that is currently underway.

Participants represented a range of knowledge work domains: business and strategy consulting (5); architecture/workplace design (4); higher education (3); web design (3); communication and content management (2); IT support (2); event planning (2); real estate (2); and legal services (1). They came from large firms (4), small firms (14), and, in some cases, were freelancers (6). They also exhibited different forms of physical mobility: individuals who work on one site, but move around frequently (e.g. IT support staff) (1); those who alternate between working at two fixed locations (e.g. management consultants) (9), and those who work in a number of different places and are constantly moving amongst them (e.g., real estate agents) (14).

Each researcher used the same protocol to conduct their interviews, which was jointly designed by the pair with input from a third collaborator involved in the larger study. The interview protocol was developed to address three core areas related to knowledge work and infrastructure: (1) interviewees' professional background, working situation and, work arrangements; (2) the nature and structure of their mobility (e.g., spatial and temporal mobility); and (3) the way that different technological infrastructures (e.g., Internet connection, devices, and applications) and infrastructural workarounds play a role in a subject's work. Questions included the following: 1) Describe a typical workday. 2) Can you describe where you do your work? 3) Tell me about the devices you use regularly. 4) How do you get online when on the go? 5) May I take a picture of the contents of your bag/briefcase? While all interviews were similarly organized by the shared protocol, in practice each was conducted as open-ended conversation lasting approximately 60 minutes. All interviews were audio recorded and subsequently transcribed.

Observation was conducted by the first author by shadowing one subject (S1) throughout the whole of her day, beginning with her arrival at Grand Central Station by train and continuing as she traveled across New York City for a set of appointments, eventually ending at a coworking office in the Financial District where she regularly conducts her work. Data was collected by taking extensive field notes and by taking photographs to capture details about the participant's practices, context, and organizational scheme. Minimal contact occurred between the researcher and the subject other than to confirm travel and location details between meetings.

Data analysis was wholly inductive, following the established, iterative protocols of grounded theory building [69]. Between July 2014 and May 2015, the two researchers engaged in successive rounds of transcript reading, memo writing, and extended conversation to become familiar with the collected data and to collaboratively 'sensemake' to produce the initial insights on display herein. Formal *in vivo* coding was not conducted on each interview transcript at the time of this writing, but is currently underway in support of the larger study.

FINDINGS

The analysis we present here might be considered as a pair of stair steps—our first insight regarding infrastructural challenges yielded a new set of questions that, through successive analysis, produced our findings on workers' infrastructuring practices. Reaching the second step was dependent on discovering and understanding the implications of the first step.

Step 1: Seams on the Go

As noted, the practices of being a mobile knowledge worker involves a successive series of dynamic interactions with infrastructure(s) by virtue of interaction with an expanded set of geographical, organizational, and technological boundaries. Throughout their respective work practices, interviewees note that they interact with multiple layers of digital infrastructure, including networks, hardware devices, software applications, and combinations thereof. Some of these layers are experienced as customized ecosystems developed by IT providers such as Google and Microsoft, others have curated characteristics that reflect organizational/enterprise mandates, and yet others are

wholly assembled or created by users in response to immediate needs or preferences.

Throughout the collected interviews, interviewees reveal that they experience seams, gaps, and breakdowns within and among these varying infrastructure(s) as a type of constraint on an intentional task or practice. These comments about constraint led us to look for and categorize instances across the entire dataset—a process that induced a key distinction between two metatypes: technological vs. contextual constraints (see Table 1).

We identify *technological* constraints as those primarily rooted in the material properties of technologies and *contextual* constraints as those relating to impactful, yet non-technological, stressors such as a particular organizational policy or the characteristics of certain room or work setting. The identification of this dyad provoked additional analysis, which produced two sets of additional distinctions for each category. Interviewees note a difference between multiple (competing and/or non-compatible) infrastructures—a condition we call '*technological exclusion'*—and the need to negotiate a solution to extend or bridge an infrastructure beyond its designed capacity—a condition we call '*infrastructural disconnect*'.

Technological Constraints	**Contextual Constraints**
Technological Exclusion	Spatial Boundaries
Infrastructural Disconnect	Organizational Boundaries

Table 1. Typology of Infrastructural Seams.

In parallel, the fixed challenges related to context break into two types: '*spatial boundaries*'—when workers are challenged by an aspect of their geographic location—and '*organizational constraints'*—a more fluid set of dynamic social challenges. We develop each of these four quadrants in greater detail below to prepare for our secondary discussion on infrastructuring.

