Breakdown in the smart city: exploring workarounds with urban sensing practices and technologies

Abstract

Smart cities are now an established area of technological development and theoretical inquiry. Research on smart cities spans from investigations into its technological infrastructures and design scenarios, to critiques of its proposals for citizenship and sustainability. This article builds on this growing field, while at the same time accounting for expanded urban sensing practices that take hold through citizen sensing technologies. Detailing practice-based and participatory research that developed urban sensing technologies for use in Southeast London, this article considers how the smart city as a large-scale and monolithic version of urban systems breaks down in practice to reveal much different concretizations of sensors, cities and people. By working through the specific instances where sensor technologies required inventive workarounds to be setup and continue to operate, as well as moments of breakdown and maintenance where sensors required fixes or adjustments, this article argues that urban sensing can produce much different encounters with urban technologies through lived experiences. Rather than propose a "grassroots" approach to the smart city, however, this article instead suggests that the smart city as a figure for urban development be contested and even surpassed by attending to workarounds that account more fully for digital urban practices and technologies as they are formed and situated within urban projects and community initiatives.

Keywords

Workarounds, breakdown, smart city, urban sensing, citizen sensing, sensing practices

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Introduction

Smart cities are now an established area of technological development and theoretical inquiry. Research on smart cities spans from investigations into its technological infrastructures and design scenarios, to critiques of its proposals for citizenship and sustainability. One area of research that is emerging along with these studies is a focus on breakdown in the smart city. Smart cities break down through unstable technologies, through haphazard policy and development regimes, and through reductive design and planning approaches. In this article, we analyze two ways in which the smart city breaks down. The first engagement with breakdown details how monitoring technologies, in the form of sensors, databases and platforms, require fixing or adapting in order to continue to be operational. Our second engagement with breakdown in the smart city attends to how the often-monolithic smart cities discourse breaks down in practice to reveal alternative concretizations of sensors, cities and people.

The work of keeping digital sensors in operation is often iterative, ad hoc, and unseen, but is at the same time crucial to the ongoing functioning of these technologies. We detail this work through the discussion of a practice-based and participatory research process into developing citizen-sensing technologies for use by communities in Southeast London. By working through the specific instances where sensor technologies require inventive workarounds to be setup and continue to operate, as well as moments of breakdown and repair where sensors require fixes or adjustments, this article argues that these urban sensing practices can produce much different encounters with urban technologies. In the process of accounting for these moments of breakdown and working around, we ask: In what ways do accounts of smart cities or urban sensing technologies transform through an attention to maintenance, repair and workarounds that are operationalized to keep sensor technologies going? How do the everyday sensing practices of attending to digital technologies articulate much different approaches to computational urbanisms? And how might sensing practices of working around, which emerge through maintaining and repairing community infrastructures, give rise to new strategies for creating technologies that are aligned with the lived experiences of urban inhabitants?

We address these questions by discussing participatory and project-based research that involved collaborating with residents to set up urban sensing technologies, primarily for detecting air pollution. We work through the back-and-forth ways in which the monitors were installed, adjusted, fixed and taken down, as well as the attempts to grapple with the data that they generated in relation to ongoing community projects and campaigns. By accounting for these processes, we develop an understanding of the specific ways in which breakdown functions in relation to "smart" technologies, especially as encountered through everyday experiences with sensors. We then develop three key approaches to workarounds as they emerged in this project, including: 1) connectivity workarounds; 2) sensor workarounds; and 3) data workarounds. Connectivity, sensors and data are often seen to be key components of the smart city, but here they are differently configured and engaged with not through optimal functioning, but through faltering operations. Each of these workaround occasions generated moments of intervention, repurposing and reworking of urban sensing technologies. These processes of working around, we argue, more than merely being narrated as the "failure" of technology erupting into view, give rise to different ways of encountering and making urban sensing technologies not as emancipatory devices, but rather as uneven ensembles for articulating political engagements.

Rather than propose a "grassroots" approach to the smart city, this article instead suggests that the smart city as a figure for urban development be contested and even surpassed by engaging with workarounds that account more fully for digital urban practices and technologies as they are formed and situated within urban projects and community initiatives, and as they might give rise to expanded urban sensing practices and infrastructures. While we are not advocating for technologies to be high maintenance or require constant intervention, we suggest that current visions of the smart city do not adequately account for actual and potential moments of breakdown and working around, and are also limited in their universal rendering of urban life (cf. Hollands 2015; Vanolo 2016). Such oversights within smart city proposals and projects, moreover, are part of what contributes to a relatively hermetic and static understanding of urban technology. The seamless functioning of smart cities is a vision that breaks down when put to the test of citizen engagement, where different objectives and commitments emerge for how sensing technologies might be worked with, experienced and maintained. Our exploration of workarounds occurring in and through citizen-sensing practices proposes a different conceptual vocabulary with which to articulate the emergence of distinct forms of computational urbanism.

Breakdown in the Smart City

Though often associated with real-time monitoring and coordination of urban environments, the term "smart city" has no single definition and holds together a range of urban interventions (cf. Hollands 2008), including digital infrastructure, data-focused start-ups, self-driving car systems, citizen sensing, and "corporate storytelling," among others (Barns et al. 2017; Datta 2015; Gabrys 2014; JafariNaimi 2018; Söderström et al. 2014). Although smart urbanism represents a disparate set of practices and interventions, two key logics tend to animate a central core of activities. First, in the context of greatly intensifying global urbanization, smart city solutions are said to offer computationally enhanced ways to render urban processes more efficient and sustainable. Second, smart cities are meant to afford citizens new and enhanced ways of participating in urban politics and governance. Yet as often as not, these urban infrastructural logics require extensive and continuous work to arrive at "operational accomplishment" (Luque-Ayala and Marvin 2016).

Breakdown can amplify smart city logics, since real-time monitoring and city management systems seek to maintain urban order and minimize disruption (Hoyng 2016). Taking the Internet as both architecture and metaphor, smart city infrastructures are envisioned to "route around" breakdowns in urban life such as faults and congestion (Dourish 2016, 35). Yet as has often been pointed out, the optimization and efficiency that are meant to be characteristic of smart cities are also conditions that could easily be disrupted by "buggy, brittle and bugged" systems (Townsend 2013), where technology does not function according to plan, interoperable systems cease to communicate, or obsolescence of software, hardware and networks creates failures in computational processes (Gabrys 2016b). Behind the ideal of an intensively networked city stands the patching, grafting and working around that is always entailed in getting and keeping sensors, devices, software systems and communication architectures running. Technicians and system administrators must monitor errant sensor hardware out in the city, deal with regular software glitches by upgrading and patching, and secure data in the event of catastrophic loss. An "ecology of breakdowns" thus becomes evident in smart cities projects (Tironi and Valderrama 2018). Or in other words, "urban failure" can be written into the very processes of "renewal and coordination" that attempt to stave off breakdown, but that also involve ongoing negotiation of pluralistic urban conditions (Amin 2016).

