Fruit Are Heavy: A Prototype Public IoT System to Support Urban Foraging

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ABSTRACT

Smart cities are one area of interactive systems design where the technologies and services of the Internet of Things (IoT) have the potential to serve public interest. In this paper we present a design research project that explores the use of IoT technologies—specifically environmental sensing—to support urban foraging. We describe the design of a simple proof-of-concept sensing platform to monitor the relative ripeness of fruit in trees, and reflect upon its potential effectiveness for urban foraging. From the project, we draw out themes for designing in the context of smart cities, including questioning the presumed “smartness” of IoT systems, and highlight issues in designing to support diverse community economies.

Author Keywords

Foraging, Public IoT, Public Design, Participatory Design, Diverse Economies, Community Economies, Smart Cities, Digital Civics

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Sensors, data, and networks are components of the so-called Internet of Things (IoT) that—when coupled with machine learning and analytics—are offered as promising opportunities for shaping our lives in the early 21st century. Our research is concerned with understanding how these technologies might comprise a kind of civic media [30] and support the multiple and varied ways we live together. We use the term “Public IoT” to describe this broad domain of inquiry. By Public IoT we refer to the technologies of sensing that are common to the Internet of Things. In this

case, though, rather than being oriented towards supply chain management or other industrial concerns, it is instead oriented towards facilitating social relations: aiding the formation and sustaining of communal and shared attachments and commitments. One common example of this in both popular culture and academic research is the trope of the smart city, which proffers the integration of an array of technologies, ostensibly to improve cities along multiple registers, including sustainability, efficiency, and in some cases equity [35, 35, 65].

Much of the promise of the smart city remains mere rhetoric—arguments for the development and deployment of systems, platforms, and infrastructure. Much of this rhetoric is oriented towards the makers of these components and services and to municipal governments. In order to explore the potentials and issues of Public IoT—to investigate the capabilities these technologies might offer for communities to address their matters of concern and care [10, 11, 36, 42]—we have chosen to collaborate with communities that are engaged in collectivism and cooperation. In this paper we present a design research project with one such community, an urban foraging group, and our effort to prototype a proof-of-concept sensing system to aid their work. In what follows we first provide a general background to this project and set the context in urban foraging. We then describe the design and deployment of a proof-of-concept system to sense the relative ripeness of fruit as a way to mitigate one of the more onerous aspects of foraging: fruit monitoring. From this we draw out insights specific to both designing interactive systems for smart cities, and designing to support diverse community economies.

BACKGROUND

This research is situated at the intersection of three domains: smart cities, diverse community economies, and participatory design. Initially, we did not describe our work in the context of smart cities. In its place, we used the term “Public IoT.” The term Public IoT serves as shorthand for an assemblage of technologies and services that comprise the Internet of Things, and as a description of the context and purpose of that assemblage. More specifically, what is of interest to us is how IoT technologies and services work to both serve public interest and contribute to the formation

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of publics [2, 4, 11, 14, 44]. While there is no shortage of design research into IoT, little of that research is concerned with the public-ness of the technology and services. Instead it is more often focused on either industrial or domestic environments [8, 13, 63].

Outside of design research but within smart cities discourses and projects, we find many visions, explorations, and critiques of how IoT technologies and services might be integrated into the context of urban life. This includes research on governance and civics [6], devices, systems, and infrastructure [7, 56], work [4, 54], civil society [42, 44, 45, 47] and recreation [16]. Alongside the research advancing smart cities, there is also a significant amount of scholarship questioning smart cities [34, 35, 39, 40] and in particular the implications of smart cities for equity and privacy [1, 23, 28, 53, 64, 66], including concerns about the increasing encroachment of an algorithmic culture into government, civics, and our public lives [9, 28, 31, 39, 40].

Our exploration of IoT technologies and services in smart cities is grounded in the context of diverse economies. The term diverse economies is drawn from a body of research in economic geography, specifically from the work of J.K. Gibson-Graham [24-27] and researchers who have extended and built upon the theories of Gibson-Graham [55]. A fundamental aspect of the work on diverse economies is the idea that “the market” is more varied than is often recognized. So, while discussions of the market tend to assume free-market competitive capitalism, the market economy also includes many other forms of labor and exchange, such as bartering, informal lending, and self-provisioning. This occurs not just among the gainfully employed but also children, the unemployed, those employed illegally, and in a range of contexts that also include the street, within families, and in schools. These community economies provide sites for researching everyday practices in contemporary society that are often overlooked, particularly in design. There *is* some work in design that is specifically oriented towards diverse economies [17]. But more generally, diverse economies connect to work in design research that explores practices such as simple living [32, 33], cohousing and other forms of intentional communities [38, 48], community organizing [2], and other ‘alternative lifestyle practices’ [36]. What the diverse economies literature provides is a theoretical frame drawn from empirical research, which in turn can be generative for design.

