Beyond the Prototype: Maintenance, Collective Responsibility, and Public IoT

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ABSTRACT
This paper describes the reparative Internet of Things (Riot), a project investigating the role of IoT devices in maintaining public resource accessibility. Drawing on a mix of interviews, technology development, and ethnographic engagements, we explore the distribution and stratification of menstrual hygiene resources in Seattle, WA. We redesigned menstrual product dispensers placed in public settings by outfitting them with networked sensor inserts to make them easier to stock by custodial staff and easier to access by members of the public. We use this case to show how such newly connected devices structure experiences of hygiene access and help expose important consequences of integrating those devices into the socioeconomic logics and infrastructure of public life. Our interventions further examine the role of public IoT devices once they pass the proof-of-concept stage, revealing their capacity to cultivate and maintain collective responsibility.

Author Keywords
Internet of Things; menstruation; maintenance; public life.

ACM Classification Keywords
K.4.0 Computers in Society: general.

INTRODUCTION
Over the last decade, design researchers have increasingly helped articulate and imagine the possibility of a civic internet of things (IoT) — connected devices distributed throughout a city that contribute to public engagement, governance, and coordinated action. From pollution sensing [19] to foraging [12], scholars have used IoT devices to instrument urban landscapes, giving new momentum to the phrase "smart cities." Less visible in this body of research, however, is a thorough accounting for design's role in what repair studies scholar Lara Houston has called the "timeliness" of such infrastructures [25], the ways computational remainders, fragments, and breakdowns may not be contained in the tidier stories of technology prototyping that we circulate as design researchers. This paper investigates this work to maintain public IoT around the important but under-examined (and often stigmatized) topic of menstrual hygiene resource accessibility.

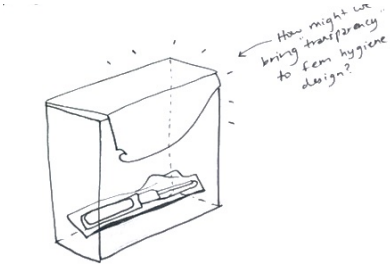

Figure 1: Rethinking Public IoT with Riot, networked sensor inserts that make menstrual product dispensers easier to stock and access.

Over the past few years, shifting government policies have sparked a flurry of interest in topic of menstruation — from local, state and federal policy initiatives calling for free and ready access to hygiene products to the formation of over a dozen startups with tens of millions in venture capital backing [46]. Alongside these efforts exist longer running programs that install and maintain dispensers in public restrooms and the efforts of activists who collect and re-distribute menstrual resources to people unable to afford them [7].

Responding to and building on recent activism, including the growing body of design work on menstruation [15,34,41] and reproductive health [1,1,3,11], this paper describes a process of outfitting restroom menstrual product dispensers with networked sensors, a project we call Riot—or, the reparative Internet of Things. The sensors collect data on product levels in the dispenser and publically share that information on an online map so that the machines might be more easily stocked by maintenance and custodial staff and accessed by members of the public. Further, we discuss how the advocacy organization we worked with to design Riot used data from the dispensers to support particular legislation aimed at promoting "menstrual equity" statewide. To inform this design process, we drew on interviews and field visits with facilities organizations across Seattle, WA, a process that unfolded over three years, from 2015-2018.

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With this case, we not only contribute a rich case study of IoT development around the stigmatized topic of menstrual health, but also begin to explore what it takes to move an activist IoT project beyond the prototyping stage — as well as what is learned as a result. Reflecting our design work beyond this specific case, our paper makes three key contributions to research literatures on IoT, maintenance, and design activism. First, we use Riot to highlight the forms of maintenance both expected and made possible through IoT deployments. Our deployment, for example, revealed political stakes of the municipal electric power grid as well as subtle class hierarchies around maintenance that we didn't see through interviews. Second, we surface collective responsibility as a core concern of IoT development, shaping both our ways of *doing* design research (in groups rather than as individual investigators and stakeholders) as well as our ways of *conceptualizing* it (framing the maintenance of menstrual resources as a collective rather than an individual burden). Lastly, we explore how IoT may work not only as a proof-of-concept (a solution to the defined problem of public resource distribution); it may also create spaces and opportunities to reframe the very problem of access such interventions are meant to address.

LITERATURE REVIEW

The ideas and literature that inform our project sit at the nexus of three central bodies of work. First is the constellation of design scholarship that examines the incorporation of IoT devices and infrastructures into the fabric of public life. A range of recent work explores the public nature of IoT designed for civic engagement [2,5,13]. Carl DiSalvo and Tom Jenkins, for example, adopt feminist scholars J.K. Gibson-Graham's notion of "communing" to challenge the narrow positioning of IoT and other sensing devices within diverse economies such as foraging [12]. Instead of reject sensing devices around communing, they write, "what is needed is careful attention to how they configure experience and agency, and perhaps, imagine ways they might in fact contribute to an even richer understanding of nonhumans in diverse economies." [ibid:55]