Technological Constraint: Technological Exclusion

Mobile knowledge workers encounter technological exclusion when heterogeneous infrastructures cannot be made to support mobile practices; another way of saying this is that technological exclusion reveals the limits of what an infrastructure is designed to enable. For example, one of our interviewees shows the limit of his Mac laptop's connectivity: "*I still haven't figured out why they don't put wireless cards in Macs yet. It would just make so much more sense, we are always in places where we could use 4G but we cannot yet (P13).*" As a Mac user, this man is *excluded* from using 4G networks while mobile because there is a technological gap in a key piece of his infrastructural ecosystem—his laptop--that cannot be bridged. A worker experiencing technological exclusion has reached a dead end.

Network speed and coverage is another area in which workers report experiencing technological exclusion. A reliable Internet connection is considered fundamental and often drives where workers choose to work: "*I work in coffee shops; I work wherever I can get an Internet connection*" (P3)" says a business consultant. Often, however, the connection is not strong enough to support video conferencing, a common activity in this profession. As a result, this woman is excluded, technologically speaking, from progressing toward her professional goal (i.e., conferencing with a client). For her, this technological constraint manifests itself as an impasse. In a similar vein, another participant points to the infrastructural exclusions present in planes, despite their new capacities to support Wi-Fi. Says this IT consultant of his time in flight: *"It's very limited what you can do. Remote access works, no problem. Skype for example, would not work, because streaming [challenges] on that type of Wi-Fi connection is terrible* (P8)."

Interviewees also continuously referenced one of the most fundamental technological exclusions of all—power. Even though the battery capacity of mobile devices is increasing steadily, it still does not keep up with the job demand of most mobile workers with a high level of mobility. For example, P14, a realtor, recounts the travails of this form of technological constraint, "*I tried to buy a phone that has a battery that will last, but even that won't fill up the full day; so when you're in a home and we rely on to get like specialized notes about the home, we actually rely on the app as well, so if your battery dies halfway through a home tour that's pretty devastating. So you have to try and address that challenge but you really can't because you're using the same phone that you need to save battery on pretty heavily.*" Workers' abilities are stymied, often to the point of exclusion, by the technological constraint of short battery life.

Technological Constraint: Infrastructural Disconnect

A second, distinct form of technological constraint is an infrastructural disconnect. This notion builds on Vertesi's [73] conceptualization of 'multi-infrastructural torque', itself a reference to Bowker and Star's [8] description of the way that categorical inclusions and exclusions enable or constrain work practice. In recounting the story of a scientist studying the Mars Rover mission, Vertesi details how a scientist, caught between multiple incompatible device ecologies, experienced a technological disconnect when incompatibilities between Mac and PC systems prevented him from using PowerPoint seamlessly to display important scientific visualizations to other members of his team [73: 276]. A disconnect in this case has exclusionary properties—he was indeed stopped in his goal—but can more accurately be described as a gap in otherwise properly functioning systems. PowerPoint on the OSX operating system worked fine as it did on the Windows operating system; they just didn't play well together, which

highlighted a chasm between means and end for this scientist.

Many of our interviewees shared similar frustrations about infrastructural disconnects that impeded their own work. P3, a consultant, found it challenging to use Microsoft Outlook on her Android phone, "*I actually have problems with calendaring right now, because I'm having trouble with making all the technologies work. [Android phone] wants Google Calendar to be your calendar. Google Calendar doesn't work well for me... I started getting really frustrated with how Google was taking over my data, and I just stopped.*" Infrastructural disconnect, in this sense, occurs when it becomes difficult or challenging to create the device ecology of your choice based on multiple infrastructural choices or automated integration. Platforms (e.g., Microsoft Outlook) often reinforce and impose the use of other components (e.g., mobile operating system) from the same technology provider. P6, a technology columnist, underscores the same issue, which also happens to be centered on calendar use: "*I do use Google Calendar. Because [the name of his company] is standardized on Outlook--which I hate--I use Outlook. But, and this is something else that I'm gonna have to bite the bullet on, I am doing all my appointments in Google Calendar. I asked how I can import Gmail Calendar into Outlook so I have one calendar, and they said, sorry, we can't help you, we don't support Gmail Calendar. So I haven't quite figured out how to do it.*"

Infrastructural disconnect can also be manifest when an application is optimally designed for a computer and therefore does not perform well on a mobile device. P14, a real estate agent, explains how difficult it is to use the MLS (Multiple Listing Service) database—the industry standard and an imperative piece of infrastructure in realty—on his smartphone: ". . . *the biggest challenge is just not having easy access through mobile devices to the databases we need...the MLS application runs best on a computer...it's really, really hard to look at that when you're out and on the go. It loads like ten times and you got to zoom in.*" The disconnect present here is not technological incompatibility but a development design choice that renders a piece of infrastructure relatively unusable in a 'non-standard' situation.