Finally, our work is situated within the theories and methods of participatory design. Although we do not reflect upon the implications of this project for advancing participatory design research in this paper, we believe it is important to acknowledge that our approach is grounded in participatory design. Using a participatory design approach to research and engage in issues of smart cities and diverse economies aligns with both the history of participatory design, and its current practice. Diverse economies are a

kind of work, a mode of labor. From its origins, participatory design has been explicitly concerned with work and with supporting skilled labor. The activities of diverse economies are most certainly skilled and, from the perspective of participatory design, warrant attention, respect, and the involvement of those who do that labor in the design of tools and systems that they might use. Diverse economies are also an example of the expanding notion of work that concerns participatory design, which increasingly involves various forms of informal work such as making in community contexts [4, 14, 15 58, 59]. Our research employs participatory design methods that strive to simultaneously contribute to invention and to produce opportunities for exploring new modes of togetherness enabled through making [58, 59]. Thus, the goal is not just to collaboratively produce proof-of-concept systems but also to collaboratively explore the feasibility and desirability of different configurations of social forces and conditions [5, 11, 22].

SETTING THE CONTEXT: URBAN FORAGING

Foraging is a canonical example of a diverse community economy, often characterized as a form of self-provisioning [55]. Foraging is the collection of naturally growing food in the wild [21, 41, 46, 50, 51, 55]. By “naturally growing food,” we mean items such as fruits, vegetables, nuts, and fungi that are not prepared or processed. By “in the wild,” we mean from sites other than farms or orchards, places other than those intended for cultivating food. Although this distinction may seem a bit awkward, it is important to understand what foraging is and is not, and to appreciate the distinct challenges inherent to foraging. For instance, foraging is different from gleanings, which is the collection of leftover foodstuffs from farms or orchards or food providers such as restaurants or grocery stores. Gleaning could include the recovering of day-old bagels from a dumpster, or the donation of leftover sandwiches from a catered event, or the gathering of corn crop remains from a field after that field has been harvested. In contrast, examples of foraging include collecting pears from trees on a golf course, or garlic from an abandoned lot, or mushrooms from under a log in the park. With foraging, the foodstuffs grow and are collected opportunistically, in an ad-hoc manner.

From the perspective of diverse economies research, these distinctions are important for several reasons. First, there are different regulations that come into play between different modes of gathering and distributing food. In some places, it is illegal to give away or otherwise distribute pre-made food items once they have left the market (for instance, to give away unsold bagels or uneaten sandwiches). Second, there are different kinds of labor involved in these different modes of gathering and distributing food. These regulations and modes of labor affect the work of foraging, and thereby affect designing for foraging.

Image 1. Concrete Jungle volunteers at a single persimmon tree along a city street

One key factor to understand about foraging, in order to appreciate its practice, is that it is decidedly **not** farming. Farming almost exclusively involves a dedicated site, a space that is intentionally developed and maintained to grow food. In contrast, foraging is distributed. The fruits, vegetables, and other foodstuffs are scattered across the city, and grow voluntarily instead of being planned. Moreover, the spaces in which they grow are not nurtured in the same way as farmland. Certainly, pear trees growing in a park or fig trees in a front yard may benefit from purposeful watering, or perhaps even soil fertilizing; however, that care is not usually taken with the express intention of supporting the productivity of the trees that bear pears or figs. The spatial distribution of these trees, bushes, and other plants means that the work of tending to and harvesting the food is also distributed in space. The work of foraging is therefore significantly different than the work of farming. These distinctive qualities of the work of urban foraging comprise one of the motivating factors of our design research—how to design systems and services to support the work of foraging.

Concrete Jungle

Over the past four years we have collaborated with Concrete Jungle, an urban foraging collective in Atlanta, Georgia. Concrete Jungle has one paid staff member but is otherwise an all-volunteer, organization. There is a core of 3 founding members, a board comprised of approximately 10 members who take on significant work in running and sustaining the organization, and 100 or so volunteers who participate in fruit picks throughout the year. Concrete Jungle has been active in Atlanta since 2009, though they only became a registered 501c3 organization in 2016. Their primary objective is to gather fruit growing wild across the Atlanta Metro region and donate it to local social service providers. These social service providers range from large organizations, such as the Atlanta Community Food Bank, to smaller programs, such as women's shelters that sit within community centers and churches.

