ANALYZING THE RELATIONSHIP BETWEEN WORKSPACE AND SMART INFRASTRUCTURE RELIABILITY AND CONTINUITY: AN ETHNOGRAPHY OF TECHNICIANS' WORK

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Abstract

Ensuring the reliable and continuous operations of complex, unpredictable, and unstable smart infrastructures, such as computerized and automated power grids or water distribution systems, is a persisting organizational challenge and a societal concern. As technologies are inherently unreliable and, especially, the behavior of complex technological systems is unpredictable, the reliability and continuity of such systems cannot be a mere technological concern, but are precarious achievements that require humans, technologies and other actors. Prior research has shown that work creates variance in organizational performance and that reliability and continuity emerges from what work is done and how it is performed. This ethnographic research focuses on technicians' IT enabled workspace to analyze how the materiality of the workspace conditions and enables technicians to perform the reliability and continuity of a smart infrastructure (smart power grid). Building on sociomaterial theorizing and infrastructure studies, a concept of infra-acting is developed to denote the technicians' possibilities for action in smart infrastructure setting, and to foreground and make sense of the reciprocity between the (materiality of) technicians' workspace and infrastructure continuity. Discussion and conclusions are provided.

Keywords: Smart infrastructures, reliability, continuity, sociomateriality, technicians, work.

1 INTRODUCTION

Smart infrastructures, such as computerized and automated power grids and water distribution systems, are the bedrock and backbone of both contemporary organizations and societies. They enable organizations to work and societies to function. Thus their reliable and continuous operation is imperative. Yet, the complex, large scale systems, such as infrastructures, have an inherent tendency towards instability, disorder and decay – towards 'normal accidents' (Perrow, 1981). Moreover, technologies are inherently unreliable (Butler & Gray, 2006). Therefore, the reliability and continuity of the infrastructures can never be achieved through technological improvements only, but require concerted and harmonious actions of humans, technologies and other powerful actors (Bennett, 2005). In particular, often invisible maintenance and repair work is required to maintain the infrastructural circulation even at times the infrastructure appears to work 'normally' (Graham, 2012, p. 19). Indeed, without the often hidden but enormous investments that are constantly put in maintaining and repairing infrastructures (Graham & Thrift, 2007), they would soon cease to function, become obsolete and gradually transform into ruins like the ancient aqueducts that now only remind us of the times of their operation. Without continual maintenance and repair there is no reliability nor continuity, only decay (Ureta 2014).

Reliability of inherently unreliable technologies seems to emerge from what work is done and how it is performed (Butler & Gray, 2006). The work that is put to maintain and repair infrastructures is, however, often invisible and performed in the background but crucial for the functioning of the system (Graham & Thrift, 2007). While such studies show that invisible work is crucial, less attention has been paid to the fact that work is always entangled with materiality (Orlikowski & Scott, 2008). The tools and the technologies we use, the artifacts that structure our environment and action, and the non-humans we mobilize – the materialities of work – both enable and constrain us in whatever work we do. In other words, materiality shapes human action and agency (Barad, 2007; Bennett, 2009), and, thereof, the way in which work is performed (Ashcraft et al., 2009). Particularly, '(a) material place/space influences the resources available for interaction and, thus, conditions agency' (Ashcraft et al., 2009, p. 31). Especially, the integration of IT and traditional infrastructures have opened up new possibilities for maintenance and repair and restructured technicians' work (e.g., Almklov et al., 2014; Østerlie et al., 2012). Consequently, understanding the reliability and continuity of infrastructures entails understanding how work to maintain and repair infrastructures is entangled with the infrastructures' materiality.

This ethnographic research analyzes technicians' IT enabled 'invisible work' to maintain and repair a smart infrastructure (a smart power grid) and focuses on the reciprocity between the technicians' material place/space of work – their workspace – and possibilities to perform the reliability and continuity of the smart infrastructure. Accordingly, it addresses the following research question: how the materiality of the workspace conditions and enables technicians to perform the reliability and continuity of a smart infrastructure (smart power grid)? The theorizing builds on sociomaterial agency (Barad, 2007; Schultze, 2011; Scott & Orlikowski, 2014). As such, this research contributes to the call to study 'the relationship between information, technology, and the changing nature of work' (Forman et al., 2014).

The paper is organized as follows. First, the relation between materiality and action in infrastructure context is discussed and the concept of infra-acting and workspace are theoretically developed as the theoretical foundations of the study. Second, the research approach is detailed. Third, the findings of the study are discussed. Finally, conclusions and discussions are provided that connect the research findings to extant research.

2 TECHNICIANS' WORKSPACE AS INFRA-ACTING POSSIBILITIES

Sociomateriality has emerged in IS as a promising – yet extremely theoretical (Leonardi, 2013) – perspective to theorize the role of materiality in social affairs. We draw on sociomaterial conception of agency (Barad, 2007; Bennett, 2009) to theoretically inform the development of a concept of infra-acting. The concept offers a lens to make sense of the relationship between technicians' workspace, materiality of the smart infrastructures and technicians' possibilities for action.