In smart cities discourses the realization of urban order is strategically foregrounded, while the work of maintaining digital and sensing infrastructures is often disregarded as a merely technical or operational matter. While smart cities might seem to arrive as complete technological plans, digital technologies and computational urbanisms tend to assemble less through streamlined processes and more through ad hoc, provisional and even experimental developments, testing, fixing, and working around. Dourish suggests in his concept of the "accidental smart city" that the city becomes smart in fits and starts, irregularly and unevenly, "under the control of different groups, without a master plan and with a lot of patching, hacking, jury-rigging and settling" (2016, 37). This is a different entry point for understanding how cities are made, where infrastructure is a provisional and daily collective practice of collaborative city-making and "collaborative infrastructuring" (de Lange and de Waal 2019; Forlano 2016; Perng 2019; cf. Simone 2004).

Yet smart cities in their lived and provisional implementation and operation are often a less studied area. Key research has been undertaken on the "actually existing smart city" (Shelton, Zook and Wiig 2015) to establish how smart city plans from technology companies are implemented, thereby providing important detail about the way that these plans materialize. Other research takes up the emergent politics involved in negotiating the disjuncture between plans and articulations of smart city projects and the contingencies of urban redevelopment (Bulkeley et al. 2016). This literature also foregrounds how smart city plans "repair" urban problems by conforming to a particular version of socio-material order. Ureta (2014) describes efforts to implement a new public transportation network, Transantiago, in Santiago, Chile, where smart systems failed to work as intended, resulting in disorganized services and long, ongoing delays for passengers. Public demands to repair Transantiago involved troubleshooting the implementation of smart technological systems, but also disciplining travelers to fit the user roles that had been assigned to them during the design phase. Ureta's concept of "normalization" draws attention to how addressing breakdown is not merely the functional restoration of a system or device, but always involves the negotiation of a wider socio-material order (Henke 1999).

While on the one hand the smart city attempts to prevent breakdown through new technologies of anticipation, and on the other hand breaks down in the process of installation and use, citizen engagement within the smart city presents another trajectory whereby the smart city might fail to function as intended. Citizens play a distinctive role in the smart city imaginary of urban maintenance work, where practices of monitoring and gathering data are expressive of distinct forms of citizenship (Gabrys 2014, 34). Platforms such as Fixmystreet.com are billed as having a democratizing effect, by providing convenient new ways for computationally enabled residents to notify their municipal authorities to forms of urban breakdown (Townsend 2013). At the same time, citizenship here is narrowly configured in relation to interactions with pre-specified platforms that are themselves oriented to a highly normative version of socio-material order. Notification platforms might work to convey data on urban problems to municipal authorities, but fail to remake the service provision that "fixing" relies upon, thereby transforming the smart city into an idiotic one (Gabrys 2016a, 206-238).

In a recent analysis of resistance to urban transformation in Istanbul, Hoyng takes up the "broken" smart city, asking how computational urbanisms are experienced through "breakdown, disconnection and suboptimal performance" (2016, 398). In this case, the introduction of smart city systems engendered both accidental and intentional breakdown (in the form of sabotage). Residents organized both physical and digital occupations, producing moments of disconnection that sabotaged smart city storytelling, and at the same time revealed how smart city processes of urban "repair" mandate particular forms of normalized citizenship.

Despite these varying instances of breakdown, the smart city as a concept remains somewhat unedited by the many attempts to build, implement and contest these technologies in practice. We consider how urban sensing practices and computational urbanisms variously challenge and rework the logic of the smart city as a plan to be implemented, even if patchily. From this perspective, the smart city might never actualize, since the very vision of the smart city would need to be rewritten or even scrapped in the process of attempting to implement it. In this way, we explore how practices of maintaining, repairing and working around lead to an expanded understanding of urban citizen engagement that moves beyond narrow modes of citizen-participation-as-data-collection. We shift from smart city cybernetic logics of "routing around" to more expansive situations of "working around" as connected sensors and data form ensembles for articulating different forms of political engagement.

The political engagements that we discuss here form multiple modes of attachment to world making, from politics of evidence that engage with policy making and local planning, to politics of worry, class warfare and environmental pollution. The questions of who and what gets to participate in the vision of the smart city signals political engagements that arise from intersectional struggles, as well as interlocking systems of oppression embedded in the materiality of digital infrastructures (Forlano and Mathew 2014; Noble 2016). By drawing attention to the politics of participation in the smart city we reflect on the ways in which citizen sensing might be rerouted as a political practice. Indeed, the articulations of politics that we bring attention to emerge as workarounds *rather* than points of resistance *because* they have to navigate and address interlocking problems. By engaging with maintenance and workarounds as key ways in which citizen participation develops in relation to citizen sensing technologies, we rework the technologies and modalities of the smart city and urban sensing away from correct functioning, and toward the experimental, the unintentional, the just-good-enough and the bodged together. Through attending to these occasions of breakdown in computational urbanisms, we also find ways to break down the logic of the smart city by attending to these more open-ended and contingent urban sensing practices.

Infrastructure and Improvisation

As we have seen with ubiquitous computing, narrations of technologically dense environments tend to exclude contingencies such as breakdown. While there is a substantial body of research in infrastructure studies that suggests infrastructure becomes most visible when it has broken down (Star 1999; Bennett 2005; Graham 2010), Mackenzie argues in his study of wireless technologies against the binary logics of visibility and invisibility, suggesting that "in relation to wirelessness and many other technical situations a flickering oscillation between breaking-down, becoming aware, and background-forgetting is more common" (2010, 96). Mackenzie further suggests that "a gap exists between the ideal of a totally networked world and a provisional, unstable reality tangled with wires, buildings, everyday habits, and the presence of others, between, in short, meaning and *praxis*" (2010, 89). Our work similarly seeks to move beyond the binary sense of working or broken, or in/visible infrastructures, by exploring how citizen-sensing technologies are often in varying states of functionality and legibility, in the process of materializing and acting on urban problems as determined by city residents.

This approach to breakdown suggests both that infrastructures and technologies such as sensors and networks are often working in partial or sub-optimal ways. Rather than narrate this as a failure or complete shutdown of urban functions, we suggest that it is a more common feature of how urban infrastructures work (cf. Howe et al. 2016), as well as how urban sensing technologies operate. These observations overlap with other research on the work of keeping urban infrastructures running. Simone (2004) suggests in the context of African and Asian cities that infrastructure is as likely made up of people, processes and relations that tie together cities and make urban life possible. We take up this approach to urban infrastructure to consider how urban sensing technology is not an abstract system layered onto urban space, but rather is an array of practices that assemble through and along with the unfolding of urban life.