Image 2. Concrete Jungle volunteers at a grove of persimmon trees in a city park

Each year, Concrete Jungle organizes dozens of picks to collect fruit from wild trees, and from these picks, amass thousands of pounds of fruit (in 2016, over 12,000 pounds of fruit and vegetables were collected). Much work goes into foraging at this scale. For instance, in addition to organizing picks and donations, Concrete Jungle is constantly looking to discover and document new fruit trees, so as to increase the amount of fruit they can provide to those in need. Most of the trees they collect from are on public property. Some are on private property, but these picks are negotiated with the property owners. As part of the effort to track forage-able food in the city, Concrete Jungle maintains a digital map of food sources that is public, as well as a more elaborate private database that tracks the approximate ripening dates of individual trees and bushes and their yearly yield. Currently, Concrete Jungle tracks approximately 2,700 fruit trees and bushes in the metro area.

Fruit Monitoring as Key Concern

One key concern for Concrete Jungle is fruit monitoring: knowing when fruit is ripe so that they can organize picks and donations. Keeping track of the ripeness of the fruit across all of the trees and bushes is incredibly time consuming. Not all of the fruit ripens at once, and the climate in Atlanta supports a long growing season. Moreover, the location of the fruit is widely distributed. These factors contribute to the significant time commitment required to walk, bike, or drive around the city, keeping track of when each plum, apple, or pear tree is nearing the time to pick.

The key reason to know when the fruit is ripe is to know when to schedule a fruit pick and the subsequent donation of the fruit. These picks tend to be labor intensive. Even a small tree will often take a team of four people with a ladder, and larger trees and groves of trees can require much larger teams for a pick (see Image 1 & Image 2). Scheduling a pick tends to involve rallying and organizing volunteers (sometimes 10 or more), so planning the timing

of that pick is important. If it is too early, the volunteers will arrive and there will be nothing to actually do. If it is too late, the fruit may have already fallen to the ground and been stepped on or eaten by insects. Finally, given the amount of fruit picked, transportation for the fruit needs to be arranged, and in some cases short-term storage must also be arranged until the fruit can be donated. All of which is to say, timing is important and that timing depends upon the ripeness of the fruit.

It is for these reasons that our collaboration with Concrete Jungle over the past several years has focused on exploring methods for remotely monitoring fruit trees. Specifically, we are collaboratively exploring how digital technologies and computational media might be appropriated or designed to support foraging. While this might at first seem amusing, the idea is not entirely outlandish. As already noted, there is a growing body of research on the smart cities technologies. There are also a substantial amount of existing products and services oriented towards so-called precision agriculture: the use of sensing and data technologies to streamline farming. This difference in scale and practice between precision agriculture and farming has been, for us, an opportunity for invention [12].

Of course, other approaches for fruit monitoring are possible, such using mobile phones for crowdsourcing images of fruit trees or even just assigning volunteers to regularly check individual trees. While we are exploring such approaches with Concrete Jungle, in this paper we report on our research into sensing technologies. With regards to use of technology in general and the specific choices of technology in this project, it is important to note that these decisions are not made by the academic researchers on our own, but rather in close collaboration with Concrete Jungle.

The Structure of Our Collaboration with Concrete Jungle

Our work with Concrete Jungle has been framed as a collaborative design research project from the start. Indeed, it was Concrete Jungle who first approached the academic researchers about the possibilities of developing a mobile mapping application and later proposed the notion of using drones for foraging. Concrete Jungle is not only interested in improving their capacity for foraging right now but also in exploring how technologies might aid and amplify their work in the near future. In part, this stems from the fact that one of the founding members has a background in engineering and has worked in multiple startups, contributing to a predisposition to technological experimentation. In part, it also due to the fact that Concrete Jungle recognizes that foraging itself is a playful practice. While the issues of hunger and food security that Concrete Jungle work to address are serious, part of the mission of the organization is to “promote fun and intriguing ways to provide fresh produce to those who need it.” Exploring the role of technologies to support foraging becomes another means of achieving this mission.

We work together with Concrete Jungle in multiple ways. First, we participate in all almost all aspects of their volunteer efforts, including fruit monitoring and picks. In terms of the design research, we collaboratively define approaches to problems. That is, Concrete Jungle may present us with a general problem, such as fruit tree monitoring, and then we work together to discover the range of possibilities to address that problem. In this way, our activities—what we choose to research and to make—are collaboratively articulated. Many aspects of the design process itself also involve collaboration. For instance, in the proof-of-concept system described below, we regularly drew upon the engineering insights of one of the Concrete Jungle members to make design decisions. This extends to all aspects of the design, from the industrial design of housing, to the user experience design, to the optimization of the hardware and software. In short, members of Concrete Jungle are integrated into our design research. In describing the design and deployment in the following sections, the “we” usually includes the authors, student designers who work on the project, and members of Concrete Jungle.