Contextual Constraint: Spatial Boundaries

A second type of constraint relates to workers' geographic and social context. Regarding the first of these, Brown and O'Hara [10] concur that workers' locales provide affordances that both constrain and enable work activities. It is the dividing line between the possible and the restricted that forms the boundary in our label. Spatial boundaries can be seen most clearly in our data regarding the intersection of technology and transport. Although the rising ubiquity of wireless networks has increased the range in which people can maintain a network connection these days, it doesn't mean that individuals can be constantly connected. For example, P3, P7 and P8—all consultants—regularly spend several hours every day driving to client locations in order to deliver their services. Driving and mobile screens do not go well together, however. P3 notes that most of today's mobile tools are "screen-obsessed" meaning that they require near constant visual attention. As such, they are not designed to be used (and cannot be used effectively) during long hours of driving.

Other contextual challenges for mobile knowledge workers begin to blur the spatial and the organizational—as is the case regarding cellular data networks. Despite the availability of cellular networks, many interviewees reported that they were not able to rely on them exclusively because of the relatively high cost of cellular data. Real estate agent P14 consumes almost 8GB of cellular data every month because of his heavy use of the MLS application. Since this expense is not reimbursed by his organization, he restricts his use of cellular data towards the end of month and instead uses public Wi-Fi networks as much as possible: "*Most of the time if I have the time I will like pull over at a Burger King or something like that and hit their Wi-Fi to go in, but obviously if you don't have time you have got to fork it through on the phone again.*"

Contextual Constraint: Organizational Boundaries

By far and away the most impinging contextual constraints for our interviewees were those set in motion because of organizational rules, policies, or mandates. These rules create boundaries between the possible and the restricted that affect how workers can access, process, and arrange infrastructures to meet their aims and goals. This inductive insight from our empirical data mirrors prior research [e.g., 35] that evidences various ways organizational constraints in the forms of rules or policies restrict the flexible enactment of technological practices, adversely influencing the mobilization of technological resources across time and space.

Organizational boundaries can be particularly pronounced when people are reliant on infrastructures owned by third parties—almost a constant in the world of mobile knowledge workers. Take the example of P2, a web developer, who regularly meets her clients in public places. She recounts the constraints put in place by some of the restaurants she frequents for these meetings, "*Places like Panera Bread have Wi-Fi, but they kick you off after 30 minutes sometimes for the day, because they're too busy so they don't want people hanging around there.*" The challenge of maintaining an online connection for this mobile worker is not at all about technological feasibility and every thing to do with organizational policy.

Other constraints are revealed when workers want to transfer information *across* multiple organizations' jurisdictional boundaries. P11, a business intelligence developer, explains the way that his organization's security measures limit access to the resources of clients from different places: "*You have situations where companies*

have set up constraints that . . . I couldn't connect to their site right here, right now if I wanted to. There are places that have some higher level of security clearances down to a point where they need to know what IP your request is coming from" (P11). Workers feel these policy implications as infrastructural disconnects, but their origin is more obviously found at the level of rules and regulations than technical integration protocols (which, upon closer inspection are also forms of organizational constraint, but this is a story for another time).

Together, technological and contextual constraints create a playing field for mobile workers that is highly variable, unpredictable and—simply speaking—challenging. Unlike workers in fixed office settings, mobile knowledge workers do not always know where their internet connection will come from, how much it will cost, or when it will be shut down due to external protocols. Moreover, because they are highly mobile and, thus, must rely on portable tools with less customizable features, smaller interfaces, and limited power capacities, they are positioned within a constrained infrastructural ecosystem that forces them to either address these challenges or fail to progress at all. How these mobile knowledge workers take on these challenges is the topic we turn to next.