2.1 Materiality and action

Human action is always entangled with materiality, which shapes it in important ways. As Bennett argues '[w]hen humans act they do not exercise exclusively human powers, but express and engage a variety of other actants [actors], including food, microorganisms, minerals, artefacts, sounds, bio- and other technologies, et cetera' (Khan, 2012, p. 52-53). For example, even a simple task of moving a hand requires mobilizing a plethora of materialities. That is, action is always relational to the material constitution of a phenomenon (Barad, 2007) in such a way that different material constitutions open up different possibilities for action. For instance, a hammer reconfigures carpenter's possibilities for action that are different than possibilities for action without the hammer. What those possibilities are and whether they condition or enable action is relational to the practices and other materialities of which they are a part of; hammering a nail is not only relational to the hammerers' ability or intention to drive a nail, but relational to the nail (bad quality nails tend to only bend when hit!), the substance to which the nail is being hammered to, and so forth. In sociomaterility's terms, 'things' only acquire their definite boundaries and properties in relation to a practice they are a part of (Barad, 2007). Agency, then, is not a property of any individual entity, whether human or non-human, but an outcome of a particular configuration of human and non-human forces (Bennett, 2009). Quoting Ashcraft et al. (2009) '[a]gency is not about determining the attributes of actors, but is instead about the constant (re)negotiation of possibilities, such that material and human agencies keep shaping one another in evolving space and time' (p. 31). That is, the workspace that includes the various materialities as part of the place/space for action shapes the possibilities for action (Ashcraft et al., 2009). While traditionally the technicians' workspace has included such materialities as hammers, screwdrivers, and multimeters, the material constitution of the workspace of technicians working with smart infrastructures is much more complex, distributed and IT-enabled.

2.2 Smart infrastructures and action

Infrastructures, as Graham (2012) argues, are 'complex assemblages that bring all manner of human, non-human, and natural agents into a multitude of continuous liaisons across geographic space' (p. 11). It is as if the infrastructure forms a skeleton that binds together various actors into a heterogeneous amalgam of materialities. As such, the functioning of an infrastructure results from a coordinated and harmonious performance of those heterogeneous actors. As discussed above, this does not imply that all actors would be the same but that their agency is relational to the amalgam of humans and non-humans (Barad, 2007). Yet, they all have the ability to express agency and have an effect for the whole. Human agency is thus not merely a concern of intention or accurate translation of an intention to effects, but a matter of mobilizing and reconfiguring a whole bunch of other actors that do not always seem cooperative. Such a conception of agency appears more true to our everyday experience 'where it seems that one can never quite get things done, where intentions are always bumping into (and only occasionally trumping) the trajectories of other beings, forces, or institutions.' (Bennett, 2005, p. 453).

While infrastructures often evoke images of permanence and rigidity, their constitution may change abruptly as actors enter and leave, or become more and less salient. Indeed, it is the abrupt changes of infrastructures that we often experience as incidents or breakdowns. The seeming and precarious harmony between the parts that form the infrastructure may transforms in an instant into seeming violence between the parts; the infrastructure transforms into a whole where the parts do not seem to thrive towards a common goal. Further, infrastructures evolve and are dynamic (Hanseth & Lyytinen, 2010; Vespignani, 2009), and are never finished (Tilson et al. 2010). Despite their dynamic nature, infrastructures entail certain materiality without which there could not be continuity. This materiality can 'become a palimpsest of developing forms and practices. The continuity of the substrate, although allowing practice to change, simultaneously helps bring the history of practice to bear on the present'.

(Brown & Duguid, 1994, p. 18) This is also what Barad (2007) refers to as the sedimentation of practices of matter's becoming as its historicity. What this implies is that also the materiality of infrastructures sediments the practices of its becoming. While the sedimentation affords continuity, it also creates inertia for change (Venters et al. 2014). For instance, railroad tracks makes it possible for a train to move (and the transportation infrastructure to exist), but once implemented, the tracks are very rigid and hard to change. This also has implications for action, as it is not merely a question of the driver's intentions whether or not s/he will make a turn when the tracks turn when driving the train.

Contemporary infrastructures are not merely mechanical or electrical but also computerized. These smart infrastructures contain 'smart' capabilities that allow remote control, diagnostics, and repair, but also enable the infrastructures to automatically reconfigure themselves and respond to incidents. Roads, for instance, can be monitored from centralized location, certain parts of the road closed, speed limits changed and so forth. In computerized power grids (i.e., 'smart grids'), the IT technologies have even more profoundly changed the technicians' work. Various IT based systems connect and commingle with the traditional power grid that forms a seamless whole that would be very hard or even impossible to discern and dissect into separate IT and power technologies. Many of the components, while they may serve important functions for the distribution of electricity, are in themselves small computers. These technologies create and reconfigure the technicians' world like no other materials. The diagnostics information various sensors provide are responsible for the 'dual materiality' (Østerlie et al., 2012) of the grid and do not merely mediate some existing information but actively create a world that would not exist without the intermingling of those technologies and technicians' practices. The remote control and automatic rerouting capabilities the IT technologies afford, create new scales for space and time. The materiality of IT and technicians jointly perform a reality where location, distance, and time lose their previous significance, as connections and boundaries become more salient than geographic and time measured distances (Barad, 2007).