FROM DRONES TO DISTRIBUTED SENSORS

Earlier work with Concrete Jungle involved a mobile mapping application and the exploration of drone use in the context of urban foraging. It was, in fact, the design research with drones that led us to work with sensors [12]. Although drones have the potential to be useful in remotely monitoring fruit trees around the city, there are two fundamental problems. The first problem is battery life. No affordable drone has enough battery life to support the flight distances that would make the use of the drones worthwhile. While there are some cases for using drones that do not require long flight distances—for instance, checking the condition of fruits in hard to reach places such as in roadway medians or inside of gated apartment complexes—these scenarios are rare, and in and of themselves do not make enough of an impact on the workload of fruit monitoring. The second problem is regulatory. During our initial work with drones, federal policy concerning unmanned aerial vehicles (UAVs) use was being debated and the status at the time made our envisioned use of drones, if not outright illegal, within a grey area of regulations that was untenable for our ongoing experiments.

In line with the general notion of appropriating the tools and techniques of precision agriculture for foraging [12], the use of sensors in trees was a logical next step in our exploration and experimentation. Using sensors to detect ripened fruit is an active area of research in agricultural engineering. The majority of the research is oriented towards using gas sensors to detect the presence and concentration of specific organic compounds that are emitted from fruit as it ripens [3, 60]. Other sensing techniques include the use of computational vision to detect visual changes in the fruit (usually color) [57, 62], and

ascertaining the acoustical qualities of fruit, which in some cases can also change as fruit ripens [20, 61]. While many of these techniques offer the promise of high-fidelity monitoring, many of them are prohibitively expensive, and almost none of them are feasible for field deployment.

The insight into the system we developed came through our co-design work with Concrete Jungle. In the process of discussing the fruit spotting and monitoring processes and brainstorming possible uses of mobile phone cameras as sensors, one of the foragers commented that, *at a certain point, it becomes easy to see that a tree is full of ripe fruit*. When we asked how, they replied, *the trees droop, a lot, enough that you can see the droop from a ways away*. We quickly began considering options for using mobile phone cameras to compare images of a given tree at multiple points in a growing season. In the process of this brainstorming, it dawned on us that sensing the droop of a branch directly should be a relatively easy and inexpensive affair. This insight sparked the development of the *Fruit Are Heavy* sensing system.

DESIGNING THE FRUIT ARE HEAVY SENSING SYSTEM

Drawing on the insight that tree branches bend as fruit ripens, we developed the *Fruit Are Heavy* sensor system. The system is a prototype; it is not entirely functional. As a prototype, it is intended to allow us to explore the conditions and potentials of using a sensing system to support of the work of urban foraging.

The *Fruit Are Heavy* sensor system measures the bend of fruit tree branches as a proxy for tracking the ripeness of the fruit on those branches. The system is comprised of three primary components. The first is the platform hardware and software, which utilizes a custom board and software to monitor the sensor (see Image 3). The second component are the sensors. To date, we have prototyped the system with two different methods for sensing the bend in a tree branch: a bend sensor and a stretch sensor. The third and final component is the housing for the sensor platform, which both provides protection and lets the platform attach to the tree. In order to be of value in monitoring the relative ripeness of fruit, the sensor platform needs to be deployed for a minimum of a month, to detect the progressive bend in the branch that corresponds to the growth of the fruit. As such, making the system robust enough to last for full deployment was a primary concern throughout the design process.

Sensor System Design

Early testing found that a standard Arduino board would drain the battery too quickly to support an extended deployment. At idle, a standard Arduino board draws around 200 milliamps. Even with the largest capacity battery we could find, holding 6,000 milliamp hours, a stock Arduino would run for only 30 hours. This current draw comes from a combination of the LED indicating that

Image 3. Custom electronics and stock parts for the sensing platform.

regulators, oscillators, and a USB controller. In order for the batteries on these sensor platforms to last an entire month, we designed a custom board. This board design takes advantage of several techniques to minimize current draw during the deployment period.