We bring such an approach to urban sensing technology and infrastructure in-the-making to suggest that improvisation, following Suchman, is key to the way that technologies are constituted. "Local improvisation," as Suchman writes, "is not just a matter of receiving something already made and incorporating it into a new site of use." Instead, she suggests, "improvisational activities are the generative practices out of which new technologies are made" (2002: 139). Technology is often presented as a free-floating and finished object that is transplanted on to urban space. But by attending to practices of working around through improvisation, maintenance and repair we find that both computational urbanisms and notions of technology transform. Technologies are co-constitutive entities that contribute to the mediations of urban life (Rose 2016). Here we draw on work such as Philip et al. (2012) to suggest that the development and use of technology cannot then be detached from the many practices of reverse engineering, *jugaad* and working around that allow it to concretize along with environments and entities (see also Rai 2019). This approach aligns with urban research that attends to improvisation as a key process in urban life (Simone and Pieterse 2017).

Workarounds and Computational Urbanism

Working around might on one level refer to a set of (often technical) practices, but we seek to also broaden the concept to engage with the ways in which computational urbanisms as environments, technologies, entities and relations settle into form. The term workaround is anchored in the development of computing as "a method of circumventing or overcoming a problem in a computer program or system," (Collins n.d.) or "a plan or method to circumvent a problem (as in computer software) without eliminating it" (Merriam-Webster n.d.). Acts of repair can certainly include workarounds—ways of dealing with breakdown that enable a continuation of practices. Yet the term workarounds also draws out a different emphasis: Where repair is conventionally envisaged to involve the resolution of a failure and the reestablishing of normative structures, workarounds move forward by improvising within, between and across normative orders.

Academic studies of workarounds-in-practice appear most frequently in the fields of organization and management studies, which have been recently synthesized by Alter in his taxonomy and “integrated theory” of workarounds. According to his definition:

> A workaround is goal-driven adaptation, improvisation, or other change to one or more aspects of an existing work system in order to overcome, bypass or minimize the impact of obstacles, exceptions, anomalies, mishaps, established practices, management expectations, or structural constraints that are perceived as preventing that work system or its participants from achieving a desired level of efficiency, effectiveness, or other organizational or personal goals (2014: 1044).

Here, workarounds tend to occur when contingencies trouble the highly normative structure of a work system. Alter’s taxonomy treats workarounds as system failures that should either be designed into organizational systems (by formalizing ad-hoc practices) or designed out (through better compliance mechanisms).

In science and technology studies (STS) literatures, interplays of agency and control have also been foundational to the conception of workarounds. Akrich (1992) describes how users in French Polynesia were excluded from maintaining and repairing their photoelectric lighting kits. French designers installed a control mechanism that simply shut lights off during periods of low or high charge, rather than allow users to manage their own battery levels. Users worked around this constraint by commissioning a local electrician to adapt the device. Akrich uses this case to argue that designers of technology mobilize around a particular logic, or “script,” which orients a device. Users may take up technologies in ways that reaffirm, subvert or destabilize these power dynamics.

Pollock complicates the notion of “scripting” through his case study of software systems that are designed to be locally articulated. Here, workarounds are distinguished by their regular intensity and their infrastructural quality. Pollock argues that “constant attempts to work-around the code” shift the focus from designed-in “scripts” to the emergence of workarounds across “networks in place” (2005, 9). Pointing to instances where software developers support or withdraw access to particular fixes, he asserts that “just *when*… a workaround is a supported form of use, and when it is not, becomes a crucial question” (2005, 16). Pollock highlights how users rework and unpack “black boxed” systems, yet what counts as a workaround or a legitimate use remain contingent and contextual questions.

Citizen sensing practices potentially provide very different ways of parsing workarounds. Rather than breaking with a pre-set script, or necessarily following or deviating from a program of use to achieve a stated outcome, workarounds as we deploy the concept points to those improvisational practices and engagements with the breakdown of a digital technology as it is taking form (Steinhardt 2016). Rather than analyze an over-arching agenda for how this technology is to operate, we home in on the practices, relations and ways of making infrastructures “work” encountered through workarounds. There is no single goal or work system at play here; rather there are multiple conditions of functionality and breakdown that concretize through the process of making and installing digital technology. Working with and around monitoring technologies entails opening up different sites and spaces of possibility via practices of remaking, realignment and circumvention. These unfolding processes contribute to expressing and constituting the conditions of urban environments. As we suggest, this is another way of also working around how computational technologies are usually constituted in the smart city and beyond, where citizen sensing infrastructures create alternatives to regulatory monitoring systems, where what counts as “normative” is decided through local, contingent and improvisational actions.

Exploring Workarounds through Urban Sensing Practices

Building upon the above literature, we turn to discuss one specific urban sensing project that involved the construction and maintenance of community air-quality-monitoring technologies in Southeast London. London is a city with elevated levels of air pollution. The intractability of the air pollution problem in London has led to an environmental public health crisis, with over 9,000 residents dying prematurely every year due to air-pollution-related causes.[1] Our project engages with two neighboring wards in Southeast London that together make up the area of Deptford and New Cross. Southeast London similarly has high levels of air pollution. Increasing levels of construction and traffic due to regeneration had created concerns about air quality in the area. From the 1960s onwards, Deptford has been subject to successive waves of regeneration, which intensified around 2012. Multiple tracts of brownfield land in Deptford are undergoing redevelopment—typically into high-density housing units that would be largely unaffordable for those earning average incomes for the area, even as this redevelopment is meant to address London’s housing crisis. These factors have crystallized into a discordant spatial politics, where the sheer pace of change of the built environment and concerns over the loss and re-allocation of resources, come up against longstanding concerns about the ability of residents to participate in, and benefit from, the process of regeneration.

While in this project we engage with the constitutive technologies of a smart city, we begin not from a vision of what the smart city should be or how technology should operate. Instead, our approach involves examining urban sensing technologies within these lived urban circumstances through a participatory methodology, which takes a practice-led approach. We begin our projects by interacting with residents and communities that are already engaged in sensing practices in relation to environmental problems and intersectional political concerns that they seek to document and address (Pritchard and Gabrys 2016). We then explore collaboratively how to extend or augment these practices using digital sensors, developing sensing kits and data analysis platforms that emerge alongside community actions and campaigns. These emerging sensing practices and technologies are studied as an unfolding experiment into how citizen sensing gives rise to new modes of environmental practice and citizenship.