In brief, material aspects of infrastructures shape the way agency is understood and how infrastructures constrain and enable technicians' possibilities for action. We refer to these possibilities as infra-acting possibilities. Analyzing the technicians' infra-acting possibilities provides a fruitful way for understanding the material conditions under which technicians perform reliability and continuity of a smart infrastructure.

3 RESEARCH APPROACH

Ethnography is one of the most in-depth research approaches that allows constructing detailed empirical material of the studied phenomenon. It is broadly accepted as one of the main research approaches in IS discipline (Myers, 1999), and has yielded highly impactful research on work and technologies (e.g., Orr, 1996; Zuboff, 1988; Barley and Kunda, 2001). Ethnographic studies do not aim for statistical generalizations, but focus on single site and study it extensively to generate deep insights of the phenomenon (Myers, 1997). Therefore, also the research description and findings follow a form of 'thick description' (i.e., a detailed and verbose account of the phenomenon) (Geertz, 1973) – within the given page limit – that aim for veracity and truthfulness of the description in lieu of, for instance, validity and reliability (Guba, 1981; Golden-Biddle and Locke, 1993; Klein & Myers, 1999; Jarzabkowski et al., 2014).

Following ethnographic tradition, the empirical material was primarily constructed through participant observations. The observations took place between October 2014 and May 2015 (2-3 days a week and 8 hours on average, except between mid-December to mid-January). Participant observation is often seen as the epitome of ethnographic research (Ingold, 2014). Through participant observation, researcher is expected to take part in the daily lives of those studied, and gradually and over time build an understanding of the world of the informants. Collecting observations in lieu of, for instance, reading documents or interviewing informants allowed the first author to observe the social and the material aspects of technicians' work in situ rather than reading or listening what the management thinks the technicians do (cf. Orr, 2006). Further, work practices are often so contextualized that informants may find it hard to explain their work when not actually performing it (Nicolini, 2009). As participant observer, the first author 'threw' himself to the empirical site (Chughtai & Myers, 2014) and followed closely the technicians' daily activities. Most of the time, he sat in the operations center from where the technicians control the power grid. In addition, he had several occasions for informal discussions as the informants daily asked him to join the morning coffee breaks, lunch breaks, and afternoon coffee breaks. He also participated to other informal and formal gatherings that took place within and outside the operations center (for instance, training sessions organized for the technicians). He received an unrestricted access to the premises from a 'gatekeeper' (Cook & Crang, 1995) which allowed him to arrive and leave as best fitted to his schedule. While the technicians worked 24/7 in 12 hour shifts, with few exceptions, the first author made observations during office hours. At first, as typical, he encountered some recalcitrance and suspicion (van Maanen, 2011). His presence raised concerns and questions over the motivation and reason for studying the technicians. Despite that he assured for the technicians the motivation was purely scientific, among some, his presence continued to raise occasional concerns and suspicions, even whether he was a 'spy' working for the management. Nevertheless, during the extended observation period, he was able to win their trust. As the author has no formal education neither in electricity nor in power distribution systems, he had to learn the basics during the stay. He actively read publicly available material on the power distribution systems, about their history, legislation, and resilience in order to be able to discuss with the informants with their professional language and to be able to discuss the observations between us. What caused further complexities and steepened the learning curve was the technicians' intensive use of jargon. Most of the concepts were derived from the physics related to electricity, but included also other concepts that seemed to be highly salient, information intensive, and relational to the particular idiosyncrasies and history of the company. For instance, each substation and other important locations in the grid have a name derived from its physical location. While at first, these concepts seemed to be merely labels for the physical locations, we came to learn they embody and communicate a whole bunch of other information for a knowledgeable and experienced recipient. The label carried with it a whole history of the location, the technological equipment and its affordances, the physical location and how to get there, and so on. As such, the concepts provided the technicians an effective way of communicating. Gradually, and after several moments of slight embarrassment, the first author learned the jargon, their habits and their practices. Towards, the end of the stay, several informants commented that he could start working as a technician. While this was clearly a complement and exaggeration, we took it as an indication for gaining sufficient understanding of their 'world' for the research purposes.

The first author took field notes, as the primary method of documenting the observations. The field notes document events that seemed important at the moment of their creation (Jarzabkowski et al., 2014). The field notes reflect a template provided by Schultze (2000). Often, however, when physically at the site, the first author recorded merely short notes with paper and pen that served as memory cues to recollect the moment of their collection. He then elaborated the notes shortly after each site visit (often during the same day). In addition, he was able to collect several organizational documents, such as yearly reports, contingency plans, and standardized operations procedures. Further, we closely followed and collected any news related to power outages in Finland and other information concerning the field (such as legislation changes). In other words, we sought to collect any information that could help to shed light on the phenomenon of interest (Hammersley & Atkinsson, 2007). These observations, informal discussions, and the documents provided us the basis for our theorizing.