To make our board use as little power as possible, our custom version strips away all unnecessary components. Instead of including USB connectivity on-board, we use an FTDI cable to program the boards directly, meaning we can omit USB controllers entirely while still leaving the boards simple to program via the Arduino IDE. To remove the external 16Mhz oscillator from the board design, we flash the microcontroller's default firmware with replacement firmware so that uses the microcontroller's internal 8MHz oscillator instead. This firmware was originally designed for the Arduino Lilypad, and the low-power mode that is helpful in wearable computing is also useful in our application. Finally, we do not include any LEDs to indicate power status, saving a constant 40 milliamp draw.

The hardware design is only part of energy savings. The software, too, needed to be optimized to reduce energy use. Initially, the microcontroller itself would still draw a constant ~80 milliamps of current. The best way to reduce that current draw is to set the device to sleep when it is not actively reading sensor data or writing that data to the microSD card. Because we are already using a real-time clock (RTC) to keep track of the day and time during data collection, it is relatively straightforward to use it to wake the microcontroller up when it is time to take a new reading. Every 24 hours, the RTC module sends an interrupt to the microcontroller. It in turn wakes up, takes the current sensor reading, writes it to the SD card, and then go back to sleep. In this way, we can dramatically extend the battery life of the sensor platform.

Data Transmission and Storage

Data transmission was, in many ways, fundamental to the system design. In order for the system to achieve the objective of reducing the work of fruit tree monitoring, the sensors need to be able to send the data on a regular basis to

Image 4. Experimenting with forms and mechanism for sensor and platform attachment.

Image 5. Another experiment with forms and mechanism for sensor and platform attachment.

foragers. Data transmission, however, was elusive in our system design. In our initial iterations of the platform design, we explored using cellular communication—having the platform send text data over a cellular network.

However, the cost of the additional electronic components together with the cellular network subscription cost was prohibitive. In a subsequent iteration, we explored the use of WiFi. Unfortunately, no open WiFi was available in our test locations. Rather than shelving the project, in a compromise collectively reached between the researchers and foragers, we decided to pursue the development of the prototype system in the absence of data transmission. Recording data, however, was still necessary as part of the proof-of-concept for the sensing mechanism. Our solution was to equip the sensor platform with microSD card for storing sensor readings. Although this solution was far from ideal, it was a trade-off we deemed reasonable in order to produce a prototype system.

Sensor Housing Design

The custom boards are designed to be placed alongside the batteries in boxes that are 3D printed with laser-cut lids. The boxes provide a substantial amount of protection from the elements, as well as providing a sturdy shell that protects the electronics. However, we were unsure if the boxes alone would be enough to withstand the regular, and

Image 6. Early material and functional prototype of backpack form and clip mechanisms for housing.

Image 7. Final design of housing with sensor platform placed inside and sensor extending out.

sometimes torrential, summer rains. Moreover, we needed a way to attach the sensors onto the trees. So, in parallel with iterations on the sensor board designs, we began researching and prototyping custom housings that would provide additional protection from the elements and enable the foragers to easily attach the sensors to the trees.

We began our design exploration by collecting examples of existing products that served similar functions. We quickly realized that products designed to carry things on the human body were a good analogy for the functionality that we needed, including the capacity to strap on to a range of sizes and angles. So, for example, we experimented with the straps and buckles mechanism used by fanny-packs as well as armbands for holding mobile phones while exercising. Placing these in situ while using simple cardboard mockups for the sensors allowed us to quickly prototype and iterate through a variety forms and mechanisms (see Images 4 & 5) for both holding the sensor platform to the tree and for connecting the sensors to branches. At multiple points in the design process, a partner from Concrete Jungle provided feedback as informal assessment of the proposed housings, sharing insights and suggestions based upon his experiences of foraging. We finally settled on a backpack-like form with clips that would allow for a range of adjustments to accommodate a

Image 8. Bend sensor attached to branch

variety of thicknesses of tree trunks and branches (see Images 6 & 7). The two straps wrap around a sturdy branch, tightening around both the sensor box and the tree.

From the box, snaked under a flap in the backpack, wire leads connect to the sensor placed in the tree. The simplest solution we found for attaching the sensors themselves to the tree branch was to use plastic ties. The backpack is made from a cloth material used in DIY diaper (or nappy) making. We happened upon this fabric in our material exploration as we were searching for something that was water resistant, inexpensive, and easy to sew. When it is time to recover the sensors, it is as simple as cutting the zip ties and detaching the backpack's straps. From there, the backpacks are easily opened and the microSD cards removed from the sensor boxes.

SENSOR PLATFORM IN USE

We currently use two different kinds of sensors to approximate ripeness. Each of these sensors use the bend of the branch as a proxy to tell when the fruit is ready to be picked by Concrete Jungle volunteers. The first of these is a flex sensor that is placed on a branch to read the bending of the branch directly (see Image 8). The second is a stretch sensor. In this case, one end of that sensor is placed on the bending branch, and the other on the trunk or nearby stable limb of the tree. In this case, the branch bending away from the stable end will stretch the sensor (see Image 9).