Seeking to learn more about the sensing practices already being undertaken in this area, we attended community group meetings to better understand the histories, issues and modes of environmental organization that were underway. In some cases, there were long-standing practices of working against regeneration to maintain the character of the area, while other practices engaged critically with redevelopment processes in an attempt to make space for residents’ input into the urban design process. Sensing practices of monitoring and measuring environments were important in both of these approaches. In the course of our research, we met residents’ groups that were working to observe and document dust and noise pollution from nearby building sites. These were compiled and circulated via neighborhood blogs, as an attempt to hold building contractors to account, when dust suppression policies were not being properly adhered to. Another pressure group focused on the health of the high street used vehicle counting to demonstrate that a side road was too heavily used; first enrolling the police to measure vehicle speeds, and then using the data to work with local government representatives to change the road layout. A coalition of residents and activist groups conducted a study of nitrogen dioxide air pollution in the area in order to contest the use of a local park as the tunneling point in a major infrastructure project. A park user group surveyed the condition and usage of several local parks. A community forum used nitrogen dioxide monitoring in the process of developing neighborhood planning policy—taking advantage of new powers provided in the Localism Act 2011. Across these multiple campaigns three key concerns emerged, including road transport congestion, intensified construction of apartment blocks, and a lack of green and open spaces. Cutting across these concerns were residents' longstanding worries about air quality, which they were keen to investigate using digital sensors.

As we learned more about the concerns of residents in Deptford, and began to establish connections to understand how people would like to test and use sensors, we also began to develop an air quality monitoring kit that might respond to these specific urban conditions. Drawing on and extending residents' DIY sensing practices, we built a prototype device, the Dustbox, for monitoring particulate matter 2.5 ($PM_{2.5}$). This pollutant is composed of small airborne particles that are particularly hazardous to human health (Grigg 2017), yet is only monitored by statutory instruments in select sites across London. The Dustbox includes an optical sensor that uses infrared light scattering technology to measure the density of PM in the air (for more detail, see Pritchard et al. 2018). The casing was 3D-printed in black ceramic shapes that resemble particles when viewed under an electron microscope, and was designed to be a tactile and provocative device that would indicate its sensor function. As part of this sensing infrastructure, we also set up additional digital architectures, including a database that received sensor data, and a publicly available data analysis toolkit, Airsift, for analyzing and visualizing sensor data. Unlike other air quality monitors that form part of the smart city landscape, the work of developing the Dustbox and Airsift data analysis toolkit was not intended to produce a stabilized product and platform that could scale up across urban populations. Instead, the process of putting together a citizen sensing infrastructure was a way to encounter the practices, problems and imperatives that emerge from operationalizing low-cost sensors in participation with communities. Rather than opening the black box, we made our own black boxes that were less hermetically sealed systems, and more "open" technologies that activated urban relations.

During the project we organized a series of public events that brought together residents, community groups, health researchers and political representatives to discuss and setup urban sensing technologies. At our first workshop, we collectively mapped locations that residents and community groups were particularly interested in monitoring, and walked to some of those sites to observe emissions sources. Some participants borrowed monitors while attending this event, while others checked them out of the local library or contacted us directly when they heard about the monitoring study. If required, we offered help and support to get Dustboxes up and running: a moment where workarounds proliferated. As the project progressed we regularly worked with participants during "drop-in" data analysis workshops. We also attended public meetings hosted by community groups and the local authority to discuss the project and provide interim updates. In total, around 30 monitors were distributed to participants. During the monitoring activity, there were approximately 30 Dustboxes in operation. The full monitoring period ran for nearly 10 months from December 2016 until September 2017. We now turn to describe three workarounds that emerged in the process of mobilizing the Dustbox infrastructure to measure the Deptford air.

Workaround 1: Connectivity and Contingent Infrastructuring

Smart cities are often presented through visions of heightened, accelerated and optimized connectivity (Wilson 2015). When setting up the Dustbox sensors however, we found that connectivity was a site and process that generated considerable obstacles. For many participants, working with citizen sensing equipment was a form of contingent infrastructuring (LeDantec and DiSalvo 2013; Star and Bowker 2002) that allowed residents to shape infrastructures in relation to their particular concerns. For some members of the group, setting up Dustboxes was a way of working around the differently "normalized" orderings present in smart city, regulatory or private sector monitoring infrastructures, in the context of activist campaigns. As a result, the question of where to site Dustboxes was crucial to how the environmental observations and experiences of participants could be materialized through sensor data.

In order to measure urban air quality, the Dustboxes needed to be placed outdoors with some protection from the weather. They required access to mains power and an Internet connection in order to run the sensor and cloud-based software, and to transmit readings to the database. Some participants were initially frustrated by these infrastructural demands, approaching the Dustboxes as stabilized, product-like forms that should have been designed as self-contained units powered by solar energy that could be strategically positioned anywhere in the city in order to provide maximum flexibility in relation to observed problems. Getting the Dustboxes up and running then involved engaging in collective workarounds that attempted to balance sensors' access to urban locations that participants were keen to measure, with the challenges of accessing Wi-Fi and electricity.

[Insert Figure 1 here: A connected Dustbox, part of a collaborative air quality infrastructure. Citizen Sense, 2016.]

The Dustbox in Figure 1 was one of the first to begin streaming data. This sensing infrastructure was set up by an indomitable artist and activist who lives close to a cluster of active building sites. With a sense of exasperation, she told us how dust and noise from construction activities and Heavy Goods Vehicle (HGV) visits were profoundly impacting her home life. Dense blocks of new housing were replacing a hodgepodge of ex-industrial buildings, creating a wall along the corridor of Deptford Creek. Adjacent sites were about to begin the planning process—threatening years of disruption. Her dismay at the rapid pace of change in the area was keenly felt, and she seemed exhausted at times tracking objections, rejections, approvals and redesigns. In addition to photographing and blogging about the high levels of dust in the area, she wanted to generate data on local levels of $PM_{2.5}$ to gauge the impact of construction in a different register.

Across the block, her neighbors were more exposed, and she considered these "better" sites to measure. But since none of them could be convinced to join the project, she set up a Dustbox on an elevated walkway outside her home. Figure 1 shows the care and attention she extended to the Dustbox device as part of this process of ad-hoc infrastructuring: she wrapped a cardboard box with cling film to provide it with weather shelter, and rallied a stool from inside to keep it off the ground in case of rain or frost. In order to access power she had to thread the power cable through her cat flap, causing an obstruction to the door, and letting in a cold draft all winter long (an inconvenience she trusted that the data would repay).