Analyzing the empirical material was informed by qualitative data analysis techniques (Miles & Huberman, 1994) which involved noting down emerging ideas and categories during and after the visits to the empirical site. These notes included emerging ideas on the relation between the technicians' work, materiality and the infrastructure continuity. The theorizing proceeded throughout the collection of empirical material and continued afterwards. In other words, these 'processes [of analyzing and theorizing] were not separate from the fieldwork as they continually fed back and impacted on the fieldwork' (Cecez-Kecmanovic et al., 2014, p. 571). After the observation period, we continued the data analysis by looking back at the emerging ideas and categories, but also leaned on the first author's experiences and knowledge gained during the site visits (i.e., on 'head notes' as Schultze (2000) calls them). During the analysis we continued reading theoretical literature, focusing particularly on sociomateriality. By reading iteratively literature and the data, we began to form an understanding of the phenomenon (Klein & Myers, 1999). Thus, the data analysis included simultaneously both, theoretical as well as empirical development of our ideas. From these iterative cycles, we gradually began to see certain patterns. The patterns resulted in three aspects that we found explanatory of the relationship between the materiality of technicians' work and infrastructure continuity. For instance, during the analysis we identified 'rigidity', 'material resistance', 'inertia', and 'history' as potential categories, but assimilated them as one since they all seemed to contribute to the same 'story'. In the end, to put it short, the historical materialization of the grid, the openness and dynamic presence of other actors in the constitution of the grid, and the inherent unreliability of action in relation to the grid emerged as plausible and truthful abstractions and explanations of the phenomenon. These three aspects will be elaborated next.

3.1 Empirical site

CityGrid Co (a pseudonym) is one of the largest power distribution companies in Finland (based on the number of subscriptions). It operates mainly in the area of one city, but its network extends also to broader area that covers some rural areas and archipelago. It is also one of the oldest power grids in Finland, dating back to the beginning of 20^{th} century. The extensive history is reflected in the grid. Some of the cables still date back to as far as 1950s, and the grid contains a very heterogeneous mixture of old switches, relays and other mechanically operated devices that now operate in contemporary setting but also latest modern digital technologies that automate recovery and configuration tasks. By integrating internet protocol (IP) based control and diagnostics systems to the old mechanical switches, the devices have been updated to meet the needs of the contemporary power grid. The company has been able to perform highly reliably and produce a steady flow of electricity to its customers (2015 the average downtime per subscriber was under 10 minutes).

The grid is managed from a centralized location that was enabled by the technological advancements as in the beginning the grid had to be managed in such a way that each substation was populated by two or more technicians in oil and dirt stained white collar shirts and dark suits that used to be their normal work outfit. There is no single system that would cover all the technicians' tasks but a range of systems of which the supervisory control and data acquisition (SCADA) and distribution management system (DMS) are the most central ones. These two systems (in addition to email and similar office systems) forms the technicians' core 'tools'. Where the SCADA enables them to control, configure and monitor the status of the substations, the DMS provides them a geographic information system, and work flow management system that enables the technicians to coordinate the field technicians, have an overview of the current configuration of the grid, and structure their routine maintenance and repair work through pre-planned operations procedures. It also enables the technicians to simulate the impact of configuration changes to the grid's overall performance and configuration. Other important 'tools' the (local) workspace includes are the (IP-based) telephones; a separate and designated communication network for the society's critical functions; paper copies of the planned maintenance work; Closed Circuit Cameras (CCTV) on the substations; a separate workstation for internet access (physically isolated from the grid's control network); and a system to control the (physical) access to all premises. Figure 1 illustrates the technicians' workspace (to preserve anonymity, the technician is not shown in the figure).

Figure 1. Technicians' workspace (authors' own).

The technicians work to create affordances for others to work (Barley, 1996). Thus, what happens behind the scene as the invisible work and how the affordances are created is significant for all IS work. As Graham (2012) argues, 'digital media use continues to have an aura of transcendence, as though the "virtual" world exists in a completely separate sphere from the messy materialities of the "real" one'. Instead, by focusing on the 'messy materialities', 'we can begin to 'see' 'cyberspace' for what it is – not an ethereal domain of 'virtual' bits and bytes, but a gigantic, materialized and electrically powered system requiring massive amounts of continuous and concerted maintenance and repair' (Graham & Thrift, 2007, p. 13). As such, by focusing on the work of the technicians we may learn a great deal about how the reliability and continuity of smart infrastructures are performed, but also to remind us of the tight connection the production of continuous electricity has to reliability of other ISs that would cease to function in an instant without electricity (but also without which the production of electricity would become difficult or even impossible). Thus, the power grid provides an interesting and important site for this study.

4 FINDINGS

In contrast to what seems to be the general perception, the infrastructures require constant and repeated cycles of maintenance and repair. These practices of maintenance and repair serve as 'normalizing' practices (Ureta, 2014) that seek to sustain, and return, when needed, the system to its 'normal' state. The smart grid too, has a designed normal state that is calculated to be the optimal state for the grid. The optimal state balances between economic calculations, operational requirements, and grid performance. Often, there is a conflict between the optimal economic performance and the optimal configuration for operations[1]. Further, as the technicians explained there is nearly always a gap between the optimal and the current running setup of the grid due to various exceptions caused by ongoing maintenance work or other changes. As such, the exceptional state seems more normal than the 'normal' state.