Step 2: Infrastructuring as Strategic Mobile Practice

As we have just detailed, technological and contextual constraints overtly pervade the daily working environments of mobile knowledge workers. What is less obvious to them, however, is the way that they engage in a series of strategic infrastructuring practices to right or remedy the technological, geographic, and organizational challenges that they regularly confront. Using a practice theoretical lens, we identified three primary patterns that comprise the strategies employed by our participants: *bridging*, *assembling*, and *circumventing*. Each of these practices enables workers to 'artfully' deal with infrastructural seams thereby presenting the necessary semblance of seamlessness that allows them to maintain an adequate professional identity, rhythm and/or interaction profile. Before describing each of these practices in detail, it is important to note that our findings are nascent and, as such, do not represent a universal overview of mobile knowledge worker practices. Even so, we hope that this initial typology begins to detail how the situated actions of mobile workers might help to develop our thinking regarding infrastructural dynamics in a new, if yet incomplete, direction.

Bridging Work

Bridging is an infrastructuring practice in which mobile knowledge workers attempt to bridge incompatible digital infrastructures (e.g., brand ecologies) by introducing some form of aligning intervention. This work is necessary whenever there is an infrastructural disconnect or when organizational constraints impede the ready construction of a desired infrastructural configuration. The practice of bridging can be seen as similar to what Bietz, Baumer, and Lee [5] refer to as 'aligning', which brings together already-existing entities rather than developing new ones from scratch. The outcome of such process is a synergistic alignment of infrastructures.

In our data we see instances in which bridging is done by manual intervention and we also see evidence of bridging done by actors strategically utilizing gateway technologies[1]. An example of the first form of bridging can be found in our interview with P6, the technology columnist. Recall that he grapples with an infrastructural disconnect between his organization's calendaring system and his personal calendar. He bridges this gap by manually synchronizing a calendar invite with his preferred calendaring environment (aka, not Outlook): "*Whenever anyone invites me to a meeting via Outlook, I have to manually synchronize that with Gmail*." Rather than making two incompatible infrastructures (i.e., Outlook and Gmail) work together by hacking together a software path, P6 undertakes a duplication-based bridging strategy to achieve his desired goal. Notably, P6 recognizes the possibility for a workaround that enables him to construct a working bridge and enacts it; he knows enough to know that the infrastructural disconnect can be dealt with somehow.

P10, a partner at a law firm, achieves a similar end by using a gateway technology called Clio to bridge an infrastructural disconnect in the calendaring system he must use for work. Key to P10's bridging strategy is his knowledge that this maneuver will deliver necessary information automatically to his mobile device, "*If we have a deadline, it gets entered into Clio, which then gets pushed to the Google Calendar, then gets pushed to mobile devices or computers. So it shows up on my calendar on my iPhone or iPad—all nicely integrated. People have multiple calendars, so I've got my law firm calendar, my [the 2nd firm's name] calendar; I've got a family calendar, and those are Google oriented, so they all tie together nicely, and I can access those from any device.*" Not only does Clio assist in preparing P10 for his frequent periods of mobility, it has the ancillary benefit of integrating other components of the larger infrastructural environment into alignment with one another automatically.

Another form of bridging work—now an increasingly common practice—occurs when mobile knowledge workers maintain their network connection by using a smart phone to create a hotspot for their entire device ecosystem: "*If I'm in area that doesn't have Wi-Fi, I can turn the iPhone on to make a hot spot, and then I have it for the laptop or the tablet. The laptop goes with me on the road, and I need my laptop to write and I write most days* (P9)." Faced with the prospect of exclusion or the need to work with a

[1]Gateway technologies are a large class of 'minor' technological innovations that enable users to integrate diverse and rival sub-systems into an enlarged production system or extended network [19].

constrained set of affordances, workers like P9, a conference speaker/catalyst, form a bridge among devices that allows them to maintain their preferred professional orientation to the task at hand—in this case, utilizing the laptop for writing while maintaining a network connection. In this way, brokering and bridging seams perpetuates the need for continued personalization or customization in the way(s) that an infrastructure is managed and used in situ.

Assembling

Beyond bridging, mobile knowledge workers also engage in the even more creative practice of 'assembling'[2], or customizing infrastructural solutions from various disparate parts. As Vertesi describes in her work with NASA scientists [73], assembling requires knowledge and acumen on the part of the knowledge worker; they must be able to see, first, how various technological design affordances can be integrated with one another and, second, how an newly fashioned solution relates and upholds requisite tasks and situations.