In either case, the first step in using the system is to locate a tree that is in the earliest stages of growing fruit. Apples, pear, plum, and fig trees work best because the fruit is heavy enough to produce a significant bend in the branch. Citrus trees would likely also work well. This system, however, would not work well with blueberry bushes or trees where the fruit is not heavy.

Once a tree is identified, and a branch found that will likely bend is selected for the sensors, the forager then finds a stable branch or place on the trunk to secure the sensor platform. Next, she unscrews the lid on the sensor box, turns the platform on from the switch on the board, attaches

Image 9. Stretch sensor attached to branch

the sensor leads into the screw terminals for the sensor, and reseals the box. Then the box goes into its backpack to be attached to the tree.

In the case of the flex sensor, zip ties are used to attach the sensor along the parts of the branch that seem most likely to bend. To figure out where it will bend, we hold the fruiting branch where the fruit is growing and bend it manually. In the case of the stretch sensor, one end is zip-tied to a secure, immobile portion of the tree, like a limb near to the trunk, and the other is attached to as near as possible to where the fruit is growing.

Two Test Deployments

We conducted two test deployments of the sensor systems over two summers—one in the summer of 2015 and other in the summer of 2016. In both cases we used the same tree: a pear tree that is on private property where we know the owners, and thus could have regular access to platforms with less concern about them being tampered with or stolen. In both cases, we deployed the sensor system together with a partner from Concrete Jungle, who assisted in identifying the best branches to use for testing, and hung the sensor system in the tree.

In both of the test deployments, the sensor platforms operated for approximately five weeks without interruption. In fact, in each case, the platform was still operating when we collected it from the field. This suggests that our design should support at least five weeks of monitoring, and we estimate it may actually support between six and seven weeks. Also, in each case, the housing was successful at both protecting the boxes and securing them to trees. The boxes remained in the trees in the precise location where they were initially attached, as did the sensors themselves. Moreover, despite sustained high humidity, occasional torrential rains, and regular drizzle (as is common in Atlanta), the sensor platforms remained dry and continued to operate consistently.

At the end of the five weeks, we removed the backpacks from the trees, ejected the microSD card, and reviewed the

Image 10. Concrete Jungle member and design collaborator deploying the sensor platform.

data. In both test deployments with the bend-branch sensor (2015 and 2016), there was a clearly discernable change in the sensor reading over the course of month. With the stretch-branch sensor, there was minimal change in the data (the sensor data is publicly available to view on Github at <https://github.com/PublicDesignWorkshop/foraging-platform/tree/master/data>). Despite some noise in the data, the bend-branch sensor seems to capture the drooping of the branch, with the most dramatic change occurring in the last week of the data collection. This suggests to us that the bend-branch sensor shows potential for use. We are unsure of the stretch-branch sensor—the minimal change in the sensor reading suggests that perhaps some change in the branch’s droop is being detected, but certainly not enough to claim that it works. For this sensor, another round of testing is warranted.

DISCUSSION

The *Fruit Are Heavy* project allows us to explore one way of using IoT technologies to support a collective and public endeavor. Working together with community partners, we were able to design and prototype a system that serves a public interest and contributes to the work of a public in

addressing its concerns [11]. In this case, this happened to be a public of urban foragers broadly concerned with providing food for those in need, and more narrowly concerned with mitigating the work of that endeavor. Regarding the work of fruit monitoring, the prototype platform suggests that a finished platform based on similar engineering and design principles could do the monitoring work necessary to alleviate the need for foragers to check fruit trees regularly. This could reduce their total labor, enabling foragers to direct those efforts elsewhere in the organization, such as increasing the number of trees that they monitor—thereby increasing the amount of fruit donated—or simply put, taking less time and effort to achieve the main goal of providing for others.

Of course, as a prototype, this system is partial, and has issues that could be improved upon. Most glaring is the issue of data transmission. We do not view this issue as a design flaw so much as an issue of context and infrastructure, and we address that in the following section. Some modifications to the housing are also in order. In particular, all of the control mechanisms were placed inside of the box to limit exposure of the electronics to the elements. With a more refined and robust design, those controls could be made accessible without having to open the boxes during each deployment and recovery. In addition, we believe there are improvements we could make directly to the bend-branch sensor. Currently we are using a pre-made sensor, approximately 15 centimeters in length. If we custom-built our own bend sensor, of a significantly longer length, we should be able to capture more of the bend in the branch and provide a better reading of the overall droop.