[1] The conflict between economic interests and optimal operational configuration of the grid is a complex matter and involves various factors that are not feasible to fully cover here. One of the central conflicts concerns the route through which the electricity is carried across the grid. For instance, while certain paths may provide better possibilities to remotely control the flow of electricity and provide redundant paths, if the path is longer it may be less feasible economically as long physical distances attenuate electricity and induce costs as larger proportion of the electricity is 'lost' during transmit.

Despite that technicians populate all public spaces, and the soundscape of urban cities is filled with sounds of maintenance and repair work, the technicians often go unnoticed (Graham & Thrift, 2007). Some of this work that used to be messy, laborious, and even hazardous has, due to the technological advancements, become hygienic and comfortable office work. Despite these advancements, there is still aspects of maintenance work that require field workers and their physical presence at the site. These field technicians form a salient part of the work that is put to ensure the continuity of infrastructures. Through IT enabled coordination of their activities, the field workers become an integral part of the technicians' workspace and jointly construct and extend each other's' possibilities for action.

4.1 Technicians' work at the CityGrid

The technicians' work consists of preparing upcoming maintenance works, coordinating and performing planned work, and responding to any unexpected, befallen events. All the maintenance work has to take place in such a way that it has only minimum impact to the provided service as '[d]ue to society's dependence on infrastructures, stopping them for maintenance or reconfiguration is seldom an option and operations must always be done in the context of the aggregated history of earlier operations' (Almklov & Antonsen, 2014, p. 480) As a general principle, the technicians always seek to minimize the impact of the maintenance work to customers. Thus, any maintenance work requires careful prior planning and preparation of plans. The preparation of the plans include documenting the required configuration changes, appointing resources (both, human and non-human materials such as certain types of vehicles), and verifying the feasibility of those changes to the grid. Each plan is documented using a locally standardized language that affords documenting the required procedures in unified, simple, and short manner. For instance, the plan might include a procedure "OPEN switch Location X towards Location Y". After finishing, the plans are verified by another technician who virtually simulates it and approves it or suggests changes. The maintenance work is then carried out according to the plan and when planned. By structuring the technicians' actions, the documented procedures provide material guidance for the maintenance operations that would at first seem to render the technicians work into mindless rule-following. However, this assessment is far from the truth. As Suchman (2007) has convincingly shown, such plans are not basis for action but rather function as 'informational' sources for action and require technicians' constant awareness. Often, certain maintenance operation may not be possible due to aggregated history of earlier maintenance work that is taking place simultaneously in the grid that might not have been estimated when planning. Deeming the feasibility of changes requires the technicians to be constantly mindful of the overall state of the network that they co-create with the DMS. Occasionally, there is a conflict between the reality the technicians construct with DMS, and the technicians' prior knowledge, which often requires physical visit and visual verification of the equipment by the field technicians to resolve. Further, despite the peer review to verify the plans, the plans occasionally contain mistakes or the maintenance situation might differ from the planned which requires in situ adjustment and, often, co-creating new course of actions with the field technicians or with other technicians working at operations center.

Periodically and unexpectedly, the work is disturbed by alarms the systems generate or by phone calls from important customers, construction workers, or customer care that reports potential problems. These system alarms and phone calls create a hectic and slightly chaotic soundscape to the operations center that can be, at times, stressful. However, each sound carries a specific meaning that alters the technicians' reaction to it. Most importantly, the system alarms for different events varies depending on the severity of the alarm and can be used to infer its severity without reading the actual alarm text. An alarm that is determined important, surfaces emergent behavior and practices that are not visible during other times as the technicians promptly start uncovering what has happened, where it has happened, and why it happened. While the technicians are often able to narrow the impact of the incident or fix it in such a way that the flow of electricity continues to all subscribers, repairing often requires mobilizing the field technicians.

These continuous maintenance and repair practices pace the technicians work day and give raise to reliability and continuity of the smart infrastructures. However, the materiality of the grid, in important ways, regulates the technicians' space of action and change by shaping their workspace. As such, there is no fixed timeframe or a period to describe, no trajectory to outline, but rather to describe what takes place between punctuated moments of organizational change by focusing on the everyday and the normal rather than on the exceptional. The following vignettes are thus illustrative rather than comprehensive that serve to illustrate the reciprocity between materiality of workspace and technicians' possibilities of performing the reliability and continuity of the smart infrastructure.