One of the key areas in which mobile knowledge workers engage in assembling work is to maintain power. As noted earlier, limited battery life is a major challenge so it is not surprising that several participants assemble relevant device ecologies to enable as extended an amount of work time as possible. P13's assembling solution involves the use of a dedicated backup battery while he, a web developer, is on the move: "*[the backup battery] helps you get a second charge of your iPhone 5S … So when you're using an outlet it charges the phone first and then charges the battery, and you get basically a whole full life on the battery afterwards. I also have something else for my Mac that's called Battery Box, and it's a whole full extra charge. Those two things are super useful for people working remotely. There's no way I'm not going to find an outlet in two full charges of my devices* (P13)." P13's use of the backup battery and the Battery Box are not that novel on the surface of things, but what is more important is the ecosystemic knowledge represented in his characterization of this solution. There are various noted parts here (i.e., backup battery, Battery Box, electrical grid) being brought to bear in a temporal sequence. He is aware that the rhythm of his power grid-excluded mobile periods is likely not more than 2 battery-life cycles of an iPhone 5S—likely 8-10 hours depending on the usage pattern of the device. Importantly, his assembled solution does not attempt to be more complex than it needs to be; he is aware that he will find a power outlet at some point every 10-12 hours or so and can adjust accordingly. But he is always at the ready—he has assembled a complementary infrastructure to accommodate the likely reality that he will not have access to grounded power at any point during any one day.

We also see other forms of assembled redundancy in play by several of our interviewees. P3, one of the consultants, has 4 cell phone chargers geographically distributed to accommodate her typical mobile path: one in her car, one in her house, one at a co-working space that she frequents, and one at a client location. Similarly, P4, another of the consultants, always travels with two laptops to extend his working capacity, "*I've been taking my personal laptop and my work laptop, because typically when I'm traveling for work, I constantly have to go to the East Coast, which is a long flight, so for just for battery life sake, I'll bring both*" (P4). These contrived solutions go beyond simple bridging in most cases, showcasing a constructed set of technologies or an overarching logic to the assembled pieces that belies their strategic natures.

We see a completely different example of assembling drawn from our observation of a designer in New York City. Given the visual nature of her work, S1 often has to avail herself of drawings and other forms of visual information. Because of this, she has adopted a particular assembling strategy, beginning with the mobile device that she uses—the most recent Nexus smartphone complete with a large screen (See Figure 1 below).

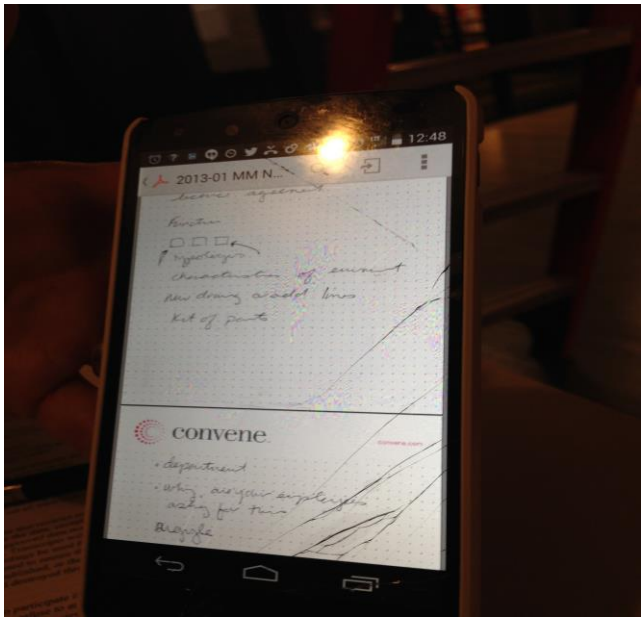

Figure 1. An example of an assembled infrastructure to support mobile access to hand-written information.

This device choice embeds S1 rather neatly within the Google Android platform, which she uses to her best advantage more notably; however, her assembling practice involves the daily scanning and uploading of any written notes or drawings in her notebook to a specified project folder in Google Drive. Completing circuit, she is able to access these written notes or rendered visualizations as she

[2] We utilize the word 'assembling' cautiously here knowing that is has other problematic connotations. That said, we seek to stress the constructed, fabricated nature of this practice and the ways that workers put disparate pieces together to form a functioning whole.

moves through the city meeting with various clients. Her large-screen device allows her to present this information with requisite fidelity to those she is meeting with, or to refer to them as she creates a new set of notes from the day's meeting(s). This strategy, again, is not novel for its technical complexity, but rather for the strategic thinking it involves to contrive a constellation of pieces that enable her to have the right resources in the right place at the right time.