In a second body of work, researchers have highlighted activism for the here and now of technology development. For instance, Susan Leigh Star famously highlighted the concept of *invisible work* after doing what she terms "feminist activist work," unpaid housework that puts laborers, often women, into the role of an "unseeable" domestic servant [42]. For HCI, this concept draws attention to expropriations and power discrepancies that design researchers may help expose [28], resonating with early participatory design orientations focusing on re-centering devalued forms of labor practice in the face of authority and power differentials [14]. Embodying this commitment, designers and artists like Sputniko! (also known as Hiromi Ozaki) have begun examining the technological domain around menstruation. In the Menstruation Machine, Sputniko! equipped a wearable device with a blood dispensing mechanism and lower-abdomen stimulating electrodes to simulate select physical symptoms of menstruation for those with a desire to experience them [34]. Within the HCI community, Epstein et al. offered an analysis of the motivations and methods behind the use of period tracking applications and put forth several key design considerations, from improving the app's accuracy to avoiding gender stereotypes within interface design [15]. Søndergaard and Hansen moved this conversation back to the realm of the speculative with PeriodShare, a connected menstrual cup that quantifies and shares menstrual data automatically, reflecting on the contemporary and near future politics of intimate forms of self-tracking [41]. Altogether these works have offered a glimpse into the range of considerations that design research on menstruation might take up—from those oriented toward the whimsical, to the sociocultural, to the practical.

Alongside these activist encounters, we look to the growing interdisciplinary field of maintenance and repair studies, an area of research and design practice given recent definition by several edited collections [9,27]. Early studies of digital maintenance include Julian Orr's [33] rich accounts of Xerox technicians and the social nature of the expertise, lessons broadened in other work by Graham and Thrift [22] and later Houston [26], Jackson [29] and Rosner and colleagues [36,37,40]. Underlying this focus on maintenance is a commitment to thinking of design as only one (widely valorized) moment within the long-term lifecycle of computational goods. As feminist scholar and former Xerox ethnographer Lucy Suchman explains, "the basic change implied by rethinking the technological object is from a view of design as the creation of discrete devices, or even networks of devices, to a view of systems development as entry into the networks of working relations – including both contests and alliances – that make technical systems possible" [43:2]. Important for our work, Jérôme Denis and David Pontille recently enumerate the regimes of practice that make up repair, including mending, repairing, fixing, restoring, preserving, cleaning, recycling, and up-keeping. Turning to the regime of things, they write, "maintenance enacts what we might think of as two-sided objects, fragile in the eyes and hands of maintainers, reliable in the eyes of users" [10]. It is this particular argument that we take up in the work that follows to consider the maintenance of IoT infrastructure.

OUR PROJECT

Riot began as a part of a wider investigation of public IoT, the sorts of connected digital systems and modes of interaction that might support public engagement. Our early work included design investigations of people's movement through public space and modes of lighting along such paths [17,38,39]. As our work continued, we quickly turned our attention to restrooms—spaces integral to participation

in public life, yet often overlooked in popular depictions of the internet of things, public or otherwise.

Methodology

To investigate the role of public IoT in menstrual resource accessibility we deploy feminist approaches to situated inquiry [23,31] and modes of interventionist research tied to traditions of participatory [6,30] and speculative design [32,35]. The first acknowledges the ways in which investigators' political and social conditions shape their ways of knowing. Following this line of inquiry, we took up approaches of ethnographic observation and interviewing to investigate existing forms of menstrual access across the city. The second uses engagements of collaborative design in order to build encounters both speculative and real at the same time. In this case, we grasp for a vision of feminist internet of things, while offering repairs to the systems already in place.

Our project uses the above investigative tools to draw out the social conditions that define access to public resources, while also contending with those circumstances through design encounters. In particular, we adopt elements of participatory inquiry to explore two core questions: (1) *What does access to menstrual resources mean to those maintaining public restrooms?* (2) *What forms of menstrual accessibility could IoT encourage or engender?*

Design Process

Our design process included two main phases: (1) ethnographic fieldwork within sites of menstrual resource distribution, and (2) design and ethnographic engagements around our Riot intervention.

To understand ongoing activity in Seattle public restrooms, for example, we conducted ethnographic field visits during the first phase across:

1. *Seattle public parks & recreational facilities' restrooms,* spaces meant for public use and open without a fee or an implicit expectation of consumer exchange. Seattle Parks and Recreation is responsible for the repair and maintenance of basic services at the city's parks and community centers. This work involves the day-to-day upkeep of the park facilities and grounds maintenance, including cleaning restrooms, removing litter, clearing trails, landscaping, painting over graffiti, and making building repairs. The organization is responsible for a 6,414-acre park system, including 485 parks and 120 miles of trails (occupying 12% of the city's land area). Those involved in this work include people in managerial positions such as district supervisors and lead crew workers, as well as grounds crew and administrative staff.
2. *Our home institution's facilities organization,* a group made up of 10 departments (e.g. building services, maintenance and construction, and transportation), each serving the university community by performing repairs, maintenance, and cleaning for campus buildings and grounds. The work of the staff involves care for over 1,300 restrooms and maintenance of "643 acres of grounds, 22 miles of roads and pathways, and services including power, HVAC, cleaning, waste, maintenance and construction for more than 15 million square feet" [49]. Among those on staff are supervisors who oversee the various departments, building managers who supervise the care of either high traffic centers or several smaller buildings, custodians who manage the day-to-day cleaning and maintenance of buildings within a certain area, and office personnel who administer service requests and address internal human resource needs.
3. *The Womxn's Action Commission (WAC)*an organization that has worked since the 1960s to promote gender equity on the university campus and amongst the broader Seattle community by hosting events and advocating for institutional and regional policy shifts. In its current form, the WAC takes an intersectional approach to justice, seeking to "[recognize] and [affirm] the multiple and intersecting identities held by woman-identified and/or female-identified-at-birth constituents" [50]. Contemporary programs of the WAC include a yearly production of the ___ monologues (a challenge to the cisgender focus of the widely known The Vagina Monologues), workshops and panel discussions on Gender in STEM, Queer Narratives, Disability Justice, health programs such as a Check Your Boobies Party, and a Queer and Trans Artists of Color series. In addition to these events, each year the group selects a political issue or cause to pursue with the support of their staff and interns. During the 2016-17 school year, they elected to support menstrual equity through both student government proposals and state legislation.