4.2 Working with and around the legacy

Central for the technicians' work with the smart grid is that their workspace is a setting to which they are 'thrown' into, where the grid's materiality brings past to present as a legacy of the history. By being thrown into means the grid is not build afresh for the (or by the) technicians for optimal and reliable performance, but the technicians have to work with – and sometimes around – that which is given for them. The history that is brought to present by the grid's materiality sediments decades of design decisions, and construction, maintenance and repair practices that all reflect certain aspects of the political and economic landscape of the time of their performance. As Vespignani (2009) has argued, even infrastructures that are often thought as carefully designed, such as road and power infrastructures in cities, evolve dynamically when analyzed over longer periods of time due to such factors as the designers' relative shortness of time perspective. Due to the long history of CityGrid's smart infrastructure, the grid also sediments design decision and materialities that date decades back. The most visible reminiscent of the past design decisions and past political and economic landscape are the grid's cables that carry the electricity. Some of the wires and cables date back decades (even as far as 50-60 years ago). The phenomenal generativity of electricity has generated services and infrastructures that nowadays power all aspects of modern life and societies that were certainly unimaginable when the grid was built to power light bulbs. The increased demands and the sunken cost of ground cabling has meant that almost all new connections are dug underground, whereas all the older parts of the grid use air wires hanged to utility poles. Powering the light bulbs was not as critical as powering, for instance, contemporary IT server facilities or cloud computing farms. The criticality, and economic rationale, also guided the design and implementation practices in such a way that often the best route for the air wires was the shortest route and not the route that would provide optimal reliability. This also meant the air wires would go through forests and other terrain that would leave them easily exposed to trees and other externalities to intervene with the power distribution. While some of the air wires are being changed into ground cables gradually, there are parts of the grid that will not be changed anywhere in the near future due to economic calculations. The development of the grid is thus better described as an evolution than an accurate representation and implementation of some master plan. Further, in addition to the cables and wires, at any given time, the grid embodies technical components of which some are old, some newer, and some new. As such, the grid is not a homogenous entity but a heterogeneous mixture, an amalgam of contemporary IT, decades old mechanical switches and relays, temporary patches that have become permanent, and workarounds to name a few. This historical legacy also structures the technicians' workspace and their infra-acting possibilities. To meet the contemporary demands, CityGrid has invested in automating the grid and in enhancing the remote control of the grid. The grid has been worked iteratively to support these new capabilities, which has meant installing new devices and enhancing old devices by embedding new technologies. One such simple solution includes integrating remotely controllable electronic motors to mechanical switches, giving the technicians an 'extended arm' to turn a lever at a distance within milliseconds for an operation that used to take tens of minutes for a field technician to perform. Thus, the technicians' work has become reorganized and their workspace extended through these simple technologies that perform new realities in which they have to operate. This reorganization of their workspace has also improved the reliability and continuity of the grid by enabling them to work around the some of the legacy implications for reliability. In the case of an outage, for instance, when a tree falls on the air wires and launches the grid's automatic protection mechanisms that shuts down the flow of electricity from the circuit, the technicians may reroute the electricity through another circuit instantly. While removing the fallen tree requires the field technicians' physical presence, by reconfiguring the technicians' workspace, the technologies allow the technicians to remediate the situation, or at least, narrow the scope and impact of the incident. The technicians' actions thus never take place in isolation or as individual actions but are part of and relational to the historical stream of actions that took place before.

4.3 Working with humans and non-humans

While the technicians are physically located in operations center, the materiality of technology extends their workspace much beyond their physical location. The technicians' workspace is no longer tied to local and to that which is on the reach of an arm, but reconfigured and extended through technologies. On the one hand, the materiality of technology creates different conceptions of space and time as through their materiality, the technicians are able to reach even the furthest corners of the grid with just few mouse clicks and perform operations at distance. This is not to imply that the technicians would feel connected to those switches and other equipment at distance in the same way as they are connected to, for instance, the keyboard at the operations center neither does it imply that the technology would somehow bend the time/space continuum nor create wormholes to it. Rather, the materiality of technology gives raise to different kinds of realities that would not exist in the absence of those technologies. In these realities the local and distant lose their previous designation, as those events that are (physically) distant have locally felt effects. The observations showed that while the technicians physically located at a single location much of their work happens at distance and involves mobilizing numerous other actors. As such, it makes sense to not only consider the local space as technicians' workspace but as the smart grid that has both local and non-local aspects. It seems the materiality of the grid creates a fabric that binds together the various actors and forms common foundations for the agencies to operate. However, the constitution of agencies, due to the openness of the power grid is not static but evolves dynamically. This dynamically changing and shifting constitution of agencies shapes in important ways the infrastructure as the technicians' workspace. As Graham (2012) argues, '[w]hile they [power grids] include humans and their constructions, [they] also include some very active and powerful nonhumans: electrons, trees, wind, electromagnetic fields' (p. 11). Indeed, technicians' work unfolds as part of this dynamically changing and shifting amalgam that is populated with other powerful actors that contribute to framing the grid's operation and the technicians' workspace. Simultaneously, however, the technicians would not accomplish much without mobilizing these actors and working with them. The challenge for the technicians to perform is that they are not solely in control of what takes place in their workspace. Based on discussions with the technicians, most often their work is affected by three other actors: careless excavators, pesky critters, and heavy winds. While those are not the only ones, they seem to be the most common and salient 'intruders' in the technicians' workspace that the technicians have to work with. While the strategies to work with each type of actors varies, one strategy is to utilize the electricity itself to solve the incident. Occasionally, as observed, a sudden sound of an alarm draws the technicians' attention, and the colors of the topography of the grid shown by the DMS change abruptly (a line representing a physical wire turns white on the display). Before the technicians are able to react, the grid reacts in milliseconds by reconnecting electricity back to the faulty part in an attempt to restore the electricity. If the electricity could not be restored, the technicians wait for around ten seconds before enacting command that attempts to restore the electricity. If restoring the electricity still fails, the field technicians will be dispatched, and the technicians at the operations center study alternative ways to route the electricity. However, after few minutes the technicians may try again to connect electricity to the faulty part of the grid. The waiting time plays a crucial role, as restoring electricity too promptly would overheat the protective devices or even melt them. Thus, the materiality conditions the technicians' ability and the frequency at which the operation can be performed. While these repeated attempts may sound irrational, what actually happens is that the technicians mobilize the electricity in an attempt to repair the problem. As brutal as it may sound, when the outage is caused by a critter or some other animal that has climbed or flown to the exposed components of the grid, the electrical current electrocutes the animals, and their bodies (or what is left after being electrocuted) may get stuck on the components. By attempting to reconnect the electricity, the electricity may combust the corpses which may then burn and drop away from the line.