The contingencies of these in-between spaces and requirements revealed how few people had access to outdoor space, or whose outdoor space presented security risks or lacked access to power or Wi-Fi. Building urban sensing technologies and practices required improvising within the existing environments to meet the needs of the devices. It involved being led by participants to gaps, crevices and interstices in their homes and workplaces, and debating how to repurpose these. Setting up Dustboxes also involved decisions about how both humans and non-humans could live convivially with the infrastructures required by the device, as participants made judgments on whether it was acceptable to have an extension lead running through the kitchen, or "worth it" to live with workarounds in order to collect air quality data.

The process of getting connected to wireless networks expanded these material explorations into another register, as multiple invisible hotspots of radio waves intersected with the built environment in troublesome ways. We would use our smartphones as diving rods to tune in to Wi-Fi networks and avoid dead zones in gardens and behind thick concrete walls. Participants had to transfer the name and password of their wireless network onto the device, which involved downloading a smartphone application and entering network details—a process that was rarely "seamless." The transfer of details was performed by removing the Dustbox casing lid, holding the smartphone screen up against the wireless module inside the device, where the network details would be transferred via on-screen pulses of light. Positioning the phone into the casing, holding it steady, shading it from ambient light and at the same time triggering the application formed a complex and embodied maneuver that would crescendo into laughter or frustration as multiple attempts were almost always required. When the wireless module flashed green to indicate connection, we all heaved a sigh of relief, as the Dustbox had become central to a social moment that required it to "behave" as promised. Before we left the monitoring site, we would use our online tool to see if readings were within expected range—checking (in addition to being connected), that the devices were communicating sensible data.

Participants often wanted to learn about the levels of $PM_{2.5}$ in a particular part of the neighborhood, and despite the Dustboxes utilizing widespread infrastructures such as power and Wi-Fi, sites of intense attachment often lacked one or both of these connections. In response, we set up new, contingent modes of connectivity with batteries and Wi-Fi using wireless 3G/4G routers contained in DIY weather shelters, but these infrastructures required much more intensive upkeep, as participants had to charge their batteries every few days to stay connected. The chunks of data collected reflected how this tedious task of Dustbox maintenance slotted into their everyday lives. Some sites were completely inaccessible, as no solution could be provided in situations where neither power nor Wi-Fi were present. Connectivity, both in terms of power and Wi-Fi networks, was an extended negotiation with these middle spaces and infrastructures, where considerable reworking and shuffling around of devices and connections was required in order to make the Dustboxes operational. Negotiating the siting of the devices in relation to environments became part of the work of building the Dustbox technology. As de Laet and Mol's (2000) Zimbabwe bush pump case deftly illustrates, what constitutes a "working" technology is a relational question, and here workarounds are shown to be interleaved across technical, material and political registers. Connectivity itself was less a continual condition of streaming, and more an uneven, and contingent terrain, where sensors switched on and off, generating patchy data sets that variously monitored air quality as well as made a record of the conditions of their viability.

Workaround 2: Sensors and Electrical Ecologies

Sensors, often in the form of Internet of Things, are the distributed digital technologies meant to monitor environments and gather data for actuating responses and enhanced urban governance. Yet sensors are likely to require testing, fixing and shifting in order to keep them in an operational state. In typical smart city discourse and practice, this work is obscured, since urban sensing configurations are often analyzed as monolithic and automated systems. Citizen sensing practices and infrastructures offer a much different rendering of breakdowns as technologies are settling into form. Here, breakdowns began to emerge as we encountered the instabilities of Dustbox devices and their ad-hoc infrastructuring over time and in use. Workarounds performed through maintenance and repair were occasions for collective politics by collaborating with participants to keep the system going, where working Dustboxes meant re-articulating infrastructures in order to achieve the shared goal of collecting a corpus of data about Deptford air.

As the physical Dustbox device does not include a built-in LED display but instead require using the Airsift platform, the project team took responsibility to ensure that devices were still connected and sending data. When a device was given out to a participant, we assigned it a codename (for the purposes of anonymity) and listed it on our office whiteboard, noting whether it was installed and running ("up") or not yet enrolled onto the network ("down"). At the beginning of the project we had yet to discover what would be the (in)stabilities of the devices, and soon learned that some installed devices could often go offline, necessitating regular checks for connectivity. This sedimented into a weekly process, where we would review the data readings of each Dustbox. When we saw a device was down, we contacted participants via email, asking them to follow a set of troubleshooting instructions to shut down the device and re-activate the wireless module. Turning devices off and on again is an initial step in diagnostic work, yet has also become a cliché, an acknowledgement of the complexity and contingency of keeping even mundane technologies aligned.

At times, device resets restored connectivity, as they remade the relationships between database structures and the networked calls that activate programs in the network architecture—reconnecting with software that is located in the cloud to save power and memory space on the devices. More often than not, Dustbox breakdowns occasioned visits to monitoring sites where repair work would unfold collaboratively with participants (much like the setup process). Given the ad-hoc infrastructuring in which Dustboxes were embedded, conversations with participants began by establishing whether anything had changed with the wireless or power configurations. In semi-public sites, the patterns of breakdown often reflected the rhythms of life unfolding in that space. The Dustbox located at a church went off almost every Sunday morning, as the extension lead was repurposed to vacuum the carpet. In other cases, participants had migrated to new Internet Service Providers (ISP), and conversations with participants drew out the realization that Dustboxes were attempting to connect to a wireless network that no longer existed. After establishing that the infrastructures of wireless and electricity put in place previously were still running, our focus would turn to the device itself, as our second example illustrates.

[Insert Figure 2 here: Troubleshooting a Dustbox plug. Citizen Sense, 2017]

The Dustbox in Figure 2 belonged to an experienced community organizer who has led community initiatives and political participation for many years—including those making space for residents' participation in larger regeneration schemes. Regarding London's high levels of air pollution an outrage, he wanted to understand the role community gardens might play in mitigating pollution. During a visit to the community garden that he tended—a place-in-the-making, replete with handcrafted structures and visible traces of more-than-human inhabitants—we could trace Wi-Fi networks as they crossed the site, but couldn't secure access to any of them. When no connectivity workaround could be found, he set his Dustbox up on the balcony of his home. During our visit he explained that his aged (yet carefully preserved) washing machine had been regularly causing power outages. He had already performed some basic troubleshooting—establishing that power was reaching the device by looking at the fan and LEDs on the wireless module inside the casing. He drew our attention to the Dustbox's USB plug, which was a sealed unit that he had not been able to access for testing. Sure enough, swapping over to a new plug started the Dustbox working again. With this failure, Dustbox USB plugs—a highly mundane and stabilized technology—became a suspect element of the infrastructure. In the process, we found that keeping the sensor running was an extended arrangement negotiated with other electrical and electronic appliances, where plugs and circuit breakers, washing machines and recycled monitors, lined up along with air quality sensors to become part of the moving electrical ecology of people's homes and balconies.