By engaging these sites, we began to deepen our understanding of menstrual resource accessibility across the Seattle community writ large (from maintenance to advocacy), while also forming partnerships across various concerns, contingencies, and ideological commitments.

Data Collection

Our design research methods draw on ethnographic fieldwork and collaborations spanning a three-year period (from the winter of 2015 to the winter of 2018), including a wide range of interviews and observations with custodial professionals (at parks, community centers, and homeless shelters) and members of activist and advocacy organizations such as the Womxn's Action Commission (WAC). Data included:

- *Ethnographic fieldnotes* based on first-hand accounts produced by Sarah Fox while she worked as a custodian and a front desk volunteer at two hygiene centers (one specifically for women and children, and the other all gender)—spaces offering free access to restrooms, showers, and laundry—for a total of 6 months. There we began to learn about the limitations of access throughout the city. For instance, though day centers offered menstrual products to visitors, they were closed in the

evenings and on weekends. This meant clients needed to stockpile products or go without for times when centers were inaccessible. We also learned about individual preferences when it came to particular products, noting that many gravitated toward pads and high absorbency tampons in order to avoid regular changing when without easy access to restrooms.

We also collected fieldnotes from observations with staff of the Seattle public parks and recreational facilities, as well as our home institution's facilities organization, including visiting 46 restrooms. At each restroom site we documented the sorts of objects, resources, and infrastructure we found inside. Often these spaces included paper towel dispensers, hand dryers, sinks, mirrors, toilets, toilet paper rolls, condom dispensers, and trashcans, but rarely did we find operational menstrual product dispensers. We charted this initial fieldwork on a city map, beginning to note the spatial relationships to access (the online map of Riot later borrowed from this form).

- *Interview data* collected across each of our field sites. Specifically, building on our public restroom facilities observations, we conducted 15 interviews with members of the municipal maintenance staff, learning about the processes and political structures that guide their labor and define public hygiene accessibility. We also interviewed 13 organizers of local activist and nonprofit organizations that collect and distribute pads, tampons, and other menstrual resources. Additionally, we interviewed representatives of the largest manufacturer of menstrual product dispensers in the country, Congress members and staff of state and US governments, and social entrepreneurs focusing on promoting change to the treatment of menstrual resource accessibility through enterprise-based initiatives.

Data analysis

We thematically analyzed our data drawing on inductive techniques of contextualized grounded theory [8] to highlight the forms of menstrual accessibility enabled within public spaces and the role IoT might play in them. During weekly meetings, we reviewed reflective memos that we developed based on our field notes and other empirical materials. Across later rounds of analysis, we iteratively revisited and refined our interpretations to build emergent themes such as collective responsibility, as outlined in the sections below.

Riot

The Riot insert is a lightweight, networked sensor outfitted for commonplace menstrual hygiene dispensers. The device counts the number of menstrual products (e.g. tampons and pads) inside the dispensers and stores and shares this information for both maintenance staff and public viewing. The insert comprises two distance sensors—a low-cost microcontroller with Wi-Fi capability and a simple, portable power bank—all housed in a custom cardboard box fitted to the dimensions of prominent dispenser models.

PHASE I: SETTING THE GROUNDWORK FOR RIOT

To help set the stage for our discussion of Riot, we begin by introducing the alliances we built with members of WAC and other key organizations developed to collectively direct the project's outcomes. We recognize that in concentrating on our organizational partnerships, we lose out on providing detail on 'users' of the restrooms (a focus we take up in other accounts [16]), yet we believe this focus is worthwhile for two key reasons. The first has to do with the nature of our collaborative process, which involved not only enrolling individual stakeholders (as is common in other prevailing design methods [18]), but also understanding what is required for producing and maintaining those connections. We sought to examine the integral role that policy, media, and organizational structures play in the development and, crucially, the sustainability of our collective work. The second reason for emphasizing our partnerships has to do with the recognition that despite developing novel IoT infrastructure, like many others digital designs, the broader initiative was not wholly new. Indeed, we built on many existing menstrual advocacy efforts, as outlined below. Our project thus required charting the WAC's evolution and the emergence of central advocacy concerns over the years leading up to our interventions.

Public Restrooms Maintenance

We began our project with site visits to public parks and community centers where we later conducted interviews and observations with members of the municipal maintenance staff, learning about the processes and political structures that guide their labor and define public hygiene accessibility. In one interview with custodial staff, an administrator to a district head named Debra described how the city introduced soap to restrooms in municipal parks, a relatively new addition from the 1990s. It was one "very adamant" resident, she told us, who "gathered the forces, communicated to all layers of government," and convinced those at the head of the parks department to revise their policy on this form of hygiene infrastructure. Prior to this advocacy, Debra told us, soap was considered a "courtesy" and was thus left for individual area supervisors to decide if it was worth the cost and additional labor to upkeep. From a maintenance lead named Linda, we later learned that it was not just any adamant resident, it was the spouse of a city councilmember. Linda claimed he also took up the cause, advocating to his colleagues in city government who, in turn, put pressure "back down" on the department. Those who tended get their voices heard and their needs met, Linda told us, were the ones who had "time on their hands" or "know the system"—likely those already in positions of prominence, as the case of the soap illustrates.