4.4 Working with invisibility, complexity and uncertainty

When functioning, the infrastructures seem to become ‘invisible’ and withdraw to background and only surface on breakdowns (Star & Ruhleder, 1996). This invisibility of the infrastructure also characterizes the work of the technicians. What they know about the infrastructure, how they know it, and when they know it are largely dependent on the technicians’ information systems, and other actors. Even the electricity itself, flowing in the cables and through various switches, relays, valves, and so forth is not visible per se but only expressible in quantified metrics (e.g., in watts, amperes, volts). Thus, ‘knowing’ the electricity would be impossible (and unquestionable a hazardous attempt) without the sensors that co-create this information together with the technicians and the information system. In such a way, through their joint agency, the electricity, the sensors, the information systems and the technicians jointly construct and give raise to realities that would not exist in the absence of the social or the material. As the technicians expressed, the grid’s complexity surpasses any single technician’s comprehension, and always contains an element of surprise. The grid embodies certain unpredictability which seemed to be a source of stress and anxiety for the technicians even to such extent that in the past some technicians had changed the work. Thus, the concern is not so much theoretical of whether the behavior could be known in principle but whether it is known or can be known in practice. The unpredictability also animated the grid giving it *geist* and agency to seemingly act on its own. The technicians seemed to accept that when working with such a large scale system the behavior of that system exceeds their control. Experiences from the past have shown that ‘anything’ can go wrong, as the technicians expressed their view. However, this inherent unreliability and uncertainty importantly shapes the technicians infra-acting possibilities. As described above, the constitution of the grid is always dynamically changing. But in addition to the aforementioned reciprocal and mutual shaping of actors and possibilities, it seems the possibilities do not exist prior to their enactment in practice. This is most visibly projected in technicians’ actions when intentions do not translate as expected results. When observing, on several occasions, despite the technicians attempts to reconfigure the grid in order to respond to an emerging incident, the grid would not perform the requested operation. While in some occasions it was possible for the technicians to construct a posterior explanations of what went wrong, in other occasions the technicians merely had to acknowledge the grid works in mysterious ways. Especially, during an incident in the power grid, the unpredictability profoundly shapes the technicians’ workspace and alters their possibilities to perform the reliability and continuity of grid. An unsuccessful attempt, a failure to perform a command at distance reworks their infra-acting possibilities. In an instant, what seemed to be near and within the reach of the mouse click becomes desperately distant.

5 DISCUSSION AND CONCLUSIONS

This ethnographic study aimed to investigate the relationship of work and materiality in the context of infrastructure reliability and continuity. To study the relation study builds on sociomaterial theorizing and on the conception of agency to explicate the implications of workspace to continuity and reliability. Sociomaterial theorizing proved fruitful to foreground the ways in which material forces intermingle with, interfere, and condition the social world that would not have been possible when focusing merely on social aspects of work. Building on the sociomaterial conception of agency, the concept of infra-acting was developed to denote and study the relationship between infrastructures and action in order to make sense of the technicians’ workspace in smart infrastructure setting. The study contributes to earlier discussions that view technological reliability and continuity as performed in practice (Butler & Gray, 2006). More broadly, the study contributes to the call to study the relationship between technologies and work (Forman et al., 2014). Next, the contributions and implications of the research are elaborated and abstracted towards more general discussions.

This study asked ‘how the materiality of the workspace conditions and enables technicians to perform the reliability and continuity of a smart infrastructure (smart power grid)?’. The findings of the study (see Table 1) suggest that the technicians’ possibilities to perform reliably is conditioned and enhanced by the materiality of the smart infrastructure. This recognition has significant implications to understanding reliable organizational performance by arguing that in the infrastructure setting human-centric views that focus solely on the social or cognitive processes to explain reliability do not suffice. As the findings indicate, the technicians' work is shaped by non-local aspects of work and that the material forces influenced the technicians' possibilities for performing their work. Omitting material aspects of work when considering reliability and continuity of infrastructures risks overshadowing other salient factors and overemphasizing the role of the technicians as individual actors. Instead, the study suggests that their performance is relational to the infra-acting possibilities of their workspace. The findings indicate the historical legacy that the grid carries can explain some of the variation of how the technicians perform. That is, the way in which the infrastructure has materialized influences how the technicians can perform its reliability. In addition, especially in open and exposed infrastructures, as the power grid at CityGrid, other human and non-human actors shape the infrastructure as the technicians' workspace. Further, break downs in complex technological systems are part of their 'normal' mode of operation (Perrow, 1981), and they always depict a degree of unpredictable and uncertain behavior (Butler & Gray, 2006), due which the outcome of an action cannot be known for sure before the enactment of that action. Taking into account the materiality of infrastructure does not mean that the technicians are irrelevant, but that their actions needs to be placed within the wider material constitution of infrastructures. However, by recognizing that agency is distributed and not solely a property of humans suggests that reliability and continuity studies should focus less on designating responsibility, or even blame, to individuals (or to human collectives), and instead focus on discerning the webs of actors and forces that affect situations and events (cf. Bennett, 2010).