But more than that, these visits were also occasions for conversations about breakdowns in urban life more generally. Between participants and researchers, questions and concerns about changing air quality in relation to urban events were half-formed and articulated. Participants narrated what pollution events had been noted in recent weeks, or what traffic accidents had caused intolerable tailbacks and idling. The monitoring network came into these conversations too—what was the data showing, what might it pick up, how did this site relate to others across the two wards? On the balcony, after replacing the blue plug, these expanded into speculation and rumination about the future of "smart" technologies as they sedimented into the fabric of everyday life. These most mundane workarounds offered occasions where participants articulated perceptual and affective registers of citizen sensing (Prichard and Gabrys 2016). Sensors, in this way, were less streamlined technologies and more points of attachment and negotiation, where repair and workarounds enabled the ongoing functioning of devices for gathering data, and where breakdown and inattention could as easily lead to their failure.

Workaround 3: Data and Urban Projects

Data is the integral component to smart cities, where sensor-based and online data, made interoperable, are meant to enhance the intelligence of urban systems. Yet the collection, flow and use of data generates new relations and blockages that are productive of distinct urban processes. Here, participants sought to gather data in order to inform urban politics in the form of community projects and campaigns—a use of data that deviates from seamless logic of smart cities and their development, since here data was meant to challenge the very process of urban development (cf. Shelton and Lodato 2019). The formation of citizen data became a process replete with workarounds, from the streaming of data to the use of data in urban projects.

Dustboxes were not only "broken" when they stopped producing readings in our database. Another perspective onto the (mal)functioning of Dustboxes came from looking at the data as visualized on our Airsift web tool. We were confused when devices that had been down during one check went back up without intervention. When we plotted time-series graphs of the data, we saw small gaps where data had not been recorded. Since the value of real-time sensing can emerge in relation to fine granularity and continuous flow, our missing data was noise that required a "normalizing" repair. At one time, all the devices had experienced the same breakdown, implying a system error. Looking in detail at the database structure we discovered that the dataset had grown too large, and readings that were being streamed over Wi-Fi from the distributed monitors were no longer consistently being recorded. Given the big data ambitions of smart city infrastructures—where gaps in the data are meant to be offset by the sheer volume of data—we felt some irony that the size of our small test data was creating a meltdown in our database. A series of database workarounds were required, and we took measures to increase its size to accommodate the accumulation and analysis of more data.

[Insert Figure 3 here: A time-series graph of one Dustbox showing gaps in the data, and the scaling issue with shifted baseline. Citizen Sense, 2017]

Our ways of understanding Dustboxes through the online interface were further destabilized when a new category of error emerged. As shown in Figure 3, in the process of plotting time-series line graphs of the sensor data, we noticed that the baseline levels of several Dustboxes had suddenly and dramatically risen. We were uncertain about the cause of the problem: Possible fluctuations in voltage caused by issues with the power supply? The failure of a component on our custom circuit board? A malfunction of the sensor? Practices of noticing data outside the expected range were an important way in which infrastructural breakdowns were detected.

Dustboxes are indicative monitors, intended to highlight patterns of environmental change, rather than generate precise numerical quantifications of $PM_{2.5}$ levels. Additionally, the collection of Dustbox particulate matter data has been organized around processes of emergent inquiry and political concerns such as local policy making or the use of green spaces, rather than reading environmental data against legal thresholds, where the quantification of data within particular ranges is what matters. Yet the validity and accuracy of data as meaningful patterns about particular environments was still central to our project, and to participants' ability to make claims about the characteristics of certain places and the quality of the air. As such, a "reasonable" range of readings still emerges as an indication that a sensor is working, where errant readings or patterns reflect a likely breakdown somewhere in the system.

The moving baseline identified in Figure 3—what we termed a scaling issue—suggested something serious was wrong. When a Dustbox exhibited this behavior, it was brought back to our office for further testing, and when it became evident that the hardware had malfunctioned, a replacement device was deployed in its place. This was a "normalizing" measure in Ureta's terms (2014), where our response—based on substitution rather than repair—was oriented towards conforming to norms about data validity. The reconfiguration or removal of devices is organized here so that some "normals" remain in place, but these practices can also contribute to open-ended processes of configuring and reconfiguring devices in relation to data to be analyzed and used as evidence.

The online database and Airsift web tool were developed in order to enable citizen participants in our air quality studies to be able to view and visualize their data, in ways that draw from techniques in atmospheric science. In citizen science discourses, data collection practices are often foregrounded, while the messy and challenging aspects of analyzing and operationalizing environmental data are not attended to in detail. The increasing accessibility of low-cost sensors is not enough to democratize environmental knowledge, as citizens need to be able to work with, and on data in ways that can be "just good enough" to interface with other actors including regulatory or governing bodies (Gabrys et al. 2016). The Airsift tool on one level could be seen to develop the capacities for citizen data analysis by instantiating and maintaining a series of workarounds, following Alter's definition—a set of improvisational practices that adapt existing systems in order to achieve particular goals (2014). But as the "goals" for collecting sensor data are here a shifting if even open-ended set of inquiries, workarounds proliferate not just in collecting, storing and analyzing data, but also in attending to the formations of evidence that are still ongoing as participants now work through their data sets and consider how to operationalize data in neighborhood plans and community projects, in air quality campaigns and in contestations over new development proposals.

Conclusion

The smart city is an inevitably incomplete project that—like previous instantiations of technologically driven urban planning such as the "modern infrastructural ideal" (Graham and Marvin 2001)—can never reach full closure. The indeterminacy, complexity and contingency of breakdown in the city will always exceed the systems in place to anticipate or react to disorder. Likewise, breakdowns, repairs and workarounds are moments that disturb the rather settled positions imagined for citizens in visions and instantiations of the smart city. In this article, we have staged a more deliberate encounter with these occasions and conditions of breakdown by accounting for the workarounds that proliferated in setting up urban sensing technologies with a community in Southeast London. The conditions of installing, operating, maintaining and repairing sensing technologies were not ones of simply achieving "fixes." Instead, as we suggest here, multiple and intersecting urban processes that are often unaccounted for in monolithic smart city plans come to the fore, where overlapping infrastructures and access to resources, concerns about urban pollution along with urban development, and attempts to operate and work around technologies are more evident.