Those unlikely to have a seat at the table were members of the city's homeless population who spent time in the parks,

and who many of the maintenance staff described as perpetrators of "vandalism," the name they gave to perceived malicious destruction or defacement of the restroom infrastructure that they were left to fix. Lead maintenance crew member Robert told us that his district had to deal with the remains of bathrooms burned to the ground in what he described as "arson." As we continued chatting, he told us that he had an idea for why this arson was happening with such frequency. He had spent time sleeping outside while deployed in the military, he said, and, "used do a lot of things to keep warm." "If this is the only paper [referring to toilet paper] you had, then this is what you burn to stay warm," he continued.

In this recollection, we saw experiences of the maintenance staff such as Robert and others resembling the circumstances of people they accused of vandalism and arson. But rather than form a sense of connection with these residents, crew members instantiated programs to limit homeless people's access to the sites—locking the restrooms in the early evening and calling the police or service workers when maintenance staff spotted people they believed to be "campers." Across the areas and districts we observed, maintenance crews took up similar approaches to deter the homeless population from spending time in public parks, with an express preference for the "good people" (middle class families or those with regular access to housing). We noticed that maintenance staff like Deborah, Linda, and Robert could sympathize with people using restrooms but ultimately couldn't see past their own assumptions about the types of inhabitances they saw as fit for these sites. Some kind of connection between the homeless lived experience and restroom maintenance seemed missing.

Seeds of an intervention

Early in our fieldwork we noticed that when discussions with city maintenance staff turned to menstrual hygiene infrastructure, maintenance staff often expressed ignorance or apathy. Most staff didn't know where someone might go to find menstrual resources, much less determine who was responsible for them. One maintenance crew member suggested that dispensers were only available at community centers, while community center staff told us they were not required to install them and thus many did not have them. Much like we observed with the councilmember-led soap dispenser campaign, the lack of institutionalized policies created uneven access across districts.

With this new understanding of the city's public restroom landscape, we gained new sensitivities to what access meant in these sites. This sensitivity involved better understanding the maintenance labor involved in sustaining the present infrastructure and the political will that would likely be needed to shift or expand it. We proceeded puzzling the question: how might we design an intervention to probe at this space, while recognizing the crucial work of those already there?

University Facilities Organization Staff

To answer this question, we turned back to our own institutional context to see what existing initiatives we might contribute to or partner with locally. Following city-wide efforts, we organized a drive out of our university lab, collecting items such as pads, tampons, and menstrual cups (often under-donated to shelters and day centers [21]), as well as other products like lotion, toothpaste, and denture cream to be donated to youth and emergency shelters in the area. As we circulated an email announcement for the drive, we were met with messages expressing support and questions on how best to contribute. In one of these emails, we were connected with a representative from our university union (representing both graduate student workers and staff) who inquired about our research and suggested we get in touch with fellow members from our home institution's facilities organization. With this introduction, we met an institution plumber who contributed to initiatives such as the implementation of lactation stations and all-gender restrooms. The plumber eventually connected us with the members of the broader university facilities organization.

Echoing our prior fieldwork with municipal facilities staff, the university custodians described a tedious process of maintaining existing menstrual infrastructure, alongside their other duties. A group of facilities managers told us about struggling to keep track of the single, unique key for each dispenser and a constant need to troubleshoot broken devices. Machines often featured signs of struggle attributed to what the managers called "vandalism where a visitor might have tried to break in after a failed attempt at buying a tampon or pad—either because they didn't have cash or they wanted to take the handful of coins inside.

Reparability here was difficult to establish. The machines held small, indispensable parts and staff had few options for their repair other than replacing coin mechanisms or installing entirely new units, which a Facilities Manager told us ran upwards of $300 for even older models. To deal with the labor and financial costs associated with keeping up the dispensers, the organization opted to divvy up access. Rather than installing the machines in every restroom, they selected a subset of buildings that would feature them (determined by "building use, traffic, and accessibility"). The staff then put in their absence a piece of paper listing the sites where dispensers were placed (not a map that might show how to navigate to them, but a text-based list). We later learned that this practice had first come under scrutiny by the WAC about two decades earlier.

Local Histories and the Womxn's Action Commission

Looking across these first two sites—the Seattle public restrooms and the university facilities organization—we found tensions played out over decades, sometimes in productive ways and other times recursively. In the early 1980s, the university facilities organization made the decisive move to remove all menstrual product dispensers

"due to vandalism and maintenance costs," the then director told the campus newspaper [44]. For almost a decade, the university community did without the dispensers. Yet, due to student pressure throughout the 1990s, maintenance crews incrementally reintroduced them, with an initial installation of 55 devices across campus.

By 1998, the Womxn's Action Commission (WAC), the main student organization concerned with women's issues, had secured more than 1,000 signatures on a petition lobbying for an additional 19 dispensers. Successful with this push, they moved on campus menstrual infrastructure once again in 2010, scrutinizing what they took to be the uneven upkeep of machines and a lack of revisions to the list meant to guide visitors to available dispensers (which purportedly had not been updated for the decade following the WAC's last effort). The then director of WAC pleaded to the university newspaper, "If you're going to have those machines, you need to fill them" [47]. Following this attention, the university facilities organization formed a committee to review the dispensers, repairing broken and jammed machines and adding a half dozen more.