Finding	*Relation to extant research*
Technicians' possibilities to perform the reliability and continuity are conditioned and enhanced by the materiality of the smart infrastructure which frames their workspace.	Extends research on how technological reliability and continuity are performed in practice (Butler & Gray, 2006).
Technicians' workspace entails and is shaped by both local and non-local constitutions of the smart infrastructure.	Support previous findings that that work in infrastructure context has local and non-local aspects (Almklov et al., 2014). Extends research by arguing that 'local' and 'non-local' are not given but created in practice.
Technicians' workspace is conditioned by the historical legacy of the smart infrastructure.	Extends Almklov and Antonsen's (2014) concept of 'historical continuity of operational work' in the context of a smart infrastructure. It extends Venters et al. (2014) by arguing that material legacy creates inertia to technicians' work but it can be worked around by smart technology.
Invisibility, uncertainty and breakdowns of the smart infrastructure characterize technicians' workspace.	While unreliability and unpredictability of the infrastructures is widely known (e.g. Perrow, 1981; Graham, 2012), its relation to technicians' work in maintaining the reliability and continuity of the infrastructure has been less understood.

Table 1. Findings and contributions of the study

Leaning on the sociomaterial theorizing enables to account for the non-local forces and abandon a user-centric view on action which was necessary to appreciate the reliability and continuity challenges the technicians face. To this end, the research suggests that understanding of 'workspace' needs to be reconsidered. The concept of infra-acting provides a way to conceptualize the reciprocity between the dynamic material constitution of infrastructure and action, and thus provides an alternative way for understanding the technicians' workspace. From this perspective, the workspace is not merely that which is in the reach of an arm, but relational to the material constitution of the workspace that creates technicians' realities. As other studies have also asserted (Almklov et al., 2014; Jonsson et al., 2009), in infrastructure context non-local effects may have local causes.

This study also underlines the importance of infrastructure design to be mindful of the technicians' work. The challenge here is that the smart infrastructures have often developed over long periods of time and evolved dynamically rather than along some predetermined trajectory (cf. Hanseth & Lyytinen, 2010). This was also what the technicians at CityGrid were experiencing. The smart infrastructure the technicians at CityGrid work with, the workspace of their work, is not a result of any single design plan, but has resulted through its long history and is ‘given’ to technicians by the past. As it would be unfeasible to assume that the infrastructure could be built from scratch, the design has to focus on enhancing and extending the existing workspace in relation to that which already exists. That is, the power grid can be worked iteratively by building onto existing rather than building completely anew. Indeed, by integrating IT technologies and mechanical and non-IT technologies, the power grid at CityGrid had been reworked iteratively to incorporate the ‘smart’ functionalities. Here IS researchers can have an important role to play. As IT technologies are populating areas where they have not existed earlier, the task is to determine ways in which to build information systems on existing (material) infrastructures. This requires increasing our understanding not only on embedded systems but embedding those embedded systems and their technological capabilities to existing, traditional infrastructures to enhance and enable ‘smartness’ through techniques such as ‘Internet of Things’.

More broadly, the research provides an empirical case of the changes smart infrastructure brings to technicians’ work. As such, the research contributes to discussions showing the implications of infrastructures to work (e.g., Almklov et al., 2014; Østerlie et al. 2012; Jonsson et al., 2009). The smart infrastructure at CityGrid enables the technicians to perform operations that traditionally would have required technicians’ physical presence, such as rerouting the electricity or performing other control operations. This paints a different image of the technicians work and tools as we have traditionally viewed them (cf. Orr, 1996; Barley, 1996). In the CityGrid’s smart infrastructure, the IT has profoundly entangled with the technicians’ work and the power grid. As we have sought to show in this research, the entanglement gives rise to a new types of workspaces and new forms of realities that would not exist in the absence of the technologies.

Lastly, limitations apply to this research. Most central limitation concern the generalizability of the findings. The study did not sought to make statistical generalizations, and thus, it should not be viewed as a limitation of the study per se. However, by focusing on the single empirical site, the findings are neither directly applicable to other settings nor representative of any population or sample. By relating the findings to more general and abstract theoretical constructs, the research findings could be generalized from particular to theory and related to existing body of knowledge (Lee & Baskerville, 2003). As such, the research extends the existing body of knowledge with one particular study. Nevertheless, the theoretical conceptions brought forth here, may provide useful lenses to study the relation of work and infrastructures also in other settings.

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