At the same time, the literature on workarounds has often been used to accentuate user agency in the co-production of technology as it is taken up in use—a proposition that we suggest becomes more complex in settings where computation is distributed and operationalized across environments. Digital technologies such as those that are considered to be the key components of smart cities, including networks, sensors and data, materialize much differently when approached through their installation and negotiation in everyday settings. Rather than approach the workarounds that arose in these contexts as attempts to arrive at the normalization of technologies, however, we suggest that technologies have the potential to become more open in their development, imagining, installation, running, application and use. In this way, what registers as a technology would have to account for the extended environments in which it operates and on which it relies. By working around these urban sensing technologies, we suggest it is possible to rework the contours of what counts as the technological by not foreclosing technological objects, as is so often the case with smart cities. Such an approach involves attending to the sensing practices, such as workarounds, that are articulated through sensing technologies.

If, as Shelton et al. suggest, "smart city projects help produce new ways of thinking about different urban spaces, as well as how these spaces are transformed as a result of such practices" (2015, 18), then we suggest these ad hoc, contingent and open-ended processes of urban sensing practices and technologies are a crucial part of these transformations. Even more than transforming spaces, however, these workarounds point to the ways in which smart city projects might themselves be transformed in order to attend more fully to the creation of technologies that are aligned with the lived experiences of urban inhabitants. Technologies do not land fully formed in urban spaces and processes. Instead, they form along with and in relation to the cities that we are making in our day-to-day encounters. Rather than suggesting a "grassroots" alternative to the same old smart city vision, we suggest that computational urbanisms fundamentally shift through this more open-ended approach to cities and technologies. The shifting and gradated dynamics of breaking down and working around that emerge in citizen sensing practices point to different registers of urban encounters that are entangled with struggles for housing, concerns about environmental pollution and attempts to create a more livable and just city. Through these encounters, the scripted automaticity of smart technologies is subverted as citizens knit together technical architectures with urban practices and affective concerns in ways that work with and around multiple processes of malfunction to realize more relevant, democratic and collective urban-technical engagements.

The workaround, however, is not a salvation discourse, nor is it the final solution to our urban dilemmas. In this article we hold the politics of participatory workarounds in tension with the circumscribed citizen roles envisaged in smart city systems that "route around the user" (Dourish 2016, 35) in addressing urban problems. Being able to work around is vital, and requires urban infrastructures to allow design and repair to intermingle, so that even "normalized" systems can unfold in their buggy realities in relation to environments. Yet, the politics of workarounds are not always so productive, as practices can become calcified and hardened where workarounds fill the void of collapsing structures. Workarounds, it might also be argued, have become the baseline condition for living in conditions of austerity. Urban services, park services, and wider systems such as health services all rely on the continual strategy of inventing new practices, collectives and infrastructures in order to get by. Rather then preserve the goal-driven qualities of the workaround, our analysis has shown workarounds to be different practices through which to reconsider the more radical transformations of "normalized" systems, as well as openings into new types of collective and contingent computational urbanisms that extend beyond the smart city.

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Notes

[1] The Mayor of London provides "Air Quality Statistics and Research" to capture the scale and scope of the air quality problem in London. The reference to over 9,000 early deaths due to air pollution every year draws on the report, Heather Walton, David Dajnak, Sean Beevers, Martin Williams, Paul Watkiss and Alistair Hunt, "Understanding the Health Impacts of Air Pollution in London," King's College London (14 July 2015), produced for Transport for London and the Greater London Authority, https://www.london.gov.uk/sites/default/files/hiainlondon_kingsreport_14072015_final.pdf.

References

Akrich, Madeleine. 1992. "The De-scription of Technical Objects." In *Shaping Technology/Building Society: Studies in Sociotechnical Change*, edited by Wiebe E. Bijker and John Law, 205-224. Cambridge, MA: MIT Press.

Alter, Steven. 2014. "Theory of Workarounds." *Communications of the Association for Information Systems* 34 (55): 1–29.

Amin, Ash. 2016. "On Urban Failure." *Social Research: An International Quarterly* 83 (3): 777-798.

Barns, Sarah, Ellie Cosgrave, Michele Acuto and Donald McNeill. 2017. "Digital Infrastructures and Urban Governance." *Urban Policy and Research* 35 (1): 20-31.

Bennett, Jane. 2005. "The Agency of Assemblages and the North American Blackout." *Public Culture* 17 (3): 445–65.

Bulkeley, Harriet, Pauline M McGuirk and Robyn Dowling. 2016. "Making a Smart City for the Smart Grid? The Urban Material Politics of Actualising Smart Electricity Networks." *Environment and Planning A: Economy and Space* 48 (9): 1709-1726.

Collins Dictionary (n.d.). "Workaround." https://www.collinsdictionary.com/dictionary/english/workaround (accessed 17 July 2017).

Datta, Ayona. 2015. "New Urban Utopias of Postcolonial India: 'Entrepreneurial Urbanization' in Dholera Smart City, Gujarat." *Dialogues in Human Geography* 5 (1): 3–22.

De Laet, Marianne and Annemarie Mol. 2000. "The Zimbabwe Bush Pump: Mechanics of a Fluid Technology." *Social Studies of Science* 30 (2): 225–263.

De Lange, Michiel and Martijn de Waal, eds. 2019. *The Hackable City: Digital Media and Collaborative City-Making in the Network Society.* Singapore: Springer.

Dourish, Paul. 2016. "The Internet of Urban Things." In *Code and the City*, edited by

Rob Kitchin and Sung-Yueh Perng, 27-48. Abingdon UK: Routledge.

Forlano, Laura. 2016. "Decentering the Human in the Design of Collaborative Cities." *DesignIssues* 32 (3): 42-54.

Forlano, Laura and Anijo Mathew. 2014. "From Design Fiction to Design Friction: Speculative and Participatory Design of Values-Embedded Urban Technology." *Journal of Urban Technology* 21 (4): 7-24.

Gabrys, Jennifer. 2014. "Programming Environments: Environmentality and Citizen Sensing in the Smart City." *Environment and Planning D* 32 (1): 30–48.

Gabrys, Jennifer. 2016a. *Program Earth: Environmental Sensing Technology and the Making of a Computational Planet*. Minneapolis: University of Minnesota Press.

Gabrys, Jennifer. 2016b. "Re-Thingifying the Internet of Things." In *Sustainable Media: Critical Approaches to Media and Environment*, edited by Nicole Starosielski and Janet Walker. New York: Routledge.

Gabrys, Jennifer, Helen Pritchard and Benjamin Barratt. 2016. "Just Good Enough Data: Figuring Data Citizenships through Air Pollution Sensing and Data Stories." *Big Data & Society* 3 (2): 1–14.