Upon learning of this history, we knew that familiarizing ourselves with the WAC should be our next step. As we interviewed those currently working for the university facilities organization we found similar maintenance issues emerging again (about 6 years on from WAC's last push). For instance, a plumber detailed the ways in which the placement of machines and the rapidness of repair was unevenly distributed amongst the units of the same institution. She described services being relayed more quickly to larger, more resource-rich departments. Those departments already had dedicated maintenance staff (rather than employees covering multiple buildings, as with most) and could afford preventative infrastructural care such as checking for leaks.

It was at this point that our own building manager emailed us with the WAC's appeal for support in their latest campaign to seek permanent menstrual infrastructure through the institutional and state legislature. She suggested that we connect with the group directly, seeing productive overlaps between our design research and their aims of policy revision.

In the coming weeks we learned that the WAC planned for a suite of three legislative proposals that would guarantee residents of the area the same resources. The first proposal, introduced to the student government in the fall of 2016, codified the installation of dispensers in the newly built all gender restrooms. This bill gained quick, sweeping approval in the student senate and acknowledged the need for private spaces of menstrual management for the community's transgender and gender non-conforming members. The second piece of legislation, a measure also introduced to the student government in late fall of 2016, proposed enforcing access to menstrual products in the campus' 15 busiest buildings. The third and final measure, planned for introduction to the Washington state government during the 2018 legislative session, would propose policy requiring all public schools (from elementary to university) to stock these items. In control of their own budgets, the student government was seen by members of the WAC as providing a uniquely rapid path to institutional change (with a board of some 65s people to convince, rather than with city- or state-wide bills that would likely require bipartisan negotiation). Together, these initiatives became a part of a longer legislative trajectory that began with the hyperlocal (just a few restrooms) and moved incrementally toward broader access for more and more (expanding with each level of government).

In our first meeting with both the university facilities organization and the WAC, their political astuteness became clear as members discussed shared goals for improving menstrual accessibility and how each group might aid the other toward this end. For instance, a member of the WAC touted the press coverage fellow institutions received after the launch of similar programs, such as initiatives at Brown University and University of Wisconsin, Madison. Meanwhile, the university facilities organization lent legitimacy to this effort by giving their support, stating they would explore options for funding the program themselves if the legislation did not pass. Here, a conversation at the intersection of maintenance, policy, and design set in motion a partnership that would later scaffold menstrual access.

PHASE II: DESIGNING AND DEPLOYING RIOT

Throughout our engagements with these key sites—the public restrooms, the university facilities organization, and the WAC—our design team sketched and imagined ideas for menstrual hygiene access. Initial concepts focused on developing a sensing technique capable of integrating within pre-existing dispenser models already in place in the public bathrooms we surveyed. We settled on the idea of counting product levels after exploring various sensing options (described in more detail in the Appendix) and abandoned ideas that might compromise the privacy and security of those visiting the restroom.

Proof-of-Concept Prototypes

Our first prototypes mobilized the gap inside the typical dispenser's cache, which becomes wider as tampons and pads are discharged. A set of two distance sensors (one for pads and the other for tampons) monitors this gap, prompting the system to calculate the number of remaining items (see Appendix for more detail on our sensor selection process). During this proof-of-concept phase, our team created an off-the-shelf Arduino-based structure to collect the field data as well as a web-platform for registering new restrooms and providing public-facing records of product counts from across the city. We used an Arduino Uno as the baseboard, ultrasonic sensors, a power management circuit integrated with a LiPo battery, and a Wi-Fi shield. The setup allowed us to explore this approach, with it capturing

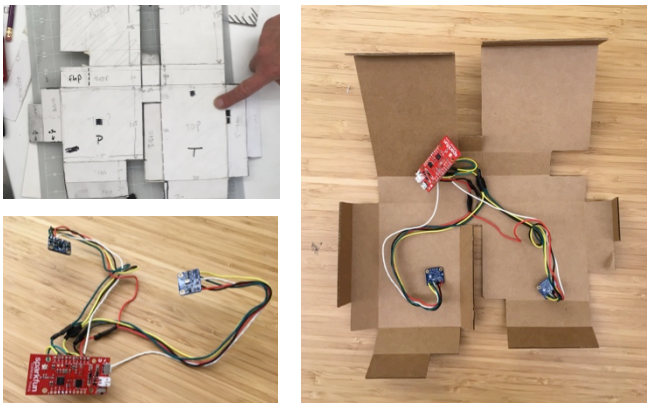

Figure 2: The Riot design is comprised of two distance sensors, a low-cost microcontroller with Wi-Fi capability, and a simple, portable power bank—all housed in a custom cardboard box.

and sending data during a limited period of time (a few hours to several days). Yet, as we attempted to extend our trial beyond our design lab or a couple of targeted sites, we faced challenges around scalability and maintainability.

Designing for Reproducibility and Sustainable Maintenance

As we learned more about maintenance labor and the potential for a broad, public deployment within our field sites, we focused our next iteration on emerging issues of adaptability. Specifically, we worked on longer power operation, more consistent internet connectivity, better precision in product count, and lowering the cost of the unit. Each of these factors reflected concerns for how the device would be taken up in our sites—from staying powered on for long periods in spaces constructed of cinderblock (power and connectivity) to ensuring the output was useful and reliable to those who look to the data (product count). Toward this end, we replaced the Arduino Uno, Wi-Fi shield, and power boost board with a newly released DIY toolkit the ESP8266. This reduced the overall cost (by $50, from about $95 to $45) and lessened power consumption and the physical dimensions of the insert. We also replaced the sonic sensors with laser-based ranging sensors, allowing more accurate distance measurements. To address concerns for electrical power, we used a disassembled portable charger, connecting the microcontroller directly to its internal 18650 battery cells (a practice growing within the DIY community to produce projects such as domestic power walls for "off the grid" houses).

Mixed (Initial) Reactions

When we introduced the concept of Riot to members of our key field sites we received mixed reactions, from curiosity to ambivalence to annoyance. Two crew members of a Seattle Parks maintenance crew told us that the device would likely end up being just one more thing to be vandalized and in need of repair. They advocated instead for "minimalism," or fewer rather than more restroom artifacts, thinking it would reduce maintenance demands. Yet, the device occupied the imagination of members of our home institution's facilities organization, who viewed it as a connective link to the student body and as a means of contributing to research on campus. As the design work continued, they also saw links to the state of the art of bathroom design—later entertaining a pitch from the multi-national "personal hygiene" corporation Kimberly-Clark on smart restrooms during the week of our first deployment.

Members of the WAC saw utility for the Riot dispenser design beyond our own understanding of it as a maintenance tool. When holding discussions with building managers, for instance, they heard a concern first and foremost for funding the proposed shift to free products: how much would it cost? With many comparable programs across the country still in their infancy, they could not point to an agreed upon average amount. Instead, they needed to estimate through current usage patterns and viewed the dispenser inserts as a source of data to gauge the potential cost of the proposed legislation, with plans to also use it as a means of tracking the program's uptake if the law were to pass. In doing so, they invited us to view Riot as a form of data advocacy, or as data gathering object to be used in support of their cause. This effort became particularly potent as one of the earliest campus campaigns from Columbia University came to a quick halt after administrators suggested there was a lack of interest on the part of students [24]. Even when passed, these initiatives were vulnerable to swift rollbacks.

Deployment

We conducted two deployments of the sensor system over several months, from September to December 2017. In both cases, we deployed the sensor system at our home institution with members of the facilities organization who assisted in identifying the restrooms to use for testing and advised us on how to hang the sensor system within the dispensers. With each, we affixed the device to the top interior portion of the dispenser with the support of a removable adhesive Velcro strip. This allowed for the sensor insert to be both secured in place and also easily detached for regular maintenance by members of the facilities team, for the replacement of batteries by the research team, and for the eventual removal of the insert at the end of the deployment term. The use of the Velcro also ensured that we made no lasting alteration to the dispenser (for instance, avoiding drilling holes or stronger glue that might have left a mark), for this would impact the maintenance of the machine in the longer term.

In both deployments, the sensor platforms operated for about a month at a time without interruption, sending data to a web server hosted by our home institution. In each case, the device housing successfully protected the components and secured them to the dispenser. The boxes remained in the dispenser in the precise location where they were initially attached, as did the sensors themselves. Furthermore, the platform continued to operate when we

monitored it in the field (and it is still in operation during the writing of this paper). Based on our continued development of power handling over the course of the deployment period, we estimated that our design could support between 7 to 8 weeks of monitoring.

Installing Riot, uncovering existing entanglements

The installation invited additional opportunities to understand the way access developed across the university restrooms. Consider, for example, an episode during our field engagements when the first author, Sarah Fox, met building manager Felicia to implement a long-term deployment in the restroom of a heavily trafficked campus building.

Though Felicia had volunteered to be a part of the research, and although she was at first curious about the device, when we met her at the campus building she appeared to oscillate between excitement and skepticism over the course of the installation. As Fox told her how the system worked, for example, Felicia said under her breath, "just bring [the tampon] from home," referring to students in need of menstrual products. She seemed disappointed, pointing to individual accountability as the answer to the problem of too few public menstrual resources. After a moment of reflection, however, she shifted tone; "although, I guess it comes in handy sometimes," she said. Her view of responsibility seemed to change over the course of our conversation—from institutional to individual and back again.

This tension between individual and collective responsibility remerged as we turned to the machine itself. When Felicia opened the door of a dispenser we noticed there was nothing inside. Fox asked if she had any menstrual products to fill the machine, and she responded, "Oh, you need those?" To her, the device was the solution to the problem—the technological standalone that would ease the burden of upkeep and make certain visitors had the menstrual resources they needed. It seemed tales of design solutionism had preceded us. Yet, Riot was no such thing. Instead, the IoT device relied on a web of connections between maintenance, advocacy, and design intervention—interdependent, much like the relationships that gave rise to it.

Without products already in place, we were unable to calibrate the device. Without calibration, the device was unable to count the products. And without the count, we were left facing an empty, under-considered machine once again. This revelation exposed something about our design we had not yet considered: the machines had to be filled for the system to work. It highlighted an assumption we were making about the types of enrollment we assumed from our collaborators—namely, we expected them to know where to locate the products. But this insight also represented an immediate intervention into the way maintenance practice worked. The machines had to be filled, right then and there.

After calling a crew member to locate the products, Felicia found pads in a nearby supply closet, but the tampons were "all the way at the tower," a building easily a half-mile away or more from where we stood. As she went to retrieve them, Fox waited by the open machine, with visitors to the restroom commenting, "thank you" and "Finally!" Continuing to stand there, Fox found a tiny, ripped post-it note stuck to the door next to the lever for the tampons with a handwritten message. It read, "Empty July 2017 :(". The dispenser had been unfilled for months, but not without notice from the menstruating public.

As our fieldwork continued we noticed that custodians passed by the dispenser as well, peaking into the restrooms when they saw Fox standing there. "Are we going to do that again?" one woman asked as she passed by on her way through the hall, referring to stocking the machine. "We just had to do it a long time ago. Are we starting again this year?" she continued. When Fox described the Riot project and its installation the woman nodded and continued walking. Minutes later, from another custodial professional, "Are we supposed to do that?"

Marked by our presence, the dispenser gained new attention and prompted questions of responsibility. Whose duty was it to maintain these machines? For the visitors who moved through the space during the installation, there seemed to be a quiet desire that dispensers be kept by university staff, but when that job was left undone there was only small evidence of resistance (in the form of a post-it note). Custodial staff, on the other hand, expressed curiosity, asking if it was something that might be under their authority to do.

When Felicia returned from her mile-long journey, she had two large trash bags full of individually wrapped tampons and pads. She began filling the dispenser and asked how the system works. Walking through the different IoT components, Fox described what each part did and how it communicated with the online system. In response, Felicia's face relaxed a bit. She said that she hoped this platform would help facilities see how difficult it is for building managers to keep the machines up. Custodians aren't allowed to fill the dispensers, she told Fox. Instead, building managers or their superiors have to travel between the areas under their supervision, empty the coins, and fill the machines with more products. This work currently sits outside of their regular tasks of managing schedules and it involves overseeing the facilities of many buildings at once, which means the work often goes undone, she admitted. Those closest to and with arguably greater knowledge of individual restrooms and their care, the custodians who maintain them, were not entrusted with the replenishment of the machines because of the money handling involved. Felicia laughed at the thought of this and offered to count the money inside of the machine in front of me. Pulling out a separate, and even smaller key she opened a small metal box in the interior of the dispenser and counted the coins

there, "$2.25." She counted again just to be sure, "Yeah, $2.25," and laughing again.

Through this encounter with Felicia we gained a deeper appreciation of the forms of labor enacted (and made invisible) in public sites such as university restrooms. Our presence during the installation prompted reflection on the varied responsibilities expected of and entrusted to those maintaining the restrooms. It also surfaced larger questions of individual accountability and collective responsibility in regards to public resources. What is and isn't considered vital to sustaining a healthy public? Who is expected to supply the material to support it? In some ways these questions were made more fascinating by the fact that we only discovered them at what might be considered the end of a traditional design encounter: the deployment.

Reflecting back, we find it interesting to contemplate what our project might have looked like had we learned about these conditions and questions sooner. Would the project have shifted to reflect these power differentials—focusing further on class or labor relations? Or, could it have confronted more directly the fact that the responsibility of resource distribution is unevenly assigned? Without the slow-collaborative design process and installation, it seems unlikely that we would have uncovered these complexities at all.

DISCUSSION

With Riot we began to reveal the kinds managerial and service labor hidden away and deeply intertwined with IoT deployments. Our project exposed the value of frequent and repeated engagements with key community allies, but also the way we built those alliances across multiple sites in parallel, and not in isolation. Where typical community-based design projects partner with local groups to develop design solutions, Riot required understanding the numerous histories of advocacy and maintenance our deployments operated within. This understanding developed as part of iteratively refining the Riot platform and, in particular, re-defining what it meant to build a robust technology. The project necessitated that we conceptualize the robustness of our IoT devices from "two sides," as Denis and Pontille [10] might say. We examined their fragility from the perspective of the custodians who maintain them and their reliability from the perspective of the people who look to them for access and support.

Adopting this dual attention to repair, we illustrated a design approach that in some ways contrasts with typical IoT design. For the IoT dispenser to live in public, it had to enroll a variety of actors, each with numerous influences, concerns, and interdependencies. From limited power supplies to uneven authority, we found that defining discrete stakeholders and identifying their needs or desires could not capture or do justice to the web of relationships our design inhabited. Even from our small glimpse at these arrangements, we began to see how the Riot platform demanded multiple scales of engagement. At the device-level, Riot opened possibilities for extending menstrual resource accessibility. At the infrastructural-level, it showed us how prototyping was insufficient for understanding the range of dependencies and interests at play. At the policy level, it occupied the imagination of grassroots organizers and facilities staff, offering opportunities for advocacy. Rather than ground its design in the interests and desires of individual actors, each with the perceived ability to take up our designed solutions and feel empowered by them, our project began to show what it might look like for designers to take seriously the broader political, economic, and historical forces shaping IoT design as well as the collective concerns of those implicated in accessibility (here, custodial staff and menstruating peoples, for example).

Although the design of an IoT for public hygiene resource distribution—a timely and important topic for the DIS community—has been ostensible focus of this paper, this work was not simply about the creation of a novel digital tool to serve a stigmatized need. Instead, drawing on traditions of design inquiry [4,20,48], we focused on what our tool exposed about those public sites: showing how that which is novel or digital cannot work in a vacuum if it must survive beyond proof-of-concept deployment. Our design interventions always interact with a complex constellation of organizational actors with their own histories of design and policy work, each opening some paths for design while closing others. Below we discuss three of these broader lessons for maintenance around IoT design.

Designing Lasting IoT Installations through Adaptability

A crucial concern for our research around Riot was how our installation would last over time, a relatively important but under-explored concern within design research projects around IoT. For our initial design, we focused on proving that an IoT deployment could be achieved—emphasizing the selection of the right sensors. However, as we continued with different phases of the design process, we began to stress reparability and sustained use instead, trying to make the device cheaper and more easily maintainable. In partnership with the WAC and the university facilities organization, we saw the need for IoT to live in the world and not just be a prototype. It was critical that we were not the only ones interested or able to maintain it.

Moving forward, this insight has useful implications for design research on smart cities and public sensing. Interactive systems development within IoT projects typically serves populations for short periods of a research cycle. By ending a deployment early, or according to academic timelines, design researchers may unwittingly cut short the advantages their tools offer the groups or the communities they engage. Our work suggests that the responsibility for design interventions in the long term—the care and attention required for sustained engagement—needs further examination in the now. For us this meant understanding how community partners may take up and continue to use, service, mend, and rework IoT

infrastructure, work that may be as important or challenging as devising the initial design concept.

As we saw throughout our fieldwork, some of the steadiest figures of the menstrual movement have been community activists running product drives and sewing circles—filling gaps of access using the tactics of grassroots organizing. Although the WAC's recent push for legislation has helped advance the codification of menstrual policy, their ongoing advocacy for product transparency—over 25 years of work—has produced a proposed bill that has yet to appear in the state congress. This slow and unpredictable process offers lessons on flexibility, posing collective adaptability as a key concern for the development of any community resource or product design effort. With this concern in mind, we ask: what might a flexible IoT look like, one that is adaptable and community supported? To start with, designing for such IoT may not only mean attending to the particulars of component selection or environmental surroundings (in our case, building menstrual resources), but also the regimes of maintenance (in our case, WAC advocacy efforts) that envelope and define it.

Harnessing Collective Responsibility

Connected to concerns for maintenance, our investigation into menstrual resource distribution also holds lessons for the shared authorship and responsibility of public IoT. When the WAC was not able to get their second proposal for broad ranging menstrual equity through the appropriate channels of the student government, the directors of the university facilities organization took up the proposal anyhow. They installed our sensors in university restrooms and piloted a program that made free products available in select restrooms across campus. Thus, our partners reconceptualized the maintenance of menstrual resources as a collective rather than an individual burden.

This case suggests that the design of public IoT takes not only work, but certain kinds of work that meaningfully extend IoT design methods through collective responsibility. Our intervention reveals for design researchers the types of obligations held by different organizational actors, and the classed nature of those commitments. In our case, custodial staff were not interested in the $2.25 worth of coins sitting in each dispenser, yet the organization shifted the responsibility for emptying the coins away from such staff — ultimately making the majority of machines unusable. Here, the rules and policies guiding the practices of those attending to the restrooms reflected deeply entrenched power differentials and forestalled forms of collective responsibility that could exist, highlighting again the importance of attending to the conditions of one's deployment site.

Alongside finding a power outlet or securing the device, the historical and political matter of IoT may just as critically inform how an intervention works. Rather than merely focus on particular utilitarian gains, our project exposes how IoT can also work as what Sherry Turkel might call an "evocative object" [45] contributing to wider debates on access, resource distribution, and public health. It is this ability to inspire and imagine, and to do so collectively, that point to key implications for public IoT beyond the individual.

Sustained Prototyping: Making IoT "work"

When we began this project, something like a networked counting device made sense for a deployment since it supported the interests of both the facilities organization and the WAC. It was a tool that addressed a defined need: accounting for and supporting the necessary expansion of menstrual resource distribution across our community. In this sense, our initial proof-of-concept was simultaneously a real and speculative campaign. Yet, as the parallel efforts of advocacy and design unfolded, the utility of that particular IoT object turned out to only hold so much weight. It was not able to fully solve the problem of access on its own, as perhaps Felicia had imagined, nor did it capture the imagination of all who encountered it (as was the case with the Seattle Parks crew members). Instead, our Riot platform affected change in other ways. For example, it served as an object for gathering around, for forming partnerships that had long elided the facilities organization and the WAC. It also shed light on issues of menstrual accessibility more broadly, amongst those at home institution, the wider city community, and our academic circles, while showing signs of design solidarity with those advocating across the country. Even as the technology itself became less central, it produced something larger, a connection that might live on beyond the tenure of the device.

CONCLUSION

With Riot we have sought to extend HCI's concerns for IoT to consider its place in the distribution of public resources. We began by outfitting dispensers with networked sensor inserts to make them easier to stock by custodial staff and easier to access by members of the public. However, our goal was not to suggest our device as the core solution to problems of menstrual resource accessibility. Nor did we seek to produce a generalizable technical intervention that might move to other contexts unchanged. Rather, we brought a sensitivity to the political and social dimensions of our sites of public resource maintenance, and explored the textures and dependencies of the partnerships that emerged through the Riot design and deployment. In doing so, we focus new attention on role of public IoT devices once they move on from the proof-of-concept stage, revealing their capacity to cultivate and maintain forms of collective responsibility.

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