Circumventing

The third infrastructuring practice that we discovered in our data refers to the ways that mobile knowledge workers circumvent technological and contextual constraints in order to accomplish their work. Like bridging and assembling, circumventing is a form of improvisational intervention that relies on a worker's knowledge of an infrastructural landscape, particularly where functional equivalence lies among alternate technologies or technological processes.

A small example of circumventing work showcases one mobile knowledge worker's strategy for overcoming an organization boundary. P4's organizational regulations restrict him from using specific software such as Google applications on his work laptop, so he carries out his work on two parallel laptops—one personal and one work-issued. This issue sometimes comes to a head when he needs to transfer data to use a restricted software application, such as Photoshop. Like many before him, P4 uses email to transfer the needed files, because both cloud storage services and external drives are restricted on his work computer. He comments about this strategy, "*When I email something from my work email to Gmail, I get this popup that says, you know, you are about to send an email to an untrusted source, blah, blah, blah, do you wanna proceed. Because technically we're not supposed to, and I'll always override it and say yes. I'm not working with anything that serious that you know that much.*" Though this example may be quite mundane, it exemplifies a genre of strategic infrastructuring actions that mobile knowledge workers undertake all the time to fashion functional circumventions in the face of both technological and social constraints.

Improvisational practices are not only directed at organizational boundaries, however. Our interviewees also report that they circumvent infrastructural seams by hacking systems when they can. On flights, for example, P13, a web developer, found a way to utilize the Internet connection without having to pay for it: "*I love when planes have in flight Wi-Fi because I don't actually pay for it. What's really funny is that when I'm developing [web applications], it's happening locally on my computer. Well we still have to make calls, like API calls out to other services. All those in flight Wi-Fi services redirect continually to this page, which is where you get to pay; that's all it does over and over again. You still have an internet connection so the calls from my local website that I'm hosting still get on perfectly fine so I can run our website on my laptop 100% just like I would if I was at home or at a co-work space. So I can develop with absolutely no hindrance on the flight without paying any money.*" The workaround here, like the example immediately preceding it, shows the creative way that these workers achieve their goals—i.e., usage of a preferred application on a preferred operating system, maintaining a network connection without having to pay for it, etc. This circumvention work allows the actors in our sample to showcase their ingenuity while also maintaining professional progress.

These examples merely scratch the surface of the inventive practices regularly undertaken by the subjects in our sample. They are meant to underscore not the sophistication of the bridging, assembling, or circumventing solution in play, but rather the bricoleur[3] orientation that mobile knowledge workers appear to inhabit on a perpetual basis. We develop this idea, as well as the implications of the mobile knowledge worker as bricoleur, in the following section.

DISCUSSION

In each of the infrastructuring practices highlighted above, mobile knowledge workers engage their knowledge to strategically bridge, assemble, or circumvent an infrastructural seam as discovered in situ. While others rightly describe these sets of practices as forms of infrastructuring [e.g., 7,52,67], we draw forward two additional points for further discussion here.

First, we consider infrastructuring as an important type of articulation work [28,63,67]—work that is less evident, if not totally absent, in the case of stationary knowledge workers. Strauss [68] defines articulation work as the "extraneous" activities beyond core work tasks that must be performed to account for contingencies. As we have shown, for mobile knowledge workers, infrastructural contingencies are part and parcel of the job. Because infrastructures are more often platforms *for* rather than core components *of* primary work tasks for mobile knowledge workers, their infrastructuring practices can be distinguished from prior descriptions of infrastructuring for this articulation work aspect. Akin to Gerson's formulation of articulation work [27], the form of infrastructuring we showcase here ensures that infrastructural resources are in place and functioning cohesively across different locales for our study participants. In order to accomplish their core work tasks across time and space and establish a "common field of work" [60], the mobile knowledge workers in our

[3] The Oxford English Dictionary [46] defines a bricoleur as "A person (esp. an artist, writer, etc.) who constructs or creates something from a diverse range or materials or sources; the creator of a bricolage." Original credit for this term is attributed to the French anthropologist Claude Levi-Strauss in his book *La Pensée Sauvage* (1962).

study *must* overcome technological and contextual constraints by engaging in this extra layer of articulation work to ready/align infrastructure(s) into productive configurations. The infrastructural aspects of articulation effort are in effect *synergizing* activities that knit together divergent sociotechnical systems to make them interoperable [64], in the end generating a larger combined effect that would have been possibly without the synthesis [5]. This hidden layer of infrastructure, accomplished by way of articulation work, can often effectively explain why some systems work and some do not [66].