Graham, Stephen. 2010. "When Infrastructures Fail." In *Disrupted Cities: When Infrastructure Fails*, edited by Stephen Graham, 1-26. New York: Routledge.

Graham, Stephen and Simon Marvin. 2001. *Splintering Urbanism*. New York: Routledge.

Grigg, Jonathan. 2017. "Where Do Inhaled Fossil Fuel-Derived Particles Go? *American Journal of Respiratory and Critical Care Medicine* 196 (7): 804-806.

Henke, Christopher R. 1999. "The Mechanics of Workplace Order: Toward a Sociology of Repair." *Berkeley Journal of Sociology* 44: 55–81.

Hollands, Robert G. 2008. "Will the Real Smart City Please Stand Up? Intelligent, Progressive or Entrepreneurial? *City* 12 (3): 303–20.

Hollands, Robert G. 2015. "Critical Interventions into the Corporate Smart City." *Cambridge Journal of Regions, Economy and Society* 8 (1): 61–77.

Howe, Cymene, Jessica Lockrem, Hannah Appel, Edward Hackett, Dominic Boyer, Randal Hall, Matthew Schneider-Mayerson, Albert Pope, Akhil Gupta, Elizabeth Rodwell, Andrea Ballestero, Trevor Durbin, Farès el-Dahdah, Elizabeth Long, and Cyrus Mody. 2016. "Paradoxical Infrastructures: Ruins, Retrofit, and Risk." *Science, Technology, & Human Values* 41 (3): 547–565.

Hoyng, Rolien. 2016. "From Infrastructural Breakdown to Data Vandalism." *Television & New Media* 17 (5): 397–415.

JafariNaimi, Nassim. 2018. “Our Bodies in the Trolley’s Path, or Why Self-Driving Cars Must *Not* Be Programmed to Kill.” *Science, Technology, & Human Values* 43 (2): 302-323.

Le Dantec, Christopher and Carl DiSalvo. 2013. “Infrastructuring and the Formation of Publics in Participatory Design.” *Social Studies of Science* 42 (2): 241–264.

Luque-Ayala, Andrés and Simon Marvin. 2016. “The Maintenance of Urban Circulation: An Operational Logic of Infrastructural Control.” *Environment and Planning D: Society and Space* 34 (2): 191–208.

Mackenzie, Adrian. 2010. *Wirelessness: Radical Empiricism in Network Cultures*. Cambridge, MA: MIT Press.

Merriam-Webster Dictionary (n.d.). “Work-Around.” https://www.merriam-webster.com/dictionary/work–around (accessed 17 July 2017).

Noble, Safiya Umoja. 2016. “A Future for Intersectional Black Feminist Technology Studies.” *Scholar & Feminist Online* 13 (3): 1-8.

Perng, Sung-Yueh. 2019. “Promises, Practices and Problems of Collaborative Infrastructuring: The Case of Dublin City Council (DCC) Beta and Code for Ireland." In *Creating Smart Cities*, edited by Claudio Coletta, Leighton Evans, Liam Heaphy, Rob Kitchin, 155-168. London: Routledge.

Philip, Kavita, Lily Irani, and Paul Dourish. 2012. “Postcolonial Computing: A Tactical Survey.” *Science, Technology, & Human Values* 37 (1): 3 – 29.

Pollock, Neil. 2005. “When Is a Work-Around? Conflict and Negotiation in Computer Systems Development.” *Science, Technology & Human Values* 30 (4): 496–514.

Pritchard, Helen and Jennifer Gabrys. 2016. “From Citizen Sensing to Collective Monitoring: Working through the Perceptive and Affective Problematics of Environmental Pollution.” *GeoHumanities* 2 (2): 354-371.

Pritchard, Helen, Jennifer Gabrys and Lara Houston. 2018. “Re-Calibrating DIY: Testing Participation across Digital Sensors, Fry Pans and Environmental Media.” *New Media and Society* 20 (12): 4533-4552.

Rai, Amit S. 2019. *Jugaad Time: Ecologies of Everyday Hacking in India.* Durham, NC: Duke University Press. 2019

Rose, Gillian. 2016. “Posthuman Agency in the Digitally Mediated City: Exteriorization, Individuation, Reinvention.” *Annals of the American Association of Geographers* 107 (4): 779–793.

Shelton, Taylor and Thomas Lodato. 2019. “Actually Existing Smart Citizens.” *City* online first, doi: 10.1080/13604813.2019.1575115.

Shelton, Taylor, Matthew Zook and Alan Wiig. 2015. “The ‘Actually Existing Smart City.” *Cambridge Journal of Regions, Economy and Society* 8 (1): 13–25.

Simone, AbdouMaliq. 2004. “People as Infrastructure: Intersecting Fragments in Johannesburg.” *Public Culture* 16 (3): 407–29.

Simone, AbdouMaliq and Edgar Pieterse. 2017. *New Urban Worlds: Inhabiting Dissonant Times*. Cambridge, UK: Polity Press.

Söderström, Ola, Till Paasche and Francisco Klauser. 2014. “Smart Cities as Corporate Storytelling.” *City* 18 (3): 307–320.

Star, Susan Leigh 1999. “The Ethnography of Infrastructure.” *American Behavioral Scientist* 43 (3): 377–391.

Star, Susan Leigh and Geoffrey C. Bowker. 2002. “How to Infrastructure.” In: *The Handbook of New Media*, edited by Leah A. Lievrouw and Sonia Livingstone, 230-245. London: SAGE.

Steinhardt, Stephanie. 2016. “Breaking Down While Building Up: Design and Decline in Emerging Infrastructures.” *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*: 2198–2208.

Suchman, Lucy. 2002. “Practice-Based Design of Information Systems: Notes from the Hyperdeveloped World.” *The Information Society* 18 (2): 139–44.

Tironi, Martín and Matías Valderrama. 2018. “Unpacking a Citizen Self-Tracking Device: Smartness and Idiocy in the Accumulation of Cycling Mobility Data.” *Environment and Planning D: Society and Space* 36 (2): 294–312.

Townsend, Anthony M. 2013 *Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia.* New York: W. W. Norton & Company.

Ureta, Sebastián. 2014. “Normalizing Transantiago: On the Challenges (and Limits) of Repairing Infrastructures.” *Social Studies of Science* 44 (3): 368–392.

Vanolo, Alberto. 2016. “Is There Anybody out There? The Place and Role of Citizens in Tomorrow’s Smart Cities.” *Futures* 82: 26–36.

Wilson, Matthew. 2015. “Flashing Lights in the Quantified Self-City-Nation.” *Regional Studies, Regional Science* 2 (1): 39–42.

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