More than the informing the design of the platform, sensors, or housing, the *Fruit Are Heavy* project was intended to provide an opportunity for research into the potentials and issues of designing Public IoT in the context of smart cities and practices of diverse economies. Next, we discuss insights and implications for designing interactive systems within these contexts and practices.

Broader Insights Into Design and Use in the Context of Smart Cities

Our research into supporting urban foraging through the appropriation of the techniques of precision agriculture has led us to develop insights relevant for smart cities. This is perhaps not surprising, given that the uses of data, geographic information systems, drones, and distributed sensing comprise the visions of both smart cities and precision agriculture. What we have found is that urban foraging offers an example of existing and vibrant community practice that could indeed actually benefit from the infrastructures, systems, and services proffered by smart cities initiatives. Examining how those technologies might be designed and used *now* thereby provides empirical insights into the design and use of near-term smart cities infrastructures, systems, and services by communities. In

what follows, we identify and discuss three insights, moving from basic technical concerns, to policy concerns, to design concerns about the “smartness” of smart cities.

Ubiquitous Connectivity: The base, but often absent, condition for a smart city

Perhaps the fundamental issue in deploying community-driven sensing is a lack of network connectivity. This is a problem that could be easily solved through the development of free and open civic Wi-Fi networks. In fact, in some cities where such networks exist, connectivity would cease to be an issue. Without such an already-existing network, however, the transmission of data remains a critical issue. Cellular is an option for transmission, for example, meaning that the sensor would send data via text message. However, cellular options increase the cost of the device, add a cost to data transmission, and increases the battery cost as well. Together, these costs mean that cellular connectivity becomes prohibitively expensive and ceases to be a viable option. The most promising alternative would be the use of various low-power and long-range networking technologies. This, too, introduces cost and complexity into the system, but, in the absence of a free and open Wi-Fi network, seems like the most viable near term solution to the problem of connectivity.

Are We Really Allowed to Do This?: Policies for community sensor deployment

Another crucial issue is the lack of policies for community deployment of sensors. There have been enough serious repercussions from various “suspicious” electronic gadgets and projects left in public spaces that it is naïve to think that a community could choose to strap their own sensors on neighborhood trees (or light posts, street signs, or mailboxes) without causing a stir that could have significant and costly legal consequences. If drones are any indication, the policies for the use of such emerging technologies will be slow and faltering. There are real concerns with the public deployment of sensing systems that include safety concerns and privacy concerns. In our deployments, we utilized spaces where we both knew resident-owners and that were off the beaten path to avoid these issues as best as we could. If communities develop significant interest to experiment with various kinds of sensor systems, it will be imperative to develop guidelines and policies around experiments like this, and researchers should take an active role in supporting communities and municipalities in the development of those guidelines and policies.

Maybe We Don't Need To Be So Smart: Re-scaling smartness in the smart city

The overarching theme of smart cities is that sensor systems together with machine learning and data analytics will provide more and more precise evidence and acumen for civic decision-making. This is the “smartness” of smart cities. What the *Fruit Are Heavy* system demonstrates is that there is value in systems that are low-fidelity, high-latency, and carrying only few bits of data. This is a constitution of the smart city that is different from the more

familiar visions of high-bandwidth, always on, precise data streams. This is not to say one vision should take precedence over another, but rather, that when we conceptualize and design smart city infrastructures and services, we should appreciate that there may be real and immediate value in infrastructures and services that offer simpler modes of connectivity and awareness.

In a sense, *Fruit Are Heavy* is a Public IoT service that shifts the scale of intelligence in the smart city. *Fruit Are Heavy* is intended to operate at the human scale—its “smartness” is not an insight that is only made possible through big data analytics, but also an insight that is possible for any individual human to make. What the system provides is a familiar move to delegate awareness for the sake of saving effort.

Perhaps social media is an analogy for considering these design implications. While there is value in systems that enable real time synchronous video and audio from multiple sources (such as conferencing software), there is also value in systems that are constrained to a single image, 140 characters, or six seconds of video. It is not that one form of media is more “social” than another, but rather, that they provide different modes for sociality. Perhaps we should consider smart cities technologies and services similarly—that while there is value in fast and rich data, there is also value in minimal data, and correspondingly, value in the kinds of minimal computing needed to produce that data.