Our second point of discussion involves the insight that mobile knowledge workers must have to engage in this form of articulated infrastructuring, to be infrastructural bricoleurs. Drawing on the notion of literacy, we refer to this actionable infrastructural knowledge as *infrastructural competence* [25]. To have infrastructural competence is to be able to recognize where infrastructural seams may have generative, rather than exclusionary, properties and then to draw upon this sociotechnical insight to fashion and implement an infrastructural strategy to achieve a desired goal. This competence is the hallmark of an agile mobile knowledge worker.

Notably, our interviewees frequently report that proprietary seams hinder their ability to integrate multiple brand-based platforms, applications, and devices. Often these ecosystem exclusivities (e.g. Microsoft vs. Apple) bury the ability to detect generative seams by automating integration (e.g., Google or Apple automatically backing up data into their own cloud storage service: Google Drive or iCloud). Ironically, this designed 'seamlessness' *a la* Weiser puts workers in the position not only of bridging, assembling, or circumventing when necessary, but also—increasingly—of *detecting* potential seams (aka, sites of intervention) in the first place. Here we can come back to Dourish and Bell's [22] and also Chalmers' and colleagues' [11].wise words about the generativity of seams—in this case a recognized ingredient of sociotechnical agency.

A future agenda for our research involves understanding how infrastructural competence is developed and sustained by different types of workers. Because of the improvisational nature mobile work, even the most routine forms of infrastructuring require a dynamic, constantly evolving, set of knowledge. We recognize that different types of work demand different infrastructural engagements, so likely there are professional or jurisdictional variations in how infrastructuring practices are developed. This subject is a key animating focus for our ongoing research.

Interestingly, there may also be a move—seen often in the context of smaller, startup organizations—to leverage proprietary ecosystems to their full advantage for reasons less driven by task goals and more by client aims or preferences (e.g., conducting all work within Google Drive). In our studies to date, this choice appears no less strategic than the other types of articulated infrastructuring, typically expressing core sociotechnical insights as to how relationships can best be managed through specific infrastructural configurations. When and under what professional conditions these types of 'non-infrastructuring' choices occur, and concomitantly what variant types of infrastructural competence these decisions express, are questions we are currently investigating.

CONCLUSION

The rising integration of mobile technologies and practices into knowledge work has created a new type of professional—the mobile knowledge worker. Independent of any need to remain in a singular place to carry out their work, mobile knowledge workers spend a large portion of their time traversing within and among different infrastructural configurations as they move through space. These dynamic configurations are experienced as either technological or contextual constraints, which force workers to engage in a type of articulation work to identify, adopt, and configure infrastructural solutions—a form of infrastructuring practice—to overcome these constraints. In effect, these practices, which we identify as either bridging, assembling, or circumventing enable a mobile knowledge worker to transition smoothly across multiple boundaries, whether they be temporal, spatial, social, institutional, or digital.

Navigating through mutable contexts characterized by a multiplicity of competing installed bases and organizational protocols requires a great deal of knowledge—or what we call infrastructural competence [25]. Infrastructural competence embodies the knowledgeable recognition of the generative or standardized points of connection within various infrastructures in order that constituent parts can be swapped in and out to leverage structural similarities and functional equivalences. To be infrastructurally competent, in this sense, is to know the particular, likely situated, sets of infrastructural arrangements that can be pulled together to effectively and efficiently achieve an immediate goal.

While these insights seek to profitably enhance the already rich discourse underway within the infrastructure studies community, we are quick to acknowledge its limitations. Data upon which our ideas rest currently originate from a very limited context—the American Northeast and Mid-Atlantic regions. As such, our claims should be understood to reflect only specific regional practices at this point, possibly illuminating but not confirming anything more categorical or conclusive. Moreover, we draw primarily on practice descriptions (i.e., interviewee recounts) rather than a cache of qualitative observations or quantitative trace data, which, when eventually collected, will yield new evidence that will likely alter the current theses expressed herein. Nevertheless, we hope that this initial research piques the interest of both scholars and designers to further investigate mobile knowledge work and its infrastructural

relations as a rising domain of computer-supported cooperative work.

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