Sensing Technologies in the Context of Designing to Support Diverse Community Economies

This work is situated within a broader domain of practices concerned with diverse community economies. Within this literature, there is a significant amount of work on foraging [21, 41, 46, 50, 51, 55]. However, little of that research addresses the intersection of technology with foraging, or even more generally, the role of technology in diverse community economies. As such, this research provides an opportunity for reflection on what might be key themes at the intersection of fields and practices. Here, we address two of those themes.

Does Sensing Technology Affect Commoning: Are we distancing ourselves from an element of practice?

Commoning is an important notion within diverse community economies—it is a descriptor for how togetherness is created and experienced [17, 24, 26, 59]. Commoning often occurs through shared activities and knowledge. In foraging, the activities of fruit monitoring themselves, of going out into and around the city to know the trees, is a prime example of commoning. As we design technologies and services that mediate some of our knowledge practices and delegate some of our activities, we have wondered if we are, in fact, undermining rather than supporting a fundamental quality of community economies.

Future work will explore the question of whether the use of sensing technologies, or even more generally, the use of data as an intermediary to direct sensory knowing affects

the commitment to the practices of foraging. If we look to scholarship on other contexts and practices of environmental sensing, there is no clear answer [17, 18, 49]. Following from work that explores how sensing technology constructs hybrid—more than human—assemblages of knowledge and action [17, 18, 19, 37, 52], we hypothesize that while sensing technologies certainly affect what and how we know, they do not necessarily inhibit practices of commoning. Indeed, within the research on diverse economies that looks specifically at foraging, some authors note that one of the characteristics of foraging is that it sensitizes foragers to recognizing and appreciating the limits of human agency and the different forms of agency expressed through human/nonhuman encounters, which includes trees and bushes and also the multiple factors of the built environment that affect foraging [51]. So, it would seem adding sensors into the mix might simply diversify these agencies, making them different but not necessarily “better” or “worse.” Rather than avoiding sensing technologies in practices of commoning, 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.

Diverse Economies is Work: Considering automation in community economies

Building on the concern of whether mediation negatively affects commoning, we have come to realize that understanding and appreciating the significant work required to sustain diverse community economies is crucial to designing for community economies. Though it may be volunteer-based, and though it operates outside of and in parallel to mainstream markets, there is still significant labor that goes into activities such as foraging. Precisely because this work is informal, contingent, and demanding, sensing (and other) technologies may be of particular value.

Abstracting beyond the immediate context of the practices of foraging, it would seem that there is a lesson to be learned about “smartness” and automation. Sensing and other techniques of producing, analyzing, and acting upon data are part of automation in the 21st century. These technologies work to systemize and proceduralize work. There is real concern with regards to automation, in agriculture and food systems, and in work more generally. Perhaps projects such as *Fruit Are Heavy* provide another way to conceptualize and undertake these sorts of data practices without capitulating to rhetoric and techniques that undermine community agency. Automation may have its place in diverse economies, but it is imperative that it be developed from the perspective of the worker. It is for this reason that participatory design, with its tradition of acknowledging work as a skilled activity and including workers in the design of systems they will use, is relevant.

CONCLUSION

In this paper we presented the *Fruit Are Heavy* system as an example of a proof-of-concept IoT system designed to serve a public interest—in this case, to aide in the work of urban foraging. Foraging, as practiced by our collaborators Concrete Jungle, is a mode of provisioning and care that operates in parallel to more mainstream practices of providing food for those in need. While the system we designed was a prototype, our deployments suggest that the design has promise as an approach to remote fruit tree monitoring that could alleviate some of the work of foraging.

But more important that the specifics of the electronics, sensors, or housing, we believe the research we have presented in this paper is valuable, especially as we move from the vision to the design to the implementation of smart cities. By undertaking design research to explore how environmental sensing can support urban foraging, we have demonstrated the viability of an alternative approach to designing technologies and services in the context of smart cities. This approach is not inherently or explicitly critical of other approaches, but it emphasizes the potential value of low-fidelity sensing and offers a notion of “smartness” that functions at the human-scale. We also demonstrated the potential of designing IoT services to support diverse economies, to support a kind of parallel social and civic practice. This continues a long line of research in design and human-computer interaction that has explored alternative forms of social organization and everyday life and argued for the value of attending to these practices [32, 33, 36, 63, 64, 67].

For future work, we plan to continue the exploration of the use of IoT technologies and services for diverse economies generally, and for foraging specifically. This includes the continued development of sensing systems, as well as exploring the integration of sensor data into geographic information systems and other techniques for data analysis. We also plan to address how projects such as this provide the opportunity to experiment with new models of participatory design in the context of smart cities and Public IoT, expanding our notion of how we work together with communities of practice to shape not only technical systems, but also informal civics and systems of care. [10, 11, 